

Laguna de Santa Rosa – TMDL Targets and Loading Capacity Analysis

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PREPARED FOR

North Coast Regional Water Quality Control Board

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ACRONYMS AND ABBREVIATIONS

BCG	Biological Condition Gradient
BOD-5	5-day Biochemical Oxygen Demand
CEDEN	California Environmental Data Exchange Network
Chl-a	Chlorophyll a
CWA	Clean Water Act
DO	Dissolved Oxygen
FNU	Formazin Nephelometric Units
HSA	Hydrologic Sub-Area
MS4	Municipal Separate Storm Sewer System
N	Nitrogen
NCRWQCB	North Coast Regional Water Quality Control Board
NH ₄	Ammonium
NO ₃	Nitrate
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Units
P	Phosphorus
SCWA	Sonoma County Water Agency
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWTP	Wastewater Treatment Plant

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1.0 INTRODUCTION

1.1 BACKGROUND

The Laguna de Santa Rosa watershed, part of the Russian River watershed, is located in Sonoma County, CA, and is the metropolitan center of the North Coast region. The watershed occupies a total area of 255.5 square miles (163,528 acres) and includes the cities of Santa Rosa, Rohnert Park, Windsor, Cotati, and Sebastopol. Over the past century of development in the watershed, water quality in the Laguna de Santa Rosa ("Laguna") has been adversely impacted (Sloop et al., 2007). The impacts are primarily in the form of excessive sediment loads and nutrient loads; the former leads to deposition and a general shallowing of the Laguna, while the latter, primarily in the form of nitrogen and phosphorus, leads to greater plant and algal growth. Together, these cause a cascade of other adverse impacts (Tetra Tech, 2020a). Because the Laguna is home to several threatened and endangered anadromous fish species, improving its water quality is a major focus of the North Coast Region Water Quality Control Board's (NCRWQCB's) activities. The three goals of the analysis presented in this document are to outline the regulatory and policy framework that guides these activities; to estimate appropriate sediment and nutrient concentration targets in the Laguna that would minimize the impairment; and to estimate the loads of sediments and nutrients that would enable the concentration targets to be achieved.

Water quality impairments, such as those in the Laguna, are addressed by the State of California through the Federal Clean Water Act (CWA), specifically an element known as the Total Maximum Daily Load, or TMDL. The goal of a TMDL is to calculate and assign allowable loads that reduce the impairments in a water body. To address the impairments in the Laguna, the NCRWQCB is thus developing TMDLs for this water body, which consists of a series of technical analyses to quantify the impairments and to support the changes that need to be implemented. This document is one of a series of memorandums prepared for the NCRWQCB, in support of the TMDL development.

The mainstem segments of the Laguna have been identified as impaired for dissolved oxygen (DO), phosphorus, water temperature, and sediment (as well as other pollutants) and have been listed on California's list of impaired waters requiring the development of a Total Maximum Daily Load (TMDL) since 1990 (termed the 303(d) list under the CWA). The sediment and temperature listings also apply to all the tributaries to the Laguna, while the current DO listing applies to selected tributaries. Through 2010, the Laguna was also listed as impaired by nitrogen. However, California's 2012 Integrated Report (CWA Section 303(d) List / 305(b) Report; http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2012.shtml) removed the listing for nitrogen based on several lines of evidence, including a finding that "phosphorus is the limiting nutrient and reductions in nitrogen loads beyond current levels are not expected to result in added protection of the beneficial use or significant water quality improvements." Despite the delisting, it remains possible that abundant supplies of inorganic nitrogen in the Laguna are contributing to impaired conditions in the Laguna.

Under California law, water quality in state waters is regulated through Basin Plans. For the North Coast region, this document is the *Water Quality Control Plan for the North Coast Region* (NCRWQCB, 2018). This Basin Plan contains three criteria that pertain to this TMDL. The first is a narrative criterion for sediment: "The suspended sediment load and suspended sediment discharge rate to surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses." The second is

a numeric criterion for DO, described further in Section 2.4.3.1. The third is a narrative criterion for biostimulatory substances (Section 3.3.2): “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.” “Biostimulatory substances” are not defined in the Basin Plan, but the term generally refers to the addition of nutrients or other conditions that promote excessive biological activity, such as plant and algal growth. The Laguna is listed as impaired by phosphorus based upon this biostimulatory substances objective. However, nutrients, such as phosphorus, alone do not directly impair beneficial uses or cause non-attainment of the objective. Rather, they promote excessive aquatic plant and algal growth, which cause extreme intra-day variations in DO and pH, which then affect biota in the Laguna. Waterbody-specific factors such as riparian cover, flow conditions, and stream channel configuration also affect how nutrients are processed within the stream and play a large role in determining whether or not nuisance conditions will prevail. It is clear that the problems in the Laguna and the specific impairments for phosphorus, DO, temperature, and sediment could be summarized as promoting biostimulation.

Water quality impairments in the Laguna are in part driven by ongoing external loads of nutrients, sediment, and oxygen-demanding material; however, there is also a significant role played by internal recycling from existing loads, including regeneration of nutrients from excess sediment and creation of biomass (and associated oxygen demand) by plant growth within the Laguna (Sloop et al., 2007; Tetra Tech, 2015a, 2020a). Infestation of the Laguna by the exotic emergent macrophyte *Ludwigia* spp. plays an important role here. The *Ludwigia* infestation has a feedback effect on water quality as the massive growths in the Laguna channels slow water and promote deposition of sediment and associated nutrients, while the general shallowing of the system, exacerbated by the macrophytes, is itself a risk factor for additional *Ludwigia* growth. *Ludwigia* roots can pull nutrients out of the sediment and release them back into the water column when the plants decay. The organic sediment that has built up in the Laguna also provides an ongoing source of nutrients and oxygen-consuming material directly into the water column. The net effect of these interacting factors is a failure to support the Basin Plan (NCRWQCB, 2018) narrative criterion for biostimulatory substances. This narrative standard implies that a linkage analysis should be undertaken to determine the amount of nutrient and organic matter loading (“biostimulatory substances”) that is consistent with holding “aquatic growths” to levels that do not “adversely affect beneficial uses.” While there are explicit numeric criteria for DO, impairment of DO in the Laguna is also part of the overall biostimulatory condition¹ and needs to be addressed in concert with achieving biostimulatory goals. This document builds upon the previously completed linkage analyses for sediment and nutrient-related impairments in the Laguna de Santa Rosa (Tetra Tech, 2020a, 2020b) to propose draft targets for sediment and nutrient loading rates and loading capacities that can be used to support the TMDL.

1.2 TMDL REQUIREMENTS

The Laguna sediment and biostimulation problem is understood to not be straightforwardly addressed by controlling a few loads, as is common in TMDLs in other water bodies, because it is caused by widespread watershed-scale changes, and alternative approaches may need to be considered. As stated

¹ “Biostimulatory” refers to refers to substances such as nutrients (i.e., nitrogen and phosphorus) or conditions, such as altered temperature, hydrology, etc. that can cause eutrophication and can impact beneficial uses (Sutula et al., 2018). All California Regional Water Quality Control Boards (Regional Water Boards) have a narrative biostimulatory objective.

in the scope of work for Tetra Tech's support to the Water Board for the Laguna sediment and nutrient TMDL, "it is anticipated that 'standard' TMDL calculations will be needed to support the Water Boards' development of TMDL targets, load allocations, and wasteload allocations for nutrient (phosphorus and potentially nitrogen) and sediment loads in Laguna de Santa Rosa. This is the case even if the selected approach is a TMDL alternative, as the TMDL alternative will require demonstration of when and how water quality standards will be achieved." The concept of a "standard" TMDL is explained further below.

A TMDL is a means for establishing controls needed to restore and maintain the quality of water resources when effluent limits on permitted point sources alone are not sufficient to support designated uses (USEPA, 1991). The TMDL process establishes allowable loadings for a waterbody based on the relationship between pollutant sources and in-stream water quality conditions. 40 CFR §130.2(i) states that a TMDL calculation is the sum of the individual wasteload allocations for point sources and the load allocations for nonpoint sources and natural background in a given watershed, and that TMDLs can be expressed in terms of either mass per time, concentration, toxicity, or other appropriate measure.

The TMDL must also consider seasonal variations and include a margin of safety (MOS) that takes into account lack of knowledge about the causes of the water quality problem or its loading capacity. The sum of the wasteload and load allocations, the MOS, and any reserve capacity must be equal to or less than the loading capacity, which is defined as "The greatest amount of loading that a water can receive without violating water quality standards" (140 CFR § 130.2(f)).

To calculate a "standard" TMDL it is necessary to estimate the loading capacity relative to an appropriate water quality indicator and target value of that indicator. It is also necessary to assess the sources of pollutant loads and the linkages between those sources and the water quality target. Combining this information provides the basis for developing the allocations (and MOS) that constitute the TMDL (USEPA, 1991; 1999a; 1999b).

Previously, Tetra Tech developed two reports that describe available data, estimate sources, and develop pollutant budgets that link sources of nutrient and sediment loads to conditions within the Laguna (*Laguna de Santa Rosa – Linkage Analysis for Nutrient Impairments* and *Laguna de Santa Rosa – Linkage Analysis for Sediment Impairments*) (Tetra Tech 2020a,b). Those documents are incorporated by reference into this memorandum.

This report focuses on the identification of water quality indicators and associated targets. Sections 2.0 and 3.0 respectively lay out the evidence, options, and recommendations for nutrient and sediment targets relative to the TMDL.

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2.0 NUTRIENT TARGETS

2.1 APPROACHES TO ESTABLISHING NUTRIENT TARGETS

Targets in the context of TMDLs are concentration levels of a water quality constituent that minimize the impairment of concern and allow the attainment of water quality standards and the support of beneficial uses. USEPA guidance recommends three potential pathways for the development of nutrient targets (USEPA, 2000a; 2000b; 2010): 1) empirical stressor-response approach, 2) reference approach, and 3) cause-effect or mechanistic modeling approach. The reference approach involves characterization of the distributions of nutrients in “minimally disturbed” waterbodies with similar physical and ecological characteristics. Nutrient concentrations are chosen at some statistical percentile of those reference waterbodies. The empirical stress-response approach involves establishing statistical relationships between the causal agent or stressor (in this case nutrient concentrations or loads) and an adverse ecological response such as changes in algal or aquatic plant biomass or community structure, or changes in sediment or water chemistry (e.g., dissolved oxygen, pH). The cause-effect approach involves identifying the ecological responses of concern and mechanistically modeling the linkage back to nutrient loads and other co-factors controlling response (e.g., hydrology, grazers, denitrification, etc.).

Each of the three methods presents challenges. For the reference approach, two challenges are determining what constitutes an adequate reference given the many site-specific factors that affect biostimulatory responses and the wide range of nutrient concentrations observed in unimpaired sites. On the other hand, mechanistic cause-effect models have met with limited success in explaining the complexities of biological responses in flowing water. As a result, the empirical stressor-response approach has gained favor as a feasible option to define nutrient objectives (USEPA, 2010). Still, all three options are potentially valid ways to establish nutrient targets for an individual waterbody.

The following subsections consider the options for establishing nutrient targets under all three approaches, beginning with the empirical stressor-response approach that has been proposed to the California State Water Resources Control Board (State Water Board) for biostimulatory objectives.

2.2 STRESSOR-RESPONSE APPROACH

This section begins by describing the relevant work done to date on developing the State Board policy. It concludes with a discussion of how that work might be used to develop nutrient targets for the Laguna.

2.2.1 State Biostimulatory Objectives

The North Coast Basin Plan (NCRWQCB, 2018, Section 3.3.2) contains the following narrative objective for biostimulatory conditions: “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.” Quantitative targets for “biostimulatory substances” in the Laguna are not defined in the Basin Plan, although Chapter 4 (“Implementation”) does assign site-specific quantitative nutrient targets for total phosphorus and total nitrogen loading for a specific river basin, i.e., the Klamath River based on the adopted Klamath River DO TMDL. While the Klamath River targets show how the translation to numeric targets may work, the numbers are not directly applicable to other water bodies. Interpretation of the biostimulatory objective to develop quantitative targets is a key requirement for completing TMDLs for the Laguna.

The California State Water Resources Control Board (State Water Board) is proposing to adopt a statewide water quality objective for Biostimulatory Substances as an amendment to the Water Quality Control Plan for Inland Surface Water, Enclosed Bays and Estuaries of California, which may augment or supersede the existing Basin Plan objective referenced above. The State Water Board process is ongoing and is supported by a Biostimulatory Substances/Biological Integrity Stakeholder Advisory Group. A series of draft technical documents were distributed for review at the Stakeholder Advisory Group meeting of 10/26/2018 and are available on the State Water Board web site (https://www.waterboards.ca.gov/water_issues/programs/biostimulatory_substances_biointegrity/stakeholder_advisory/). While these documents remain in draft form and the Biostimulatory Substances policy is still under development, the documents and their accompanying reviews by the Science Advisory Panel in February 2019 (https://www.waterboards.ca.gov/water_issues/programs/biostimulatory_substances_biointegrity/science_panel/) provide important information relevant to establishing biostimulatory objectives for the Laguna de Santa Rosa.

The Laguna is a unique system that encompasses a variety of lentic and lotic habitats including wetlands, flowing streams, and lakes; however, most of the waterbody segments that compose the Laguna fall within the State Water Board's definition of wadeable streams: "Rivers and streams are the freshwater wetlands and deepwater habitats contained within a channel with a linear path of flow and ocean derived salinities of <0.5 ppt. Rivers and streams are further classified into wadeable and non-wadeable streams. Wadeable streams, creeks and small rivers are thus called because they are shallow enough to be sampled using methods that involve wading into the water." Significant research has been conducted on developing numeric targets to address biostimulatory impacts in California Wadeable Streams (Sutula et al., 2018). This ongoing work is central to the task of developing numeric nutrient targets for the lentic and lotic settings in the Laguna. The remainder of this subsection describes the overall components of the proposed State approach. Section 2.2.2 then describes how the stressor-response component of the state policy might be applied to address nutrients in the Laguna. Sections 2.3 and 2.4 then examine alternatives using the reference and cause-effect approaches. Results for all three approaches to nutrients are then synthesized in Sections 2.5 and 2.6. Targets for sediment (which is a co-factor in the biostimulatory impairment, but also important in its own right) are presented separately in Section 3.0.

Sutula et al. (2018) and Sutula (2018) list ten key organizing assumptions and scientific principles supporting the proposed biostimulatory policy (Table 2-1). Note that the table treats biostimulatory impacts as synonymous with eutrophication, defined as "the process by which a body of water becomes enriched in dissolved nutrients (such as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen" (<https://www.merriam-webster.com/dictionary/eutrophication>).

Table 2-1. Key Organizing Assumptions and Scientific Principles Supporting the Biostimulatory Policy
(from Sutula et al., 2018)

1. “ Biostimulatory drivers ” are defined as substances such as nutrients (i.e., nitrogen and phosphorus and associated organic matter) or conditions , such as altered physical habitat, temperature, hydrology, etc. that can cause eutrophication.
2. Assessment of biostimulatory impacts is based on the diagnosis of eutrophication and its consequences (e.g., poor odors and taste, cyanotoxins); inclusion of causal nutrients or other biostimulatory drivers are part of a comprehensive causal assessment and risk prevention approach.
3. Biostimulatory impacts to beneficial uses will be assessed through an assessment framework developed for each waterbody type, with indicators that represent lines of evidence.
4. Assessment of biostimulatory impacts should consider evidence for impacts to both human and wildlife (aquatic and terrestrial) related beneficial uses.
5. Statewide indices of biological integrity can be used as assessment endpoints from which to derive ranges of biostimulatory targets that are protective of aquatic life related beneficial uses.
6. To address total “biostimulatory” potential, thresholds should be based on total nutrients (as opposed to dissolved inorganic form) and for both nitrogen and phosphorus, as opposed to just controlling what is considered the limiting nutrient on-site (either nitrogen or phosphorus).
7. Eutrophication symptoms may be caused by biostimulatory drivers far-field from the waterbody, and thus assessment of biostimulatory impacts should take a watershed-wide approach.
8. Biostimulatory conditions can be a focal point of development of watershed-specific numeric targets and adaptive management strategies.
9. Implementation options to address biostimulatory conditions and substances should recognize the complexity of these drivers and how, they can vary spatially and temporally from watershed to watershed and among certain waterbodies.
10. Generic conceptual models of biostimulatory impacts to waterbodies, presented here, should be refined to illustrate key hypotheses for how biostimulatory substances and conditions are linked to eutrophication symptoms and their relationship to designated waterbody uses.

As displayed in Table 2-2 below, Sutula et al. (2018) assemble the results of a variety of studies conducted in California and elsewhere on threshold concentrations of nutrients, chlorophyll a, and benthic ash-free dry mass of organic matter that are associated with change points in the ability of wadeable streams to support aquatic life and human beneficial uses. (These recommended thresholds are in addition to established Basin Plan criteria for dissolved oxygen (DO) and pH).

The recommendations in Table 2-2 include derived thresholds for the California Stream Condition Index (CSCI, a composite index of benthic macroinvertebrate community health) and the Algal Stream Condition Index (ASCI, a similar index based on benthic algal taxa). Both the CSCI and ASCI are presented at a relative probability of 90% confidence, at the 30th, 10th, and 1st percentiles of the distribution across reference sites (termed Ref30, Ref10, and Ref01, respectively). Sutula et al. (2018) explain this as follows: “Mazor et al. (in prep) derived the basis for these thresholds at a 90% relative probability so that they are protective of prospective aquatic life endpoints, CSCI and the ASCI, at a range of stringency of protection levels, from the 30th to the 1st percentile of reference, using logistic regression models. These percentiles of reference represent different narratives of ecological protection, grounded in a biological condition gradient (BCG) expert synthesis (Paul et al. in prep). Sensitivity of relative probability level was explored (80%, 90% and 95%); the full range of threshold combinations explored are available in Mazor et al. (in prep), supplemental Table 3. However, the 90th percentile or higher is

recommended for further consideration based on the greatest number of models that were statistically validated and the congruence with a 10% allowable exceedance frequency in the Water Quality Control Policy for Developing California's Clean Water Action Section 303(d) list (www.waterboards.ca.gov). Specific thresholds varied on level of desired protection (30th versus 1st percentile of reference), which is a policy decision.”² [The specific percentiles were selected to correspond to a BCG where concentrations below the 30th percentile are “Likely Intact”, concentrations above the 10th percentile are “Likely altered”, and concentrations about the 1st percentile of reference conditions are “Very likely altered”. Also presented are taxon-specific changepoints for diatoms, soft-bodied algae, and benthic macroinvertebrates (BMI). Sutula et al. also provides information on the 90th percentile of the distribution of concentrations at reference sites identified as unimpaired. The reference-based thresholds are discussed below in Section 2.3.

Table 2-2. Threshold Concentrations Presented in Sutula et al. (2018)

Benchmark	Total N (mg/L)	Total P (mg/L)	Chl-a (µg/L)	AFDM (g/m ²)
<i>Derived thresholds- CSCI</i>				
Eutrophication threshold for Ref30	0.34	0.024	14	12
Eutrophication threshold for Ref10	0.59	0.104	28	20
Eutrophication threshold for Ref01	1.95	0.401	65	37
<i>Derived thresholds- ASCI</i>				
Eutrophication threshold for Ref30	0.13	0.026	24	17
Eutrophication threshold for Ref10	0.32	0.080	43	30
Eutrophication threshold for Ref01	1.67	0.394	122	80
<i>Taxon-specific changepoints</i>				
Diatom Increases	0.44	0.082	47	18
Diatom Decreases	0.38	0.048	11	11
Soft bodied algae Increases	0.58	0.075	26	19
Soft bodied algae Decreases	0.17	0.034	36	15
BMI Increases	0.65	0.091	71	31
BMI Decreases	0.65	0.080	31	20

The CSCI-derived Ref10 threshold for chlorophyll a of 28 µg/L is very close to the expert consensus recommendation of 25 µg/L from earlier work on Nutrient Numeric Endpoints for California as establishing presumptively impaired conditions documented in Tetra Tech (2006). The corresponding Ref10 phosphorus threshold of 0.104 mg/L is consistent with Welch and Jacoby (2004), who suggest a total phosphorus concentration of 0.1 mg/L (as a growing season average) is needed to prevent hyper-eutrophication in lentic waters.

² Note that the cited papers from Mazor and Paul do not appear to be available at this time, but see Fetscher et al., 2014 for further details about the process.

Sutula et al. (2018) distinguish between “targets”, which are policy decisions on the numeric limits of biostimulatory indicators, and “thresholds”, which are the output of scientific analyses “intended to inform conversations among the Water Board and its advisory groups on targets. Thresholds are defined as either a change point at which there is a large or abrupt response in an ecosystem property to a small change in an environmental driver or the value of an environmental driver that has a proscribed probability of meeting an ecosystem protection goal. At this stage, statewide targets have not been defined; however, the information on thresholds is relevant to the selection of site-specific targets for the Laguna.

Table 2-2 is thus a menu of potential threshold values of measures that could be used to set targets as part of the State’s biostimulatory policy, although no actual targets have been adopted by the State Board at this time. A variety of additional measures and associated thresholds protective of aquatic life and human uses are also discussed by Sutula et al. (2018); however, p. 23 notes “No basis currently exists for cover thresholds for vascular aquatic plants” – such as *Ludwigia*.

The terminology regarding measures comes from ecological risk assessment (ERA). In an ecological risk assessment, the true assessment endpoints are the valued ecosystem characteristics that are desired to be protected. In a regulatory context, the designated beneficial uses and their associated narrative criteria may be considered as assessment endpoints. These assessment endpoints are often difficult to predict or measure directly. Therefore, an ERA usually proceeds through the evaluation of simpler endpoints (referred to as *measures*) that are measurable and predictable and serve as surrogate measures to link stressors and outcomes.

There are two types of measures that address, respectively, effects and causes. In EPA’s ERA guidance, “measures of effect” are defined as “measurable changes in an attribute of an assessment endpoint or its surrogate in response to a stressor to which it is exposed,” while “measures of exposure” are defined as “measures of stressor existence and movement in the environment and their contact or co-occurrence with the assessment endpoint” (USEPA, 1998). A target is then simply a value of a measure (of either type) that is consistent with attaining the assessment endpoint or management objective.

Measures of effect are of greatest use in determining whether an impairment exists. In Table 2-2, concentrations of chlorophyll a and AFDM are primarily used as measures of effect, although they also in turn serve as stressors or exposure sources because of their influence on DO concentrations and habitat quality. Measures of effect are of less use for setting numeric targets on pollutant loads for a TMDL. For that purpose, it is desirable to work with measures of exposure that can be directly linked to pollutant loads. In Table 2-2 concentrations of total N and total P are measures of exposure and their thresholds suggest potential targets for nutrient loads.

2.2.2 Applicability of Proposed Biostimulatory Objectives Stressor-Response Analyses to the Laguna

The proposed biostimulatory objectives and associated threshold stressor-response analyses provide one potential source for developing TMDL targets for the Laguna. Of particular relevance to the impairments listed for the Laguna de Santa Rosa, the assumptions and principles for biostimulatory objectives presented in Table 2-1, while not yet adopted State policy, suggest the following:

- Assumption/principle 1 clarifies that strategies to address biostimulatory impairment should include both nutrients and other conditions “such as altered physical habitat, hydrology, temperature, etc. that can cause eutrophication.” Thus, biostimulatory impairments may include

alterations to physical habitat – such as the excess sediment loading and accumulation that have resulted in shallowing of the Laguna and promoted overgrowth of *Ludwigia*. The Basin Plan does not establish quantitative numeric targets for suspended or bedded sediment, but excess sediment and changes to hydrology that promote the accumulation of excess sediment will need to be addressed as part of an overall biostimulatory substances strategy.

- Assumption/principle 6 advocates basin biostimulatory thresholds on total nutrient concentrations (not just dissolved and inorganic forms), and that thresholds should be established for both nitrogen and phosphorus, regardless of which major nutrient is most limiting on eutrophication response.
- Assumption/principle 7 through 9 confirm that a watershed strategy is needed to address biostimulatory impairments, and that implementation is likely to require an approach tailored to the conditions of a specific watershed.

In sum, biostimulatory impairment of the Laguna represents a complex, interacting web of stressors and responses. Stressor sources include both ongoing loading to the Laguna (associated with changes to watershed land use and hydrology) and existing accumulations of nutrients, organic material, and sediment within the Laguna. Responses to these stresses include overgrowth of *Ludwigia* and associated slowing of flow, which in turn promotes more accumulation of nutrients and sediment. These conditions cause depletion of DO and degradation of aquatic and benthic habitat – threatening both aquatic life support and recreational beneficial uses. The complexity of these interactions is captured in the Laguna conceptual model (Figure 2-1 in Tetra Tech, 2020a).

The proposed State Water Board approach to biostimulatory objectives suggests that numeric nutrient targets should be developed for both total phosphorus and total nitrogen. The current 303(d) nutrient listing is for phosphorus only, so there is not a regulatory requirement that a traditional TMDL be developed for nitrogen. However, excess inorganic nitrogen is likely to exacerbate overgrowth of *Ludwigia*, which in turn amplifies problems associated with sedimentation and low DO and total nitrogen concentrations associated with change points in benthic macroinvertebrate and benthic algal communities have been documented. Inclusion of a total nitrogen target seems especially important if restoration of the Laguna is pursued using a TMDL alternative based on a holistic watershed management plan.

Transition thresholds based on the CSCI and ASCI at the 10th percentile of the reference distribution (Table 2-2) suggest that potential nutrient concentration targets (in wadeable streams in general) under an empirical stressor-response approach might be in the range of 0.32 – 0.59 mg/L total N and 0.08 – 0.104 mg/L total P. These values could be used as potential targets for the Laguna. However, the relevance of measures based on the reference distribution of CSCI and ASCI in wadeable streams is uncertain for the unique conditions of the Laguna, which is not a typical wadeable stream even though much of the waterbody fits within the wadeable stream definition. There are not CSCI and ASCI results available for the Laguna, which precludes direct testing of the applicability of the proposed thresholds. (CEDEN does include a few CSCI measurements from upper Mark West and Santa Rosa Creeks, but none for the Laguna itself or lower Mark West Creek.) The CSCI-based threshold in Table 2-2 appears to be supported with more data at this time, suggesting 0.59 mg/L total N and 0.104 mg/L total P as potential nutrient targets. However, evidence for targets based on the stressor-response approach is incomplete for the Laguna and corroboration from other lines of evidence is needed to support use of these thresholds as TMDL targets.

2.3 REFERENCE APPROACH

The reference approach establishes nutrient targets based on conditions in unimpaired streams. There are two general approaches: USEPA (2000a) suggested that appropriate objectives for nutrients could be established at a percentile of the distribution of concentrations at unimpaired reference sites. Alternatively, an estimate of the natural condition at a site can be used as a self-referenced estimate of unimpaired conditions.

2.3.1 90th Percentile of Unimpaired Reference Sites

A common-sense principle for setting nutrient targets is that the targets should not be less than the concentrations that would occur under natural conditions without anthropogenic influence. Identifying natural conditions for a waterbody is not, however, a straightforward task. In its guidance on 304(a) criteria for nutrients, USEPA (2000a, 2000b) proposed that the 75th percentile of the distribution of unimpacted reference waterbodies of a given type in a given ecoregion was an appropriate representation of unimpacted natural conditions (and also that the 25th percentile of all nutrient data was representative of unimpacted reference conditions). However, the percentiles based on the data available for the 2000 documents did not do a good job of discriminating between sites that were or were not impaired by biostimulatory conditions (Tetra Tech, 2006).

Sutula et al. (2018) also present a revised statistical analysis of wadeable stream data in California (with more rigorous identification of reference sites) and suggested the 90th percentile reference concentration was more consistent with analysis of thresholds in biological responses such as CSCI. The 90th percentile of the reference site distribution is presented as an approximate indicator of the upper bound of nutrient concentrations that a site can tolerate without incurring impairment (USEPA, 2000a), although the lack of an adverse biostimulatory response could be due to factors other than nutrient concentrations, such as low light and high water velocities. Results are reproduced in Table 2-3.

Table 2-3. Reference Site Concentrations Presented in Sutula et al. (2018)

Ecoregion	Total N (mg/L)	Total P (mg/L)	Chl-a (µg/L)	AFDM (g/m ²)
Reference distributions (n= number of reference sites)				
90th percentile - Statewide (n=524)	0.25	0.058	31	27
90 th le - Chaparral (n=76)	0.24	0.075	34	20
90 th le - Central Valley (n=1)	0.16	0.027	23	13
90 th le - Deserts and Modoc (n=38)	0.51	0.104	46	35
90 th le - North Coast (n=106)	0.14	0.030	22	15
90 th le - South Coast (n=115)	0.31	0.039	34	62
90 th le – Sierra Nevada (n=164)	0.15	0.058	24	17

The Laguna de Santa Rosa is within the Chaparral ecoregion, but on the border with the North Coast ecoregion. For the Chaparral ecoregion, the 90th percentile reference concentrations are 0.24 mg/L total N and 0.075 mg/L total P. For the adjacent North Coast ecoregion, the corresponding reference-based

nutrient concentrations are 0.14 mg/L total N and 0.030 mg/L total P. Whether any of these numbers are appropriate to the unique characteristics of the Laguna is again uncertain.

2.3.2 Natural Background Conditions

A more site-specific reference approach is to use modeling with “natural” land use conditions (i.e., conditions prior to European settlement) to estimate the change to current conditions. Tetra Tech (2020a) estimated nutrient budgets for the Laguna for both current and pre-settlement conditions. This suggests that reductions in loads on the order of 83 to 85 percent would be needed to match conditions prior to European settlement (see Section 8.0 in Tetra Tech, 2020a).

Table 2-4. Laguna de Santa Rosa Nutrient Budget Estimates for Current and Pre-European Settlement Conditions (Tetra Tech, 2020a)

	Total Phosphorus (kg/yr)	Total Nitrogen (kg/yr)
Current Conditions	93,734	367,210
Pre-European Settlement	13,648	61,804
Increase	80,086	305,396
Reduction to Achieve Pre-Settlement Conditions	85.4%	83.2%

For 2009 – 2018 monitoring data, the median concentrations for the long-term Laguna monitoring stations at Occidental Road and Guerneville Road were 0.59 and 0.41 mg/L for total P and 2.20 and 1.70 mg/L, respectively, for total N (see Figure 3-7 in Tetra Tech, 2020a). Applying the reductions shown in Table 2-4 would result in concentrations of 0.06 to 0.09 mg/L total P and 0.29 to 0.37 mg/L total N. These results are largely consistent with the CSCI and ASCI Ref10 proposed threshold concentrations shown in Table 2-2 of 0.08 to 0.10 mg/L total P and 0.32 to 0.59 mg/L total N. They are also slightly above the 90th percentile of reference conditions for the Chaparral ecoregion of 0.075 mg/L total P and 0.24 mg/L total N.

The natural condition estimate is uncertain and cannot be validated against data. Further, it is unlikely that a complete return to natural conditions is a necessary condition of supporting beneficial uses in the Laguna. Instead, the natural condition estimates constitute an approximate lower bound on the potential range of targets for the Laguna.

2.4 CAUSE-EFFECT APPROACH

A cause-effect or mechanistic modeling approach—relating a concentration value to a specific impact—is often used to estimate TMDLs in lakes, reservoirs, and estuaries, but has generally been less successful in flowing streams and wetlands. Use of this approach still requires selection of a target that represents the desired condition contained within the narrative criterion; however, with a cause-effect model this target can be specified as a level of a measure of effect (such as *Ludwigia* density or DO objectives) and the model relationship can then be used to determine the corresponding acceptable level of nutrient loads.

Several attempts have been made to develop cause-effect analyses for the Laguna. These have met with limited success, primarily due to a lack of models that can successfully describe growth of *Ludwigia*.

2.4.1 Nutrient Levels to Control *Ludwigia* Growth

Overgrowth of *Ludwigia* is a dominant feature of biostimulatory impairment in the Laguna. A cause-effect analysis to determine water column nutrient concentration targets sufficient to control the *Ludwigia* infestation would provide a direct route to a TMDL target. Unfortunately, evidence for such a target is weak at best and successful mechanistic models of *Ludwigia* growth are not available.

Ludwigia species are recognized as problematic invasives throughout much of the world. There is general agreement that conditions of slow flow, shallow water, and high nutrient concentrations promote dominance by *Ludwigia* (Fried, 2011; Hussner, 2010); however, quantitative estimates on the degree to which nutrients need to be controlled to reduce impairment by *Ludwigia* are lacking.

One complicating factor is that it is not simply the growth potential of *Ludwigia* that causes impairment of beneficial uses but also the form that the growth takes. The greatest risk to beneficial uses occurs when *Ludwigia* exhibits traits of massive floating mats that choke out other aquatic vegetation, reduce reaeration, and provide breeding grounds for mosquitos and other vectors (Rejmánková, 1992). However, the trailing/spreading trait may respond differently to environmental conditions than the overall growth potential.

Somewhat more work on conditions promoting excessive and deleterious dominance by *Ludwigia* species has been conducted in Europe than in the U.S., as aquarium releases have taken hold and caused problems over many decades in southern and western Europe, starting in France in the 1830s.

The environmental responses of different *Ludwigia* species (*L. peploides*, *L. hexapetala*, *L. grandiflora*) are believed to be very similar (Hussner, 2010; Fried, 2011). Their abundance is correlated with increased nutrients and decreased water levels (Hussner, 2010), with optimal growth occurring at water depths of 0.3 – 0.7 m (Dutartre et al., 2007). *Ludwigia* species tolerate a wide range of nutrient conditions but become dominant under nutrient-rich conditions (Rejmánková, 1992). The European consensus (Fried, 2011) is that nitrogen concentration in the water column is generally not limiting on *Ludwigia* growth, while growth can occur over a wide range of phosphorus concentrations. High ambient phosphorus levels are, however, believed to lend *Ludwigia* a competitive advantage (Gerard et al., 2014).

Experimental evaluation of growth potential of *Ludwigia* relative to nutrient concentrations is complicated because the plants can take up nutrients both directly from the water column and through their roots in the sediment. Hussner (2010) examined *Ludwigia* response to eutrophic versus mesotrophic conditions and found that as inorganic N in the sediment decreased from 37 to 5.3 mg-N/kg-solids and inorganic P (as P₂O₅) decreased from 112 to 13.6 mg-P/kg-solids, the relative growth rate of *Ludwigia* species declined by about one third. In contrast, Gerard et al. (2014) looked at the sensitivity of *L. grandiflora* and *L. peploides* aboveground biomass to phosphorus concentrations in the water column, contrasting treatments with ambient P concentrations at 30 and 100 µg/L, combined with nutrient poor sediment. A 70 percent reduction in water column P (from 100 to 30 µg/L) resulted in an approximately 33 percent reduction in biomass. The authors, however, note that the “relevance of our study applies to lakes and ponds where the water column has been loaded with phosphorus, but the sediment is low in phosphorus...”

It should be noted that the environmental phosphorus concentrations examined by Hussner (2010) and Gerard et al. (2014) are relatively low. The sediment concentrations evaluated by Hussner are equivalent

to 0.03 – 0.22 lb-P/ton-sediment, which is much less than is typically observed in suspended sediment in the Laguna watershed (see Section 3.2 in Tetra Tech, 2020a). Similarly, water column concentrations of phosphorus observed in the Laguna de Santa Rosa are higher than the maximum concentrations evaluated by Gerard et al. (see Section 3.1 in Tetra Tech, 2020a.). A survey of attempts to control invasive aquatic plants throughout the world (Hussner et al., 2017) concluded that nutrient control has generally been ineffective because sediment generally contains sufficient phosphorus to maintain and promote growth.

In the U.S., the Corps of Engineers published a document on research priorities for *Ludwigia*, including a summary of observations from the Laguna (Grewell et al., 2016). They suggest mechanical removal and herbicides (where allowed) as options for control, although noting that the large seedbank present in sediment makes eradication difficult. The document is not sanguine as to possible nutrient-based control: “In the Russian River watershed, *L. hexapetala* adapted to both high and low nutrient environments where it grew well and spread in sandy, low nutrient soils and in highly eutrophic conditions in the Laguna de Santa Rosa floodplain where the highest biomass production was observed.” However, subsequent work by Skaer Thomason et al. (2018) in the Russian River system concluded that “population patches expanded where available light and aqueous phosphorus were somewhat elevated relative to uninvaded areas”, although the correlation appears weak and it is not certain if *Ludwigia* expanded because of elevated phosphorus or phosphorus was elevated as a result of *Ludwigia* growth. Ta et al. (2017), addressing invasive aquatic plants including *Ludwigia* in the Sacramento – San Joaquin Delta, concur with Hussner et al. (2017) in suggesting that limiting ongoing nutrient loads is likely to be an ineffective method of control due to ample amounts of phosphorus stored in sediment.

Other American studies seem to have focused on the ability of *Ludwigia* species to remove nutrients from the water column, particularly in treatment wetlands, rather than environmental controls on nuisance growth. These studies do demonstrate that *Ludwigia* is readily able to access water column nutrients. For example:

- Ensign et al. (2006) studied instream nutrient uptake of streams in coastal North Carolina. Ephemeral ditches vegetated with *Ludwigia* sp. were found to remove 65-98% of the dissolved nutrient load delivered from agricultural runoff.
- Deaver et al. (2005) studied the removal of dissolved nutrients by *Ludwigia peploides* in mesocosm experiments based on a 4-hour hydraulic retention rate. The study showed the mean nutrient removal efficiencies of 25% for dissolved phosphorus, 83% for ammonia-N, and 40% for nitrate-N.
- ERDC/EL TR-16-2 Jing et al. (2002) studied the effect of varying HRT on dissolved nutrient removal from constructed wetlands planted with *Ludwigia octovalis*. Nutrient removal efficiencies were measured in constructed wetlands with HRTs varied between 1 to 4 days. The study showed 16-81% removal of dissolved phosphorus and 32-98% removal of ammonia-N.

To address the many threats posed by the *Ludwigia* infestation in the short term, the Laguna de Santa Rosa Foundation undertook a three-year *Ludwigia* control project (Meisler, 2008). In this project, 5.3 miles of channel and 99 acres of floodplain with *Ludwigia* infestation were treated by application of aquatic herbicide followed by mechanical removal of biomass. Herbicide-only applications only temporarily reduced biomass due to *Ludwigia*'s strong regenerative capacities. Further, leaving dead biomass in place creates additional oxygen demand and exacerbates DO problems. Deeper channels treated with herbicide followed by biomass removal retained excellent control for two seasons; however, the dry winter of 2007 resulted in low water levels and some of these areas experienced strong late season regrowth as a result (Meisler, 2008).

The final report of the *Ludwigia* control project reached the following conclusions (Meisler, 2008):

Ludwigia is symptomatic of underlying problems in the Laguna. These problems will be solved only through watershed-level efforts including reduction of nutrient, sediment, and summer water inputs, as well as physical changes to the problem areas including large-scale restoration. Because these actions take considerable time, efforts should be taken to ensure that ground gained through the project period is not lost.

Unfortunately, areas treated under the *Ludwigia* control project subsequently became fully re-infested (personal communication from David Kuszmar, P.E., North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/12/2015), suggesting the need for “watershed-level efforts” called for by Meisler.

In sum, there is wide agreement that *Ludwigia* impairs beneficial uses in the Laguna, and that the overgrowth of *Ludwigia* is promoted by sedimentation that leads to shallowing and likely encouraged by elevated levels of phosphorus – but there is little clear basis in the literature for constructing a cause-effect analysis that can determine the nutrient loads that would be consistent with reducing the impact of *Ludwigia* to levels sufficient to support beneficial uses.

2.4.2 Planktonic Algae

The most obvious manifestations of biostimulatory impairment in the Laguna are dense growths of *Ludwigia* and low DO. Planktonic algae and attached benthic algae are limited by shading where *Ludwigia* is dominant and may also be washed out of faster flowing sections during wet weather. Nonetheless, both observed and potential planktonic algal growth in parts of the Laguna can present a problem.

Chlorophyll *a* monitoring data in the Laguna is summarized in Section 3 of Tetra Tech (2020a). Chlorophyll *a* data is reported for four of the five Laguna mainstem long-term monitoring stations between 2000 and 2008. At three of these stations, chlorophyll *a* concentrations are moderate, ranging from a median of 4.15 µg/L in Santa Rosa Creek at Willowside Road to 18 µg/L for the Laguna at Stony Point. However, for the Laguna at Occidental Road (an open water area coinciding with the open water area of remnant Lake Jonive) the median chlorophyll *a* concentration was 97 and the mean 287 µg/L – much higher than the threshold concentrations discussed in Section 2.2..

Even in areas where elevated levels of chlorophyll *a* are not currently observed due to shading there is still a potential for excess algal growth when nutrient concentrations are elevated. A relevant question for managing the nutrient impairment is whether elevated chlorophyll *a* concentrations would occur if the *Ludwigia* was controlled or absent.

During low flow conditions, the Lake Jonive area behaves like a shallow lake; however, on a year-round basis it is part of the stream network, with a relatively short residence time as compared to most lakes. The tools developed by Tetra Tech (2006) for screening eutrophication responses in California lakes include a simple spreadsheet calculator for lakes and reservoirs based on the BATHTUB modeling tool (Walker, 1986; 1999). BATHTUB is a simple steady-state cause-effect model that predicts growing season average concentrations of nitrogen, phosphorus, and chlorophyll *a* in lake surface waters based on watershed loading rates and morphometry of the lake. Phosphorus regeneration from the sediment is not modeled explicitly by BATHTUB but is implicit in the net sedimentation rates used by the model.

BATHTUB can be applied to lakes with short residence times, but it is challenging to determine what the appropriate period for evaluating antecedent loading should be if most of the winter flow quickly washes through the system, and the general assumption that a steady-state approximation of summer conditions

is appropriate is suspect in shallow water bodies with short residence times. This tool may not be fully appropriate for analysis of Lake Jonive due to the shallow depth in summer (averaging approximately 0.34 m), which is outside the range of test sites (primarily U.S. Army Corps of Engineers reservoirs) upon which the empirical BATHTUB model equations were built and because of the short residence time of water on an annual basis. Nonetheless, the relationships between nutrients, residence time, and planktonic algal growth contained in BATHTUB provide an estimate of the biostimulatory approach that might be expected in lentic parts of the system in the absence of *Ludwigia* dominance.

Detailed bathymetry of this segment was not available, but a growing-season BATHTUB model of Lake Jonive was constructed by Tetra Tech (2015a) with volume, depth, and surface area consistent with the QUAL2Kw model discussed in Section 2.4.3 using the hydraulic geometry assumptions provided in Butkus (2011a), resulting in a volume of 12,426 m³ and a surface area of 35,914 m².

Average annual flow through Lake Jonive (based on records for 1998-2014 for USGS gage 11465750, Laguna de Santa Rosa near Sebastopol) is 74.4 cfs (the gage records outflow from the remnant Lake Jonive segment, but this is assumed to be equal to inflow). This is equivalent to a residence time (on an annual basis) of only 1 hour and 38 minutes). The May – October average flow is 5.4 cfs (residence time of just under 1 day). In contrast, at the extreme low flows evaluated in the QUAL2Kw model (0.0001 m³/s), the residence time would be 3.94 years.

Given the short residence time it is most appropriate to use a seasonal (May – October) representation to estimate steady-state conditions as winter wet weather flows will be flushed through this segment. Tetra Tech (2015a) adjusted the influent loads to replicate the observed median concentrations for 2005 - 2013 at Occidental Road using default values of 1 for the BATHTUB calibration factors for nutrient sedimentation factors and assuming an average flow of 5.4 cfs (total May - October volume of 400,000 m³). The adjusted flow-weighted concentration for total P entering this reach (0.78 mg/L) is similar to the flow-weighted concentration from the FLUX load analysis at Occidental Road for these months (0.90 mg/L, from Table 5-11 in Tetra Tech, 2020a). With these assumptions the BATHTUB tool predicts a growing season median chlorophyll a concentration of 106 µg/L without further calibration adjustment.

Tetra Tech (2015a) noted that observed chlorophyll a at Occidental Road ranged from 40 to 2,080 µg/L with a median of 401 µg/L based on 16 samples, which is much higher than the BATHTUB prediction. However, using a larger data set reported in Tetra Tech (2020a), the observed median chlorophyll a concentration at Occidental Road for 2000 – 2008 (38 samples) was 97.2 µg/L, in close agreement with the BATHTUB estimate. This suggests that the BATHTUB model provides a reasonable estimate of planktonic algal growth in Lake Jonive and can be used to estimate approximate growing season target nutrient concentrations to achieve acceptable water quality conditions in this segment of the Laguna.

The BATHTUB model predicts that reducing the growing season median chlorophyll a from the predicted value of 106 µg/L to the target concentration of 25 µg/L recommended in Tetra Tech (2006) or the potential CSCI-based threshold concentration of 28 µg/L (Table 2-2) would require reducing the total P May-October load by about 75%, resulting in a median water column concentration of around 0.16 mg/L total P. BATHTUB also provides an estimate of total N concentration that is in balance with the total P concentration of about 0.59 mg/L.

While the BATHTUB analysis appears to provide a reasonable approximation to observations it is the case that the conditions in remnant Lake Jonive are outside of the intended range of applicability of the BATHTUB model. Further, the analysis is only directly applicable to Lake Jonive and not to the Laguna as a whole. It also addresses growing season loads only and does not incorporate an estimate of the role of regeneration from the sediment of phosphorus load brought into the Laguna in winter storms. The

results do, however, support a conclusion that significant reductions in current summer nutrient concentrations would be needed to achieve appropriate planktonic chlorophyll a concentrations in slow-moving, open water segments of the Laguna.

Process-based cause-effect modeling of phytoplankton was also attempted with the QUAL2Kw model described in Section 2.4.3. However, that effort was not very successful as to simulation of phytoplankton growth, as is described further below.

2.4.3 Establishing Nutrient Targets Based on DO Objectives

Another potential approach to cause-effect analysis is to predict impairments in DO, for which explicit numeric criteria are in place, to excess loading of nutrients. The Laguna is listed as impaired by low DO and observations have frequently been below the applicable water quality criteria.

The Water Board staff invested considerable effort in this approach in 2011-2013, but the results were inconclusive. This was because the steady-state model employed was able to simulate, at least to some extent, the direct effects of nutrient concentrations on the growth of planktonic and attached benthic algae and their associated impacts on the diel DO cycle, but was not able to provide a clear linkage between nutrient concentrations and sediment oxygen demand derived from seasonal inputs of decaying macrophyte biomass and external inputs of organic matter,

Water Board staff used the QUAL2Kw model (Pelletier and Chapra, 2008) to simulate DO responses for lentic and lotic locations in the Laguna de Santa Rosa watershed. QUAL2Kw is a process-based or mechanistic model that simulates steady-state hydraulics and diel water quality conditions in a one-dimensional channel that is well-mixed vertically and laterally. Two models were developed: one for Lower Santa Rosa Creek to represent lotic reaches in the lower Laguna watershed, and one for the remnant of historic Lake Jonive along the Laguna de Santa Rosa mainstem at Occidental Road near Sebastopol to represent lentic areas with open water that are not dominated by emergent macrophytes, which QUAL2Kw does not simulate. Initial and upstream conditions were defined by nutrient concentration data collected by Regional Board staff for low-flow summer conditions in June and September 2008 and by diel DO, water temperature, and pH data collected in July and September 2009 (Butkus, 2011a). Following model calibration and corroboration, additional analyses were performed by staff and subsequently by Tetra Tech to help answer key remaining questions regarding the role of various assumptions and sources in contributing to nutrient related impairments in the Laguna.

The calibration and corroboration model runs for Santa Rosa Creek were conducted at steady state flows of 0.0453 m³/s (1.6 cfs) and 0.0311 m³/s (1.1 cfs). Both model runs have low observed and simulated phytoplankton chlorophyll a concentrations around 0.5 µg/L. Simulated benthic algae chlorophyll a is also low (around 2 g-chlorophyll a/m²), with no observations for verification. As a result, algae do not play a significant role in the QUAL2Kw simulated DO balance for Santa Rosa Creek.

Flows for the Lake Jonive calibration and corroboration were extremely low, at 0.0001 m³/s (0.0035 cfs) and 0.001413 m³/s (0.05 cfs). QUAL2Kw is designed to simulate flowing streams and is likely not an appropriate tool for these near stagnant conditions. The steady-state model for Lake Jonive had to be run for 1,000 days to achieve convergence. This model does show significant algal concentrations, with phytoplankton chlorophyll a around 38 µg/L (calibration) and 8 µg/L (corroboration) and benthic chlorophyll a around 190 and 165 g/m². Because of the near stagnant conditions, the algal concentrations are not sensitive to the headwater nutrient concentration specifications in this model. The algal concentrations are somewhat sensitive to the assumed rates of nutrient regeneration from the sediment (0.9 mg/m²/d PO₄-P and 100 mg/m²/d NH₄-N), but are more sensitive to recycling of organic

nutrients from the assumed initial algal biomass and modeled rates of algal growth, death, and respiration. Because the model is a steady-state representation (with diel variability) it does not explain the origin of the nutrients that are regenerated from the sediment – a common challenge when applying a steady-state model to low flow conditions.

Corroboration tests of the QUAL2Kw calibrated model were less successful. For Lower Santa Rosa Creek, the diel pattern of predicted DO generally followed observed values but did not match well with minimum and maximum observed DO. For Lake Jonive, the diel pattern of predicted DO generally followed observed values but the model showed high errors for phytoplankton (67.5 percent) and inorganic phosphorus (22.6 percent) (Butkus, 2011a). The discrepancies in predicting observations during the corroboration tests suggest that the calibrated parameter values may not be robust. As a result, the QUAL2Kw models are thus not very useful for assessing a cause-effect relationship between nutrient loads and algal growth and its effect on DO. The models do, however, provide some other useful insights into DO dynamics at the modeled sites.

Calibration of both models required relatively high estimates of sediment oxygen demand (SOD) of 10 g-O₂/m²/day for Lake Jonive and 2.6 g-O₂/m²/day for Lower Santa Rosa Creek. For Lower Santa Rosa Creek, SOD and bottom algae respiration were the most sensitive parameters for predicting DO, while bottom algae respiration and growth were the most sensitive parameters for predicting DO in Lake Jonive. For Lower Santa Rosa Creek increasing SOD by +50 percent of the calibrated value (from 2.6 to 3.9 g-O₂/m²/d) reduced the daily minimum DO from about 6.25 mg/L to about 4.80 mg/L. Decreasing SOD by -50 percent of the calibrated value (from 2.6 to 1.3 g-O₂/m²/d) increased the daily minimum DO from about 6.25 mg/L to about 7.70 mg/L (Butkus 2011a). This is equivalent to about a 1.1 mg/L increase in daily minimum DO per unit decrease in SOD (g-O₂/m²/d). SOD was also identified as the primary mechanism of DO depletion in Lake Jonive and both models show a nearly linear response to SOD (Figure 2-1).

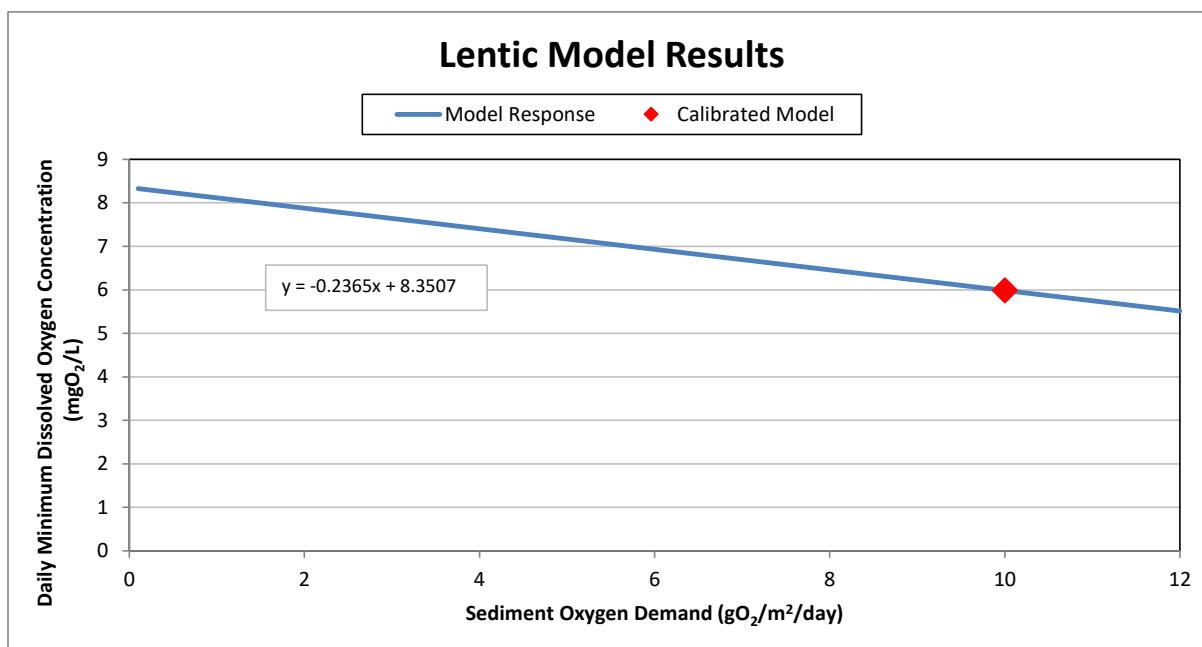


Figure 2-1. Sensitivity of Minimum DO to Sediment Oxygen Demand in the Lake Jonive QUAL2Kw Model

Note: the response shown here for Lake Jonive differs from Figure 11 provided in the original reference (Butkus, 2012c), which had incorrect assignments of SOD on the x axis)

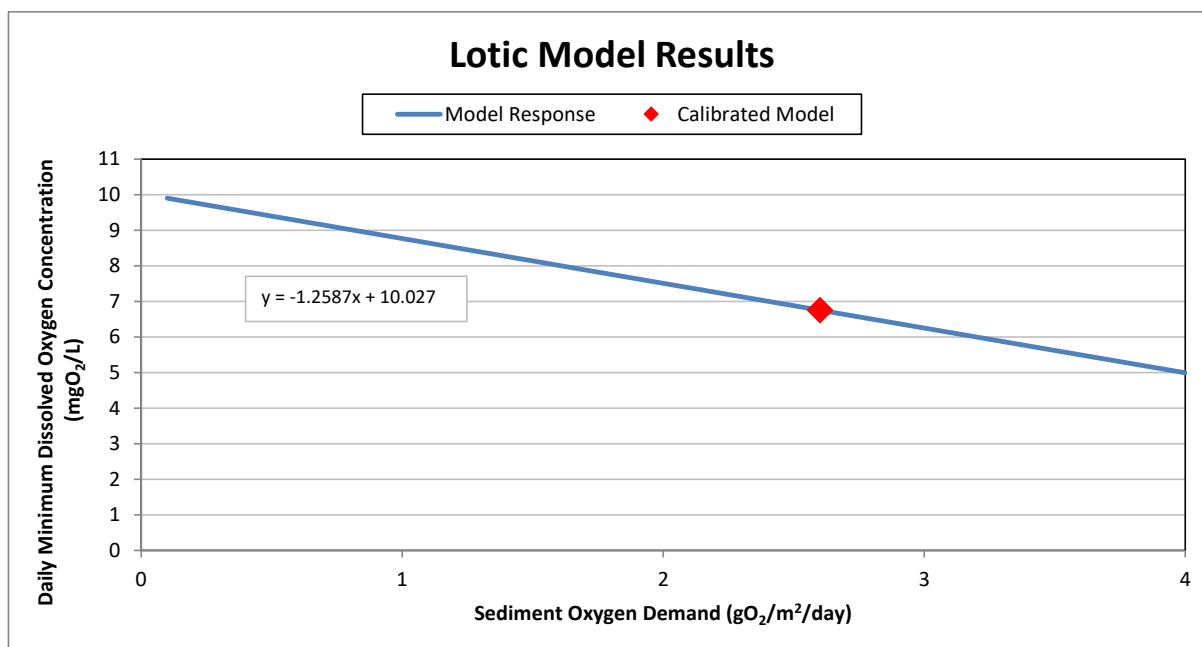


Figure 2-2. Sensitivity of Minimum DO to Sediment Oxygen Demand in the Lower Santa Rosa Creek QUAL2Kw Model

QUAL2Kw includes a sediment diagenesis module that computes a steady-state balance of accumulation, decay, and re-release of chemical constituents from the sediment bed. Simulations were run by Water Board staff to compare sediment flux rates calculated by the sediment diagenesis module to the rates determined from model calibration with the diagenesis module off (Butkus, 2012a). The goal of this analysis was to help evaluate the relative importance of contemporary versus existing sediment pollutant sources. In theory, differences in sediment fluxes between calibrated rates and predictions from the diagenesis module should indicate that existing, accumulated loads of nutrient-rich organic material from prior to the steady-state warm-season conditions simulated by QUAL2Kw are affecting the model. For Lake Jonive, calibrated fluxes for sediment ammonium-N, and inorganic P were 29 to 64 percent higher than the rates calculated by the sediment diagenesis module. For Lower Santa Rosa Creek, the ammonium-N fluxes determined in calibration were twice as large as those estimated with the sediment diagenesis model. These experiments also suggested that existing organic sediments in Lake Jonive are responsible for about half of the SOD exerted in the lake, and about a third of the SOD in Lower Santa Rosa Creek. As the simulated DO is highly sensitive to SOD, this implies that DO alone does not provide a strong basis for developing watershed nutrient instream concentration targets.

SOD is caused by the biological oxidation of organic matter on and in the sediment. This organic matter can originate from the watershed (e.g., leaf litter, organic solids) or from internal production of algal and macrophyte biomass that is deposited in the sediment. Tests with the model indicated reductions in external loading of organic carbon resulted in an improvement in minimum daily DO concentrations by reducing SOD (Butkus, 2012c).

To isolate the role of SOD in the QUAL2Kw model applications, Water Board staff increased headwaters DO concentrations (i.e., in the Laguna upstream of Occidental Road and in upper Santa Rosa Creek) to just meet various DO concentrations using observed diel DO cycles. The SOD rate in each model simulation was then reduced until the model results showed that the same criteria were met (Butkus 2012d).

For Lower Santa Rosa Creek, achieving a minimum DO target of 9 mg/L (the minimum concentration specified for the SPWN use for Sept. 15 – June 4) required a 70 percent reduction in SOD, while no SOD reduction was needed to meet a minimum DO target of 6 mg/L (consistent with the COLD use). For Lake Jonive, a minimum DO target of 5 mg/L (consistent with the WARM use) was met with no SOD reduction, and a minimum of 6 mg/L was met with a 1 percent SOD reduction. These results are, however, conditional on the assumption that all DO criteria are met in the headwaters of each model domain and are thus not very informative as to needed system-side reductions in external organic matter loading, especially within the portions of the Laguna mainstem dominated by macrophyte growth.

In sum, the QUAL2Kw model applications aid in understanding the DO dynamics in specific portions of the Laguna system, but do not provide a useful cause-effect relationship between nutrient loads and either DO or phytoplankton endpoints. The Lower Santa Rosa Creek model does suggest that the needed reduction in SOD (even after meeting all DO objectives in the headwaters of the model) could not be met by reductions in total phosphorus loading to control autochthonous biomass alone, and that allochthonous organic material load from the watershed may also need to be reduced to meet the desired SOD reduction. Such load reduction in organic solids might be part of the overall sediment loading target in Section 3.0.

2.5 SYNTHESIS OF NUTRIENT CONCENTRATION TARGETS

Previous sections discuss several approaches to establishing nutrient targets. While individual approaches are of uncertain applicability to the unique characteristics of the Laguna, when taken together they establish a reasonable range for nutrient targets. Summary recommendations are provided below in Table 2-5.

2.5.1 Inclusion of Nitrogen Compounds

Plants require both nitrogen and phosphorus to support growth. Among the principles supporting the proposed biostimulatory policy is the following (Table 2-1): “6. To address total “biostimulatory” potential, thresholds should be based on total nutrients (as opposed to dissolved inorganic form) and for both nitrogen and phosphorus, as opposed to just controlling what is considered the limiting nutrient on-site (either nitrogen or phosphorus).” Nutrient targets should include both N and P limits because aquatic primary producer responses to single nutrient reduction strategies (N or P) may exacerbate eutrophication problems and impacts on uses. For instance, changes in the N:P ratio potentially alter natural algal communities and may encourage proliferation of undesirable groups, such as toxin-producing cyanobacteria (Paerl et al. 2011).

In accordance with the State Board’s proposed biostimulatory objectives, we suggest that numeric targets be developed for both total phosphorus and total nitrogen for the Laguna. The current 303(d) nutrient listing is for phosphorus only, so there is not a regulatory requirement that a traditional TMDL be developed for nitrogen; therefore, we do not suggest TMDL allocations for nitrogen at this time. However, excess inorganic nitrogen is likely to exacerbate overgrowth of *Ludwigia*, which in turn amplifies problems associated with sedimentation and low DO and total nitrogen concentrations associated with changepoints in benthic macroinvertebrate and benthic algal communities have been documented. Inclusion of a total nitrogen target seems especially important if restoration of the Laguna is pursued using a TMDL alternative based on a holistic watershed management plan.

2.5.2 Proposed Nutrient Numeric Targets

Previous sections presented several estimates for nutrient numeric concentration targets using the Stressor-Response, Reference, and Cause-Effect approaches. In each case, the targets were developed using either summary or steady-state estimates of concentrations associated with adverse biostimulatory effects. These targets are best interpreted as growing season median concentrations that reflect time-averaged exposure concentrations.

The proposed concentration targets incorporate information from the CSCI-based and ASCI-based targets from the Stressor-Response Approach (Section 2.2), the unimpaired reference and natural background analyses from the Reference Approach (Section 2.3), and the planktonic algae targets from the Cause-Effect Approach (Section 2.4). Analyses of nutrient levels that might control *Ludwigia* growth and attempts to estimate nutrient targets based on DO concentrations did not appear to yield useful results. The viable candidate values are summarized in Table 2-5 with additional discussion provided below the table.

Table 2-5. Potential Nutrient Numeric Targets

Analysis Type	Total P (mg/L)	Total N (mg/L)
Empirical Stressor-Response Approach		
Ref10 CSCI (Table 2-1)	0.104	0.59
Ref10 ASCI (Table 2-1)	0.080	0.32
Reference Approach		
90 th Percentile Chaparral Ecoregion Reference Sites (Table 2-3)	≥ 0.075	≥ 0.24
Historic vs. Current Loads (Section 2.3.2)	≥ 0.06 – 0.09	≥ 0.29 – 0.37
Cause – Effect Approach		
Planktonic Chlorophyll a, average summer conditions (Section 2.4.2)	0.16	0.59

All these potential targets have their own uncertainties. An appropriate nutrient target for the Laguna should not be less than the concentrations (or loads) that would be present under natural conditions. These natural conditions (Reference Approach) establish a lower limit that defines the minimum potential nutrient target. The other candidate targets are all consistent with this principle.

For the Stressor-Response approach, the CSCI and ASCI targets for wadeable streams are of uncertain applicability to slower moving parts of the Laguna; however, at least some portions of the Laguna are lotic systems (and would be more so in the absence of *Ludwigia* overgrowth), so these potential targets should be considered as relevant to the protection of the beneficial uses of the Laguna as a whole. Currently, the science is better established and the database larger for the CSCI than the ASCI. At this point the ASCI is still under review and should likely be regarded as provisional and potentially subject to change.

The Cause – Effect approach analyses proved the most difficult. Analyses of nutrient-based control of *Ludwigia* growth (Section 2.4.1) and attainment of DO criteria (Section 2.4.3) did not yield clear nutrient targets, although limiting *Ludwigia* growth and attaining DO criteria will require limits on total sediment and organic matter loads. The BATHTUB analysis of planktonic chlorophyll *a* for average summer conditions does appear to be a reasonable target as it estimates nutrient limits that would be needed to prevent excess median chlorophyll *a* concentrations in the absence of *Ludwigia* within any of the lotic sections of the Laguna. Criteria need to be met in both lentic and lotic segments and are likely to be more restrictive in slower-moving waters with lower rates of downstream flushing, so these estimates are applicable as potential targets for the Laguna as a whole.

Based on the various approaches presented in Table 2-5, we suggest that the Ref10 CSCI-based targets are defensible nutrient numeric endpoints for the Laguna de Santa Rosa and are generally consistent with estimates obtained by other approaches. These targets should be interpreted as growing season median concentrations.

The REF10 CSCI-based targets represent a reduction of 79.6% for total P and 73.2% for total N relative to the 2009-2018 median concentrations for the Laguna at Occidental Road. (For observations in the Laguna at Guerneville Road, the corresponding reductions are 74.6% and 65.3%).

2.6 LOADING CAPACITY FOR NUTRIENTS

A TMDL is ultimately expressed in terms of daily loads, and not in terms of the water column concentrations. The sum of the loads that will achieve the target concentration is equivalent to the loading capacity of the system. The proposed numeric targets described in Section 2.5.2 are expressed as concentrations.

Concentration and load are not the same thing, and the relationship between the two can be complex. For example, a large proportion of annual load may be carried by winter storm events and some of this load may wash downstream to the Russian River or be stored in the sediment. (Some load that goes to the Russian River may also be forced back into the Laguna during flood backwater periods.) However, the Laguna is an efficient trap of sediment, sediment-associated nutrients, and organic matter. Further, nutrients stored in the sediment are at risk of remobilization into the water column, either by diffusion or by uptake by rooted macrophytes.

At present there is not a detailed nutrient cycling and mixing model of the Laguna available. Setting a reduction in total load that is the same as the estimated needed reduction in median nutrient concentration is a conservative approach as it does not account for nutrient losses and export. In other words, if nutrient loads are reduced for all seasons and flow conditions by a given amount (including internal loads) this should also result in at least as much reduction in growing season concentrations. Because this is a conservative approach in that it may not be necessary to impose as stringent a reduction on winter flood event loads that wash through the Laguna than on other events to achieve support of beneficial uses, this approach may be credited as part of an implicit margin of safety.

We do know that concentrations of nutrients in the Laguna represent the net effects of external loading, internal recycling from algae, macrophytes, and the sediment bed, and export to the Russian River. The system is not in steady state: Due to existing internal loading of sediment, nutrients, and organic material to the Laguna, there is a net flux of nutrients from the sediment to the water column. Therefore, reductions in either the current storage of nutrients within the sediment of the Laguna or in the flux rate from the sediment to the water column will likely be needed to achieve water quality standards.

The nutrient budgets for the Laguna are presented in Tables 7-1 and 7-2 of Tetra Tech (2020a). A whole-watershed summary of the total P budget is provided in Table 2-6 below. The left side shows the factors that affect load *into* the water column of the Laguna (point and nonpoint sources, corrected for removal by channel maintenance activities upstream of the main body of the Laguna); the right side shows the fate of phosphorus reaching Laguna – either downstream output to the Russian River or net sequestration in the sediment³. Over 37% of the estimated total P load is derived from internal regeneration from the sediments and, as this is much bigger than deposition loss to the sediment, this must mostly derive from existing internal loads.

The estimated overall load reduction needed for total P is 79.6%. Permitted WWTP discharges contribute only 3.1% of the load. As diffuse external sources and WWTPs make less than 63% of the total P input load it is not possible to achieve the desired reductions by only reducing external loads as the ongoing internal loading from the sediment will prevent the target concentration from being achieved. While the regeneration of total P from the sediment is expected to gradually decline if external sources are reduced this would likely require many decades. We can therefore conclude that (1) there is at present no available assimilative capacity for permitted loads of total P in the Laguna, and (2) a solution to impairment of the Laguna will require a holistic watershed management strategy that combines reductions in external nutrient loads with strategies that encourage reductions in net loads from sediment (by creating morphological conditions that discourage pumping of nutrients from the sediment to the water column by macrophytes such as *Ludwigia*) and decrease nutrient regeneration from the sediment due to hypoxic conditions.

Applying the 79.6% reduction identified in Section 2.5.2 to the load reaching the Laguna (i.e., after accounting for total P removed by channel maintenance activities) results in an estimate of the loading capacity – the maximum rate of loading of a pollutant that can be assimilated without contravening water quality standards (40 CFR 130.2(f)) – of 17,883 kg/yr of total P. This is confirmed to be greater than (131% of) the estimated natural condition loading rate of 13,648 kg/yr.

This calculation of the loading capacity for total P already takes into account the removal during channel maintenance of 6,074 kg/yr. The loading capacity as a fraction of source loads – prior to channel maintenance activities – is 19.24%.

³ Net loading from or deposition loss to the sediment are calculated for different sections of the Laguna. Gain from the sediment is included as an input because the loading capacity is estimated as a fraction of total current loading to the water column of the Laguna.

Table 2-6. Summary Total Phosphorus Budget for the Laguna de Santa Rosa

IN (kg/yr)			OUT (kg/yr)		
WWTP Discharges	2,925	3.12%			
External Diffuse Sources*	55,810	59.54%	to Russian River	87,660	93.52%
Net Internal Sources from Sediment	35,000	37.34%	Channel Maintenance	6,074	6.48%
Total Source Loads	93,734	100.00%	Total Out	93,734	100.00%
Channel Maintenance	-6,074				
Total into Laguna	87,660				
Loading Capacity (@ 79.6% Reduction)	17,883	19.08% of Source Loads			

Note: "External Diffuse Sources" includes nonpoint source runoff, diffuse point sources such as MS4s, and atmospheric deposition). "Loading Capacity" is based on the needed reduction applied to the load estimated to be currently reaching the Laguna. Refer to Table 7-2 in Tetra Tech (2020a) for details.

Although a TMDL is not currently required for nitrogen, Table 2-7 provides a similar loading summary for total N. Nearly 38% of the total N load is derived from internal loading. Permitted WWTP discharges contribute only 3.2% of the external load. The estimated load reduction needed is 73.2%. As diffuse external sources and WWTPs make up 62% of the total input load it is not possible to achieve the desired reductions by only reducing external loads as the ongoing internal loading from the sediment will prevent the target concentration from being achieved. While the regeneration of total N from the sediment is expected to gradually decline if external sources are reduced this will likely require many decades. We can therefore conclude that (1) there is at present no available assimilative capacity for permitted source loads of total N in the Laguna relative to the proposed reductions, and (2) a solution to impairment of the Laguna will require a holistic watershed management strategy that combines reductions in external nutrient loads with strategies that encourage reductions in net loads from sediment (by creating morphological conditions that discourage pumping of nutrients from the sediment to the water column by macrophytes such as *Ludwigia*) and decrease nutrient regeneration from the sediment due to hypoxic conditions.)

Applying the 73.2% reduction identified in Section 2.5.2 to the load currently reaching the Laguna results in an estimate of the loading capacity of 96,919 kg/yr of total N. This is confirmed to be greater than (157% of) the estimated natural condition loading rate of 61,804 kg/yr.

This calculation of the loading capacity for total N also already takes into account the removal during channel maintenance of 5,572 kg/yr. The loading capacity as a fraction of source loads – prior to channel maintenance activities – is 26.39%.

Table 2-7. Summary Total Nitrogen Budget for the Laguna de Santa Rosa

IN (kg/yr)			OUT (kg/yr)		
WWTP Discharges	11,623	3.17%			
External Diffuse Sources*	217,087	59.12%			
			to Russian River	361,638	98.48%
Net Internal Sources from Sediment	138,500	37.72%	Channel Maintenance	5,572	1.52%
Total Source Loads	367,210	100.00%	Total Out	367,210	100.00%
Channel Maintenance	-5,572				
Total into Laguna	361,638				
Loading Capacity (@ 73.2% Reduction)	96,919	26.39% of Source Loads			

Note: "External Diffuse Sources" includes nonpoint source runoff, diffuse point sources such as MS4s, and atmospheric deposition). "Loading Capacity" is based on the needed reduction applied to the load estimated to be currently reaching the Laguna. Refer to Table 7-2 in Tetra Tech (2020a) for details.

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3.0 SEDIMENT TARGETS

3.1 APPROACHES TO ESTABLISHING SEDIMENT TARGETS

As with nutrients, there are not numerical criteria specified for sediment in the Laguna. Instead, sediment loading objectives for the Laguna are governed by narrative criteria in the Basin Plan: “[t]he suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses”. There is also a requirement specific to turbidity: “Turbidity shall not be increased more than 20 percent above naturally occurring background levels” (NCRWQCB, 2018).

Sediment loading affects beneficial uses in the Laguna de Santa Rosa in both direct and indirect ways. The most direct impact is the infill and loss of volume in the Laguna due to sediment infilling. This reduces critical habitat for wildlife, and also reduces the capacity of the waterbody to provide retention for floods on the Russian River. Curtis et al. (2012) estimated that the current flood storage capacity of 80,000 acre-feet had been reduced by approximately 2 percent over the last 50 years. Shallowing of the Laguna de Santa Rosa is also one of the factors that has contributed to overgrowth of the invasive aquatic plant, *Ludwigia* (Sloop et al., 2007). The sediment loads derived from the watershed contribute phosphorus and are associated with organic matter loads that contribute to excess plant growth and sediment oxygen demand in the Laguna de Santa Rosa. Finally, excess loading and movement of sediment in the Laguna and its tributaries are likely to have direct adverse impacts on aquatic life. Other waterbodies impaired by excess sediment are typically identified as having poor physical habitat scores (including substrate complexity, embeddedness, consolidation, and percent fines) and reduced measures of benthic macroinvertebrate diversity, such as the CSCI, but these measures are not currently available for the Laguna mainstem.

The original listing of the Laguna de Santa Rosa and its tributaries for sedimentation as part of the “Russian River HU, Middle Russian River HA, Mark West Creek HSA” [Hydrologic Sub-Area] was based on turbidity data obtained during 2003 at the four Laguna mainstem compliance monitoring stations and cites Sigler’s (1984) conclusion that turbidity greater than 25 nephelometric turbidity units (NTU) can cause a reduction in the growth of cold water fish species such as steelhead. Eight of 15 samples were above this guideline

(https://www.waterboards.ca.gov/water_issues/programs/tmdl/2014_16state_ir_reports/00638.shtml#41007). For the 2018 Integrated List, this HSA was split into several smaller HSAs covering the Laguna mainstem and various tributaries. The sedimentation/siltation impairment listing was continued based on the original listing, but without presenting new data. As was discussed in Section 2.0, the role of sediment loading as a biostimulatory driver may be of greater concern than turbidity.

Similar to nutrients, the narrative criterion for sediment can potentially be converted to a numeric target for the Laguna TMDL in three general ways: by use of one of three general approaches: an empirical stressor-response approach, a reference approach, or a cause-effect approach.

3.2 STRESSOR-RESPONSE APPROACH

The Basin Plan requirements regarding turbidity are that “turbidity shall not be increased more than 20 percent above naturally occurring background levels”. As written, this is a variation on a reference-

condition approach, with an allowance for a 20 percent increase. Unfortunately, the natural background level of turbidity in the Laguna is not known.

The original impairment determination of the Laguna and its tributaries cited a comparison of observed turbidity in the Laguna mainstem to a target of 25 NTU from Sigler et al. (1984) based on reduced growth in steelhead and other salmonids. The experiments summarized by Sigler et al. are for chronic (rather than acute exposures) and thus are most relevant to mean turbidity. The target established by Sigler et al. is not proven to be explicitly relevant to the Laguna and its tributaries but stands as a general goal for maintaining health of salmonid species such as steelhead. This target thus falls into the category of empirical stressor-response endpoints.

The Sigler et al. (1984) target is a potential stressor-response target for sediment loading to the Laguna. Only limited data on turbidity have been collected from the Laguna and its tributaries, as summarized by Tetra Tech (2020b). CEDEN has 197 samples for turbidity from a variety of stations within the Laguna and its tributaries between June 2001 and June 2017 (prior to the Tubbs Fire). Forty-eight samples from the mainstem of the Laguna range up to 105 NTU, but the average is 14.1 NTU with a median of 7.2 NTU – not indicative of chronic impacts relative to the Sigler et al. criterion, although the maximum is 105 NTU. Thirty-two samples from multiple stations on Santa Rosa Creek have an average of 3.8 NTU and a median of 1.65 NTU.

From November 2017 through May 2018 USGS performed continuous turbidity monitoring near the exit point of the Laguna (Mark West Creek near Mirabel Heights, station 11466800). These samples (all taken after the Tubbs Fire of October 2017) were obtained with a datasonde that reported formazin nephelometric units (FNU) rather than NTU. FNU measurements are obtained with an infrared light, whereas NTU is obtained with a white light source. FNU and NTU measurements of turbidity are both calibrated to the same formazin standard but are likely to differ in the environment due to different light scattering properties across different wavelengths for natural materials. No translation between NTU and FNU has been established for Mark West Creek. Nonetheless, the USGS monitoring (9,723 individual readings) has an average of 21.5 FNU and a median of 14.8 FNU, with a maximum of 155 FNU. The Water Board staff also obtained 22 turbidity results from various tributaries to the Laguna after the Tubbs Fire (from 2017-2019). These had an average of 63 NTU, a median of 10.5 NTU, and a maximum of 180 NTU, but, due to their focus on post-fire impacts, may not be representative of more typical conditions. Finally, the Community Clean Water Institute presents citizen monitoring of turbidity at mainstem Laguna stations on their website for 2003-2013 and 2016-2017 (<https://www.communitycleanwater.org/stream/laguna-santa-rosa>). Turbidity readings were often elevated in earlier samples, but only one sample greater than 25 NTU has been reported since 2011.

The 25 NTU Sigler (1984) target, which is for chronic exposure, thus does not provide a useful stressor-response relationship for setting sediment targets in the Laguna. The Basin Plan objective for turbidity is applicable, but, because it is expressed relative to natural conditions, must be treated as a reference approach.

3.3 CAUSE-EFFECT APPROACH

Cause-effect approaches to sediment loading are not sufficiently well-developed for the Laguna to yield numeric targets. Conceptual models (Tetra Tech, 2020b; Sloop et al., 2007) establish a number of cause-effect relationships between sediment loading and biostimulatory responses in the Laguna, such as the role of shallowing in promoting *Ludwigia* growth, as well as other impacts such as reduced flood storage capacity. However, these apparent cause-effect relationships have not led to specific numeric

targets. We do not have a mathematical model that describes the *Ludwigia* growth and life cycle as a function of sediment loading rate. While reduction in flood storage capacity is a concern there has not been a way to establish what rate of sediment accumulation is acceptable relative to flood risk other than to refer back to natural conditions.

In many North Coast sediment TMDLs a cause-effect relationship is established between salmonid egg and fry survival, embeddedness of spawning gravels, and rates of sediment loading. Such concerns also apply to the tributaries to the Laguna including Mark West and Santa Rosa Creeks, which support salmonid spawning in their upper reaches. A variety of surveys over the years have assessed these fish communities (Sloop et al., 2007; RRISRP, 2016), although no definitive compilation of habitat condition in the spawning areas appears to have been made. The spawning reaches are primarily at higher elevations with more limited anthropogenic impact. This type of cause-effect relationship does not appear ripe for use at this time and would not directly address the effects of sediment load on the morphology of the Laguna mainstem, which is a primary way in which sediment load is a biostimulatory driver.

3.4 REFERENCE APPROACH

The stressor-response and cause-effect approaches for establishing numeric targets for sediment in the Laguna watershed were discussed in prior sections, highlighting the limitations of both approaches. The third alternative, the reference approach, is discussed below.

An appropriate target for sediment loading based on the reference approach can first be bounded between two extremes. On the one hand, the target sediment loading rate must be less than the current loading rate into the Laguna, as the current loading rate is identified as resulting in impairment of beneficial uses. On the other hand, the target loading rate should not be less than the natural loading rate into the Laguna under conditions prior to European settlement. That natural condition loading by definition supports all beneficial uses but may be a greater reduction than is needed or is feasible.

The two bounding values still cover a large range, with current total sediment loading rates into the Laguna estimated at about 91,000 tons/yr and pre-settlement loading rates estimated at a little less than 8,000 tons/yr (Tetra Tech, 2020b) – or less than 10 percent of current loads. As the surface area of water and wetlands in the Laguna de Santa Rosa has been reduced considerably from pre-settlement conditions (Butkus, 2011b), the target should be closer to the lower bound.

It is not feasible to return to natural background sediment loading rates given changes in both land use and hydrology; however, loads need to be reduced to protect uses. The Sonoma Creek TMDL (Low and Napolitano, 2008) selected as a target sediment loading at 125 percent of natural background. This was based primarily on comparison to the Noyo River TMDL (US EPA Region IX, 1999), where 125 percent of natural background loading was found to be consistent with maintaining a healthy salmonid population. The Napa River TMDL (Napolitano et al., 2007) also suggested a target of 125 percent of natural background sediment loading based on similar arguments for protecting salmonid populations and reference to the Noyo River TMDL.

The waters of the Laguna de Santa Rosa basin also support steelhead and other salmonids. According to SCWA (2009), “surveys documented fairly large numbers of steelhead in Santa Rosa Creek, and low numbers of steelhead in Brush Creek, Matanzas Creek, Spring Creek, Piner Creek, Paulin Creek, Windsor Creek, and Copeland Creek.” Thus, an argument for a target of 125 percent of natural background can also be made for the Laguna de Santa Rosa watershed to protect the COLD and SPWN beneficial uses. This target is most directly applicable to the headwaters reaches where spawning

occurs. However, it is also consistent with substantially reducing sediment accumulation within the mainstem of the Laguna.

Tetra Tech (2020b) provides estimated sediment budgets for the Laguna de Santa Rosa, including sources and sinks, under both current conditions and conditions prior to European settlement. The estimated loading rate into the Laguna prior to European settlement is 7,658 short tons per year, and 125% of 7,658 amounts to 9,572 short tons/yr – or 10.5% of existing loads.

3.5 LOADING CAPACITY FOR SEDIMENT/SOLIDS

The reference approach based on 125% of natural background sediment loading appears to provide the strongest foundation for a sediment loading target for the Laguna de Santa Rosa watershed. The loading capacity for sediment is thus estimated as 9,572 short tons/yr.

This loading capacity is defined in terms of load reaching the Laguna and thus accounts for all changes in hydrology that have occurred from the start of European settlement to the current day. Tributaries to the Laguna are also listed as impaired by excess sediment and loading rates for individual tributaries vary significantly (see Tetra Tech, 2020b). For the purposes of the TMDL we assume that the loading capacity for sediment is expressed in terms of sediment delivered to the Laguna and amounts to 9,572 short tons/yr as an aggregate. Initial sediment targets for individual tributaries that have sufficient flow to support aquatic life uses could also be assigned as 125% of estimated natural background sediment loading to protect local aquatic life uses. Because sediment is retained in transport through the stream network, such local targets are expected to be smaller than those needed to reach the aggregate goal of 125% of the natural background loading of sediment reaching the Laguna. Detailed application to individual waterbody segments would need to be developed as part of an implementation plan and should likely await the accumulation of additional data on stream conditions within an adaptive management strategy.

The proposed loading capacity estimate for sediment is based on the protection of aquatic life. It is also consistent with other objectives to reduce biostimulatory impacts in the Laguna.

- Trapping efficiency of the Laguna prior to European settlement is estimated to be 82.3% of the load reaching the mainstem Laguna, so 7,879 short tons/yr are predicted to be accumulated within the Laguna at 125% of natural background (Tetra Tech, 2020b). This is equivalent to 13.5% of the estimated current sediment accumulation rate of 58,362 short tons/yr. If a reduction of sediment deposition rates within the Laguna de Santa Rosa to 13.5% of current deposition rates is applied to the rate of sedimentation in the Laguna Floodplain estimated by Curtis et al. (2012) of 3.6 mm/yr, the resulting sedimentation rate would be 0.486 mm/yr, equivalent to 1.91 inches per century – a reduction of 86.5%. That reduced rate of sedimentation is proposed as sufficiently low as to be considered a *de minimis* impact, although the ultimate determination would be a policy decision, further supporting the selected target.
- The proposed reduction in sediment load of 89.5 percent (i.e., a target of 10.5 percent of existing loads) is greater than the proposed phosphorus reduction of 79.6% (Section 2.6). The majority of phosphorus loading is associated with sediment movement. Therefore, the loading target for sediment is consistent with the needed reductions for phosphorus.
- The modeling analysis of DO impairments (Section 2.4.3) suggested that a reduction in allochthonous organic material load from the watershed is also needed to meet DO standards. Specifically, a 70 percent reduction in SOD was suggested. SOD arises from both allochthonous

and autochthonous organic matter, so this does not translate directly into an organic solids loading target; however, the proposed sediment loading target is approximately consistent with achieving this goal.

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