Laguna de Santa Rosa – Linkage Analysis for Nutrient Impairments

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PREPARED FOR

North Coast Regional Water Quality Control Board
5550 Skylane Blvd. Suite A
Santa Rosa, CA 95403

PREPARED BY

Tetra Tech
One Park Drive, Suite 200, PO Box 14409
Research Triangle Park, NC 27709
and
3746 Mt. Diablo Blvd. Suite 300
Lafayette, CA 94549
Tel 919-485-8278
Fax 919-485-8280
tetratech.com

TETRA TECH

The primary author of this report is Dr. Jonathan Butcher, Tetra Tech, Inc., Research Triangle, NC

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ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practice
BOD-5	5-day Biochemical Oxygen Demand
CCRWQCB	Central Coast Regional Water Quality Control Board
CEDEN	California Environmental Data Exchange Network
Chl-*a*	Chlorophyll *a*
CMAQ	Community Multi-Scale Air Quality Model
CV	Coefficient of Variation
CWA	Clean Water Act
DO	Dissolved Oxygen
GPS	Global Positioning System
GWLF	Generalized Watershed Loading Functions
LCLM	Land Cover Loading Model
LGR	Laguna at Guerneville Road
LiDAR	Light Detection and Ranging
LOR	Laguna at Occidental Road
LSP	Laguna at Stony Point Road
LTH	Laguna at Trenton-Healdsburg Road
MANAGE	Measured Annual Nutrient loads from AGricultural Environments
MGD	million gallons per day
MS4	Municipal Separate Storm Sewer System
N	Nitrogen
NADP	National Acid Deposition Program
NCRWQCB	North Coast Regional Water Quality Control Board
NH_3	Ammonia
NH_4	Ammonium
NHDPlus	National Hydrography Dataset Plus
NO_3	Nitrate
NO_X	Total Nitrogen Oxides (nitrate, NO_3, plus nitrite, NO_2)
P	Phosphorus
PREWet	Pollutant Removal Estimates for Wetlands
QA/QC	Quality Assurance/Quality Control
RUSLE	Revised Universal Soil Loss Equation
SCWA	Sonoma County Water Agency
SE	South East
SRCWR	Santa Rosa Creek at Willowside Road
SSU	Sonoma State University
STEPL	Spreadsheet Tool for Estimating Pollutant Loads
SWAT	Soil and Water Assessment Tool
TDEP	Total Deposition
TKN	Total Kjeldahl Nitrogen (ammonium plus organic nitrogen)

TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WDR	Wastewater Discharge Requirements
WRS	Waste Reduction Strategy
WWTP	Wastewater Treatment Plant

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1.0 INTRODUCTION

The Laguna de Santa Rosa, located in Sonoma County, CA, is the largest tributary of the Russian River and home to threatened and endangered anadromous fish species. The watershed is the metropolitan center of the North Coast Region. Significant land uses include urban/rural residential, farming, ranching, and forestry. The Laguna is the largest freshwater wetlands complex on the northern California coast, and was designated in 2010 as a "Wetland of International Importance" by the Ramsar Convention (Ramsar, 2015).

The Laguna de Santa Rosa watershed is located within the 8-digit Hydrologic Unit 18010110 (Russian Watershed), and occupies a total area of 255.5 square miles (163, 528 acres), including the city of Santa Rosa (Figure **1**-**1**). Note that the streams shown on this and subsequent maps are the medium resolution streams from the National Hydrography Dataset Plus (NHDPlus, version 2; McKay et al., 2012). The medium resolution coverage is used to provide a clear picture of major drainages, but various small and mostly intermittent stream channels are omitted. The area of interest for this study is confined to the portion of the Laguna de Santa Rosa watershed upstream of Ritchurst Knob, a bedrock constriction just downstream of the confluence with Windsor Creek that defines the slowly moving portion of the Laguna de Santa Rosa. The area of the watershed upstream of Ritchurst Knob is 251.7 square miles (161,075 acres).

The mainstem segments of the Laguna de Santa Rosa have been identified as impaired for dissolved oxygen (DO), phosphorus, water temperature, and sediment (as well as various other pollutants) and have been listed on California's Clean Water Act (CWA) Section 303(d) list of impaired waters requiring the development of a Total Maximum Daily Load (TMDL) since 1990.

In December 2015, Tetra Tech, Inc., under contract with United States Environmental Protection Agency (USEPA) Region 9 in support of the North Coast Regional Water Quality Control Board (NCRWQCB), prepared the *Laguna de Santa Rosa Nutrient Analysis* (Tetra Tech, 2015a). The 2015 report was designed to provide information that could be used in developing a linkage analysis for a TMDL for nutrients in the Laguna and was a companion to *Laguna de Santa Rosa Sediment Budget* (Tetra Tech, 2015b).

On May 10, 2019 Tetra Tech received a contract from the California State Water Resources Control Board to provide additional support to NCRWQCB in the development of a TMDL (or acceptable TMDL alternative) for the Laguna de Santa Rosa. Under Subtask 2.2 and 2.3 of that work assignment, Tetra Tech is updating the analyses and developing Linkage Analysis reports for sediment and nutrient impairments that could form the basis for a Staff Report to support a TMDL. The current nutrient linkage analysis report has been updated to incorporate new data and research available since 2015. General background on the Laguna de Santa Rosa and available spatial data sources is contained in the sediment linkage analysis (Tetra Tech, 2019).

For the purpose of the linkage analyses, the watershed of the Laguna de Santa Rosa has been divided up into 12 subwatersheds. These subwatersheds (which correspond to the location of United States Geological Survey [USGS] gages, NCRWQCB assessment points, and the subwatersheds used previously by Tetra Tech (2015a, 2015b) and PWA (2004)) are used for both the sediment and nutrient analyses and are summarized in Figure 1-2.

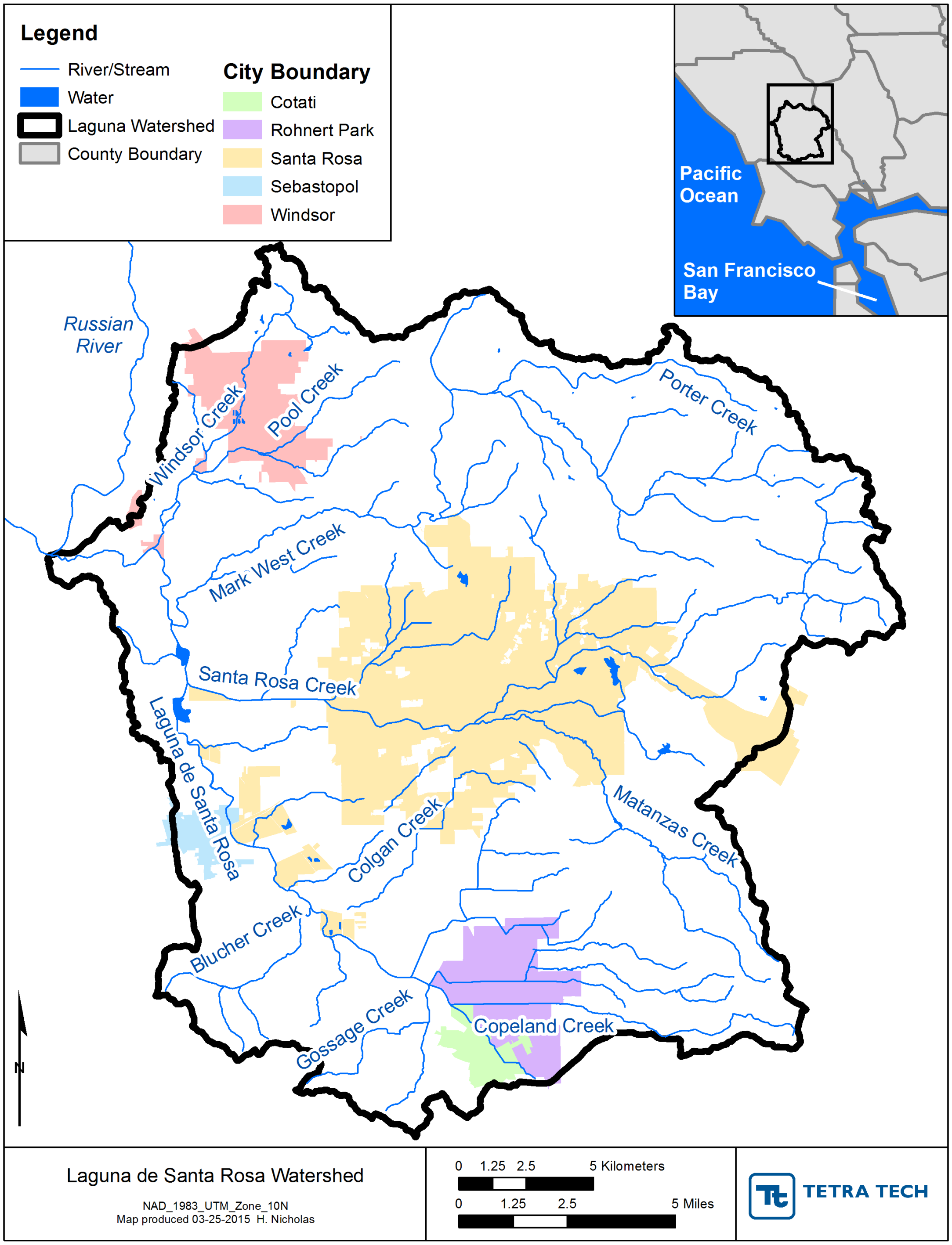

Figure 1-1. The Laguna de Santa Rosa Watershed

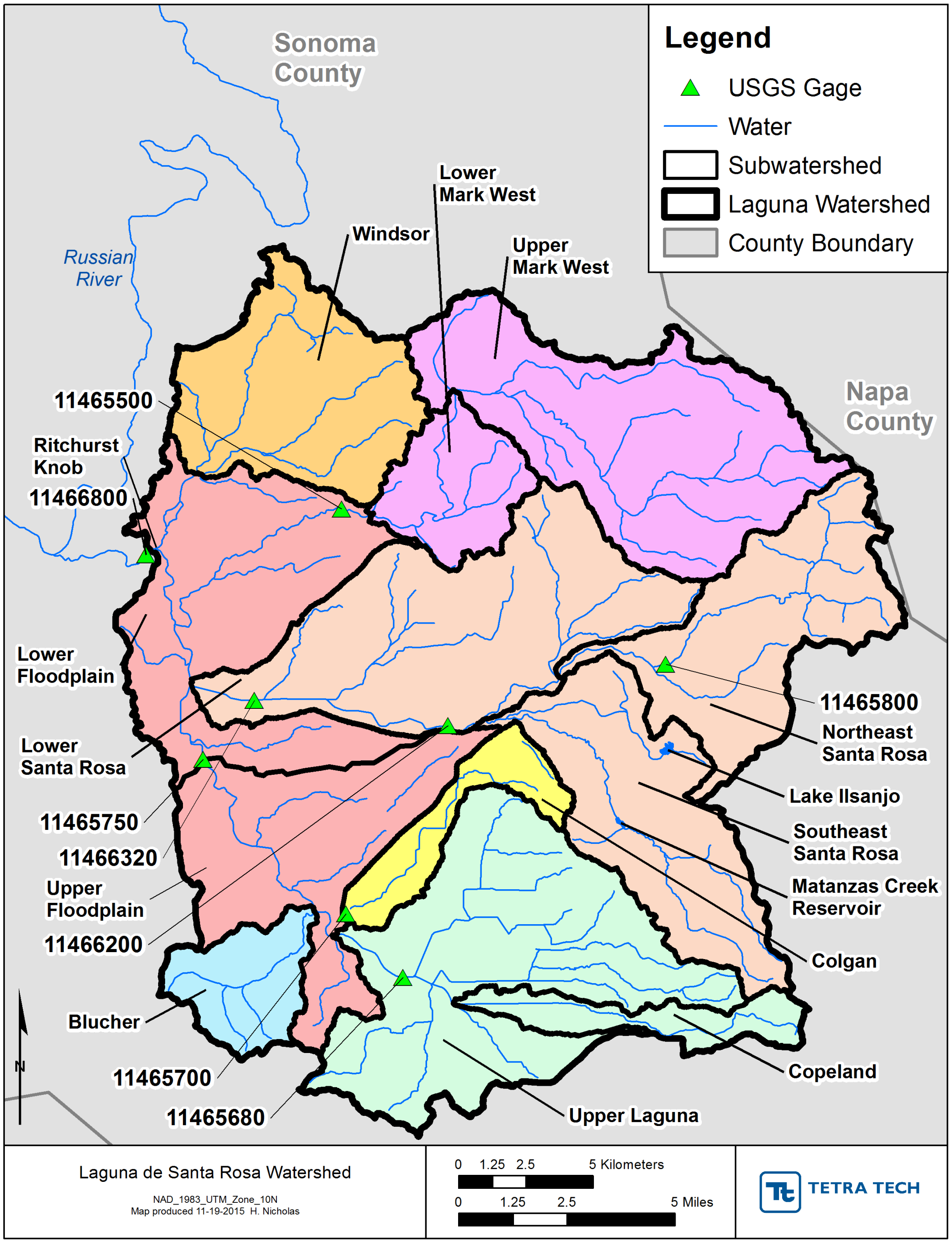

Figure 1-2. Delineated Subwatersheds and USGS Gages used for Linkage Analyses of the Laguna de Santa Rosa Watershed

A detailed discussion of spatial data for the watershed is contained in Tetra Tech (2019). A key attribute for the nutrient linkage analysis is the distribution of land use and land cover in the watershed, which is derived from the Sonoma County Vegetation Mapping and LiDAR program (Sonoma VegMap, 2018). In addition to LiDAR elevation data, the VegMap program has produced a wide range of vegetation, land use, and hydrologic products, all at a fine spatial scale. The land cover and land use information from this program provides the most comprehensive and reliable tabulations for the Laguna de Santa Rosa watershed and is used as the basis for many of the analyses in this report. The Lifeforms map provides general classification of cover types, with additional information on forest and agricultural lands in separate analyses, all combined into the Sonoma County Vegetation and Habitat Map, which delineates 23 unique lifeform classes (http://sonomaopenspace.maps.arcgis.com/home/item.html?id=2d7728a8aba44df5b154c80aa8588d79). There is also a separate Impervious Map, which provides fine scale delineations of impervious features, including identification of paved roads, unpaved roads, building footprints, and other impervious surfaces. The Vegetation and Habitat Map does not distinguish vegetation types within the city limits of Santa Rosa, Windsor, Sebastopol, Rohnert Park, and Cotati (see Figure 1-1), but instead classifies these areas as “Urban Window.” However, the Impervious Map does provide a full tabulation of impervious surfaces within the city limits, allowing identification of a general urban pervious classification for the remainder of the Urban Window area. A simplified representation of the Lifeforms Map (aggregated into 14 categories) is shown in Figure 1-3. Table **1**-**1** summarizes the percentage distribution of land use and land cover classes across the entire watershed. The watershed is 14.6 percent impervious. Over 29 percent of that impervious cover consists of public and private roads, but only 8.4 percent of the roads are classified as unpaved.

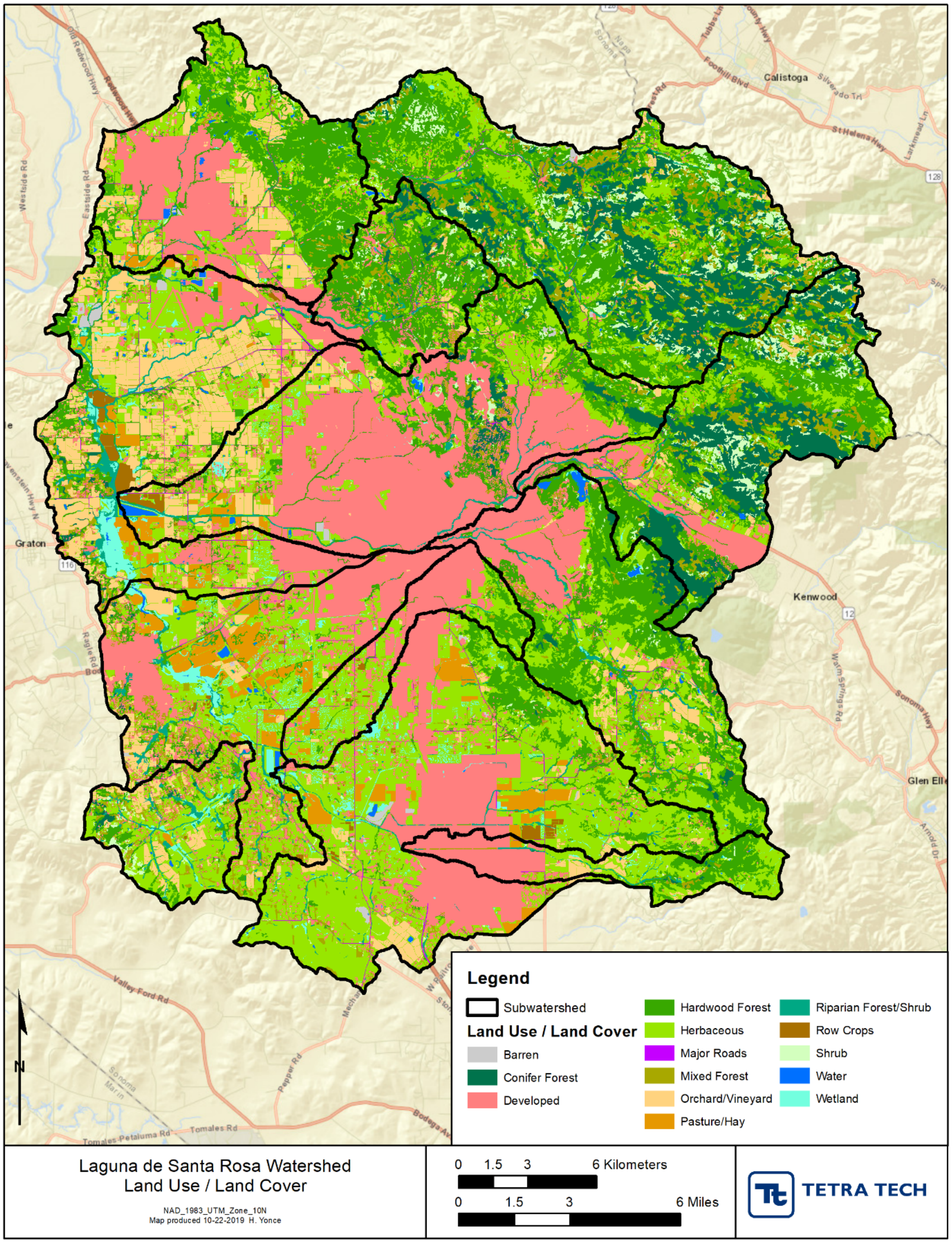

Figure 1-3. Simplified Lifeforms Distribution from Sonoma VegMap (2013 Data)

Table 1-1. 2013 Land Use and Land Cover Information for the Laguna de Santa Rosa Watershed from Sonoma VegMap Lifeforms and Impervious Coverages (Sonoma VegMap, 2018)

Land Use/Land Cover	Area (acres)	Percent of Watershed
Pervious Land		
Barren	*585*	0.4%
Conifer Forest	*10,502*	6.5%
Developed (pervious)	*16,938*	10.5%
Hardwood Forest	*32,542*	20.2%
Herbaceous	*42,486*	26.4%
Mixed Forest	*7,288*	4.5%
Orchards/Vineyards	*12,652*	7.9%
Pasture/Hay	*3,837*	2.4%
Row Crops	*812*	0.5%
Shrub	*4,417*	2.7%
Water/Wetland	*3,209*	2.0%
Woody Wetlands	*2,322*	1.4%
Impervious Land		
Paved Road	*6,312*	3.9%
Dirt Road	*575*	0.4%
Other Impervious	*9,019*	5.6%
Building	*7,571*	4.7%
Total Area	*161,067*	100%

Notes: The tabulations presented in this table combine information from the Sonoma VegMap life forms classification, the forest life forms classification, and the impervious cover classification. Impervious land classes are as defined in the impervious cover classification. After removing impervious land, the remaining pervious area classes were assembled and aggregated for use in later analyses as follows:
Barren: Barren and Sparsely Vegetated life forms
Conifer Forest: As defined in forest life form classification
Developed (pervious): Pervious portions of the Developed life form and the Urban Window area
Hardwood Forest: As defined in forest life form classification
Herbaceous: Herbaceous life form and the pervious part of the Major Roads life form
Mixed Forest: Forest Sliver, Mixed Conifer-Hardwood Forest, and Non-Native Forest life forms
Orchards/Vineyards: Orchard or Grove, Perennial Agriculture, Vineyard-Replant, and Vineyard life forms
Pasture/Hay: Intensively Managed Hayfield and Irrigated Pasture life forms
Row Crops: Annual Cropland life form
Shrub: Non-Native Shrub, Nursery or Ornamental Horticulture Area, Riparian Shrub, and Shrub life forms
Water/Wetland: Herbaceous Wetland, Aquatic Vegetation, and Water life forms
Woody Wetlands: Riparian Forest life form

2.0 OVERVIEW OF NUTRIENT-RELATED IMPAIRMENTS IN THE LAGUNA DE SANTA ROSA

The Laguna de Santa Rosa is a series of low gradient channels, pools, and wetlands that developed along the western edge of a tectonic depression formed between two tilting crustal blocks (the Santa Rosa block and the Sebastopol block). Water in the Laguna is slow-moving and poorly flushed. As a result, the Laguna naturally collects surface and subsurface runoff, sediment, and nutrients from the surrounding watershed – including urban runoff, agricultural runoff, loads from onsite wastewater systems, and loads from wastewater treatment plants. It is likely that the Laguna was always a naturally productive system that had nutrient loads sufficient to support dense growths of hydrophilic vegetation; however, it is also clear that human activities since European settlement have greatly increased nutrient and sediment loads to the Laguna, as well as altering the hydrology of the system, leading to biostimulatory conditions with over-enrichment by nutrients and associated hyper-eutrophication. The Laguna de Santa Rosa has been officially considered impaired and not fully supporting its beneficial uses since the 1990 list of impaired waters under Clean Water Act section 303(d), which states "Low dissolved oxygen and high ammonia levels due to NPS [nonpoint source] discharges have impaired fish and wildlife habitat." (https://www.waterboards.ca.gov/water_issues/programs/tmdl/records/past_reports/1990_303d.pdf).

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, including regeneration of nutrients from the sediment and creation of biomass (and associated oxygen demand) by plant growth within the Laguna (Sloop et al., 2007; Tetra Tech, 2015a). 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 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. The organic sediment that has built up in the Laguna also provides an ongoing source of nutrients and oxygen-consuming material. The net effect of these interlocking factors is a failure to support the Basin Plan (NCRWQCB, 2011) narrative criterion for biostimulatory substances.

2.1 REGULATORY BACKGROUND

Excess nutrients in the Laguna de Santa Rosa result in increased algal and macrophyte growth, which in turn affect DO levels and habitat quality. Existing regulations regarding water quality in the Laguna have explicit DO objectives, but provide only narrative objectives for nutrients, as described below.

The *Water Quality Control Plan for the North Coast Region* ("Basin Plan"; NCRWQCB, 2011) identifies two different sets of numeric water quality objectives for DO. The first consists of three site-specific objectives designed to protect beneficial uses, and the second set is based on life-cycle requirements for aquatic life. The life cycle DO objectives are based on designated aquatic life uses ("WARM", "COLD", and "SPWN").

Site-specific DO water quality objectives:

- DO levels shall not fall below 7.0 mg/L at any time.

- 90 percent or more of all annual DO levels shall be equal to or exceed 7.5 mg/L.
- 50 percent or more of all annual DO levels shall be equal to or exceed 10.0 mg/L.

Life cycle requirement-based DO objectives:

- Waters designated WARM: ≥ 5.0 mg/L minimum DO.
- Waters designated COLD: ≥ 6.0 mg/L minimum DO.
- Waters designated SPWN: ≥ 7.0 mg/L minimum DO.
- Waters designated SPWN: ≥ 9.0 mg/L minimum DO during critical spawning and egg incubation periods.

The Basin Plan does not contain explicit numeric objectives for nutrient concentrations in the Laguna de Santa Rosa; it does, however, contain a narrative water quality objective for biostimulatory substances that states: "Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses." 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."

The early history of regulatory actions to address nutrient and DO impairments in the Laguna de Santa Rosa is described in the Regional Board's 2001 update recommendations for the federal Clean Water Act Section 303(d) List of Impaired Waterbodies (NCRWQCB, 2001):

> *The Laguna de Santa Rosa was added to the 303(d) List in 1990 for high levels of ammonia and low dissolved oxygen (DO) concentrations. A TMDL was completed for the Laguna for ammonia and dissolved oxygen in 1995. The TMDL concluded that high ammonia levels in the Laguna were the result of point and non-point source nitrogen inputs of various forms. Low dissolved oxygen concentrations were a result of inputs of organic matter and nutrients which stimulate algal growth and subsequently cause depressed dissolved oxygen levels when the algae dies and decays.*

The 1995 TMDL led to the development of a Waste Reduction Strategy (WRS; Morris, 1995) that focused on nitrogen loading from point and non-point sources and was intended to directly address the ammonia listing as well as reducing excess algal growth, which in turn affects DO levels. Morris noted that there were "artificially high concentrations of nitrogen in the Laguna's water column" and that algal growth potential studies had indicated nitrogen was the most limiting nutrient. The 2011 303(d) List recommendations continue:

> *With the implementation of the WRS and operational improvements at the City of Santa Rosa Wastewater Treatment Plant as well as improvements in waste storage and disposal activities at local dairies, nitrogen inputs to the Laguna were significantly reduced. Following implementation of the WRS and the subsequent attainment of nitrogen ammonia interim concentration goals, as stated in the WRS, the Laguna was removed from the 303(d) List for ammonia and dissolved oxygen in 1998, pursuant to a recommendation by US EPA.*

Despite these improvements, subsequent monitoring revealed that DO levels in the Laguna continued to frequently fall below the Basin Plan minimum DO objective of 7 mg/L and that phosphorus concentrations were elevated above levels expected for natural conditions. Consequently, California's 2010 303(d) List identified the mainstem of the Laguna de Santa Rosa as not supporting beneficial uses and requiring the development of TMDLs for nitrogen, phosphorus, DO, temperature, and sediment. The mainstem of the Laguna de Santa Rosa was also listed as impaired for pathogenic bacteria and mercury, although these impairments are not addressed in this study. 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 the overgrowth of *Ludwigia*.

2.2 CONCEPTUAL MODEL

Sloop et al. (2007) provide extensive discussions of the impairments of the Laguna de Santa Rosa and the many complex ways that they are related to hydrology, sedimentation, and nutrient loading from the watershed. These interconnections are summarized in a water quality conceptual model, which is reproduced in Figure 2-1.

The conceptual model is divided into a series of categories beginning with external loading stressors and other exogenous risk cofactors (A) that are linked to a series of response categories (B-F) that ultimately affect beneficial uses (G). The primary response category (B) responds to stressors and exogenous risk cofactors (A) and is linked to changes in the descending categories for physical habitat and water chemistry changes.

Nutrients and organic matter were identified as the primary external stressors for this conceptual model due to unusually high concentrations and external loadings of nitrogen, phosphorus, and organic matter to the Laguna ecosystem. Risk cofactors (such as channel modification) are also stressors that in combination with nutrients can result in degraded conditions.

Reduced DO is linked to external loading of organic matter, and, via algal and macrophyte growth and decay, to external loads of nutrients. Sloop et al. (2007) concluded that the significant factors contributing to low DO "include low flow, low gradient of water, channel morphology, high loadings of nutrients and organic carbon, high sediment oxygen demand, and an abundance of algae and macrophytes." The linkage between ongoing nutrient loads and impairment associated with the overgrowth of the macrophyte *Ludwigia* is, however, difficult to quantify.

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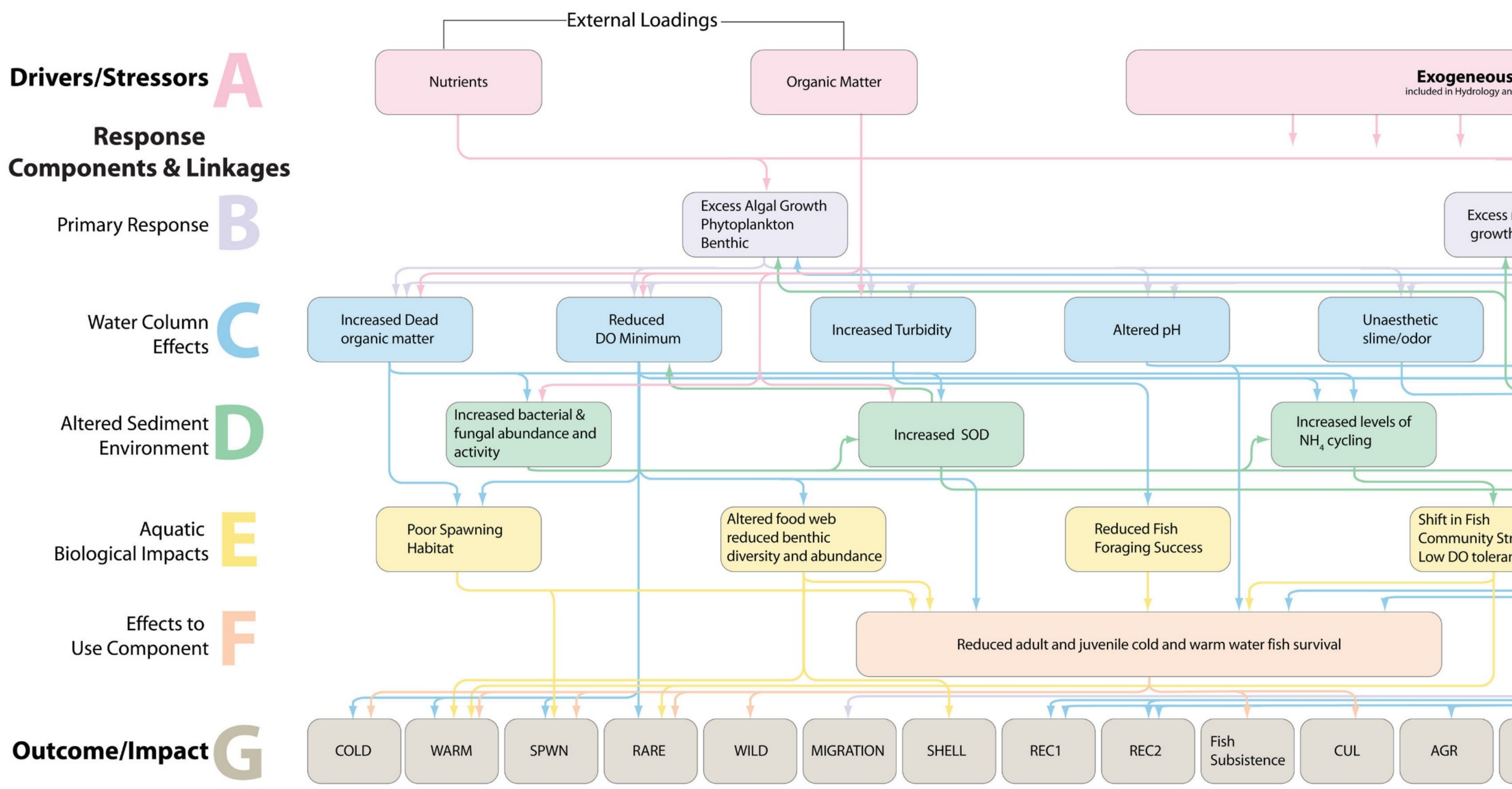

Figure 2-1. Laguna de Santa Rosa Water Quality Overview Conceptual Model (from Sloop e

Note: Line G lists the following beneficial uses: COLD (Cold Freshwater Habitat), WARM (Warm Freshwater Habitat), SPWN (Fish Spawning), RARE (Preservation of Rare and Enda Harvesting), REC1 (Water Contact Recreation), REC2 (Noncontact Water Recreation), Fish Subsistence (Tribal Subsistence Fishing), CUL (Tribal Tradition and Culture), AGR (Agri Public Health), FLD (Flood Peak Attenuation/Flood Water Storage), WQE (Water Quality Enhancement), and WET (Wetland Habitat).

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3.0 MONITORING DATA

3.1 WATER COLUMN SAMPLING

Water quality monitoring in the Laguna de Santa Rosa through 2010 is described in detail by Fitzgerald (2013). Data for nutrients in the Laguna go back to 1972 at some monitoring locations. The earlier data show elevated levels of total Kjeldahl nitrogen (TKN – the sum of ammonium nitrogen and organic nitrogen) that are indicative of nutrient over-enrichment and low DO conditions. Monitoring appears to show large declines in both nitrogen (N) and phosphorus (P) concentrations up until the late 1990s, due primarily to reductions in point source discharges. Sloop et al., (2007, Ch. 5) provide an extensive discussion of nutrient concentrations in the Laguna de Santa Rosa based on samples from 1985 – 2005. The summary by Sloop et al. documents highly elevated nutrient concentrations, but also shows decreases over time that were likely due in part to improvements to wastewater treatment and reduction in nutrient loads from dairies. Key points in the Sloop et al. summary include the following:

- *Very high total NH_3 [ammonia]and TKN concentrations (e.g., average of 6.8 mg/l at certain locations) were observed for the period of 1989 to 1994.*
- *Total NH_3, TKN, NO_3 [nitrate], and TP [total phosphorus] have shown different degrees of decreases from 1989 to 1994, 1995 to 2000, and 2000 to 2005. The largest decreases are in total NH_3 and TKN concentrations. Among the three sampling periods, 1995 to 2000 has the lowest nutrient concentrations.*
- *Current nutrient concentrations for the Laguna main channel during 2000 to 2005 are quite uniform for total NH_3, with median concentrations in the range of 0.3-0.5 mg/l. Median NO_3 concentrations remain high at 1-3 mg/l and show larger variations. Organic nitrogen is relatively uniform and generally below 2 mg/l with median values around 1 mg/l at many sampling locations. Median TP concentrations are generally between 0.5- 1 mg/l with a few locations showing median TP above 1 mg/l.*
- *For the main channel of the Laguna, nutrient concentrations are generally lower at the upstream station… increase downstream to [Occidental Road] … then further decrease downstream of [Occidental Road] … Santa Rosa Creek generally has lower nutrient concentrations. Dilution from Santa Rosa Creek decreases nutrient concentrations further downstream.*
- *Generally higher nutrient concentrations are observed during winter/spring months. Low NO_3 concentrations are observed in summer for all the locations. However, relatively high TP concentrations (0.3-0.5 mg/l) have also been observed in summer months, suggesting contribution from other sources rather than wastewater discharge.*

Sloop et al. noted that mean total nitrogen (TN) and TP concentrations within the Laguna are considerably higher than the mean of minimally impacted waters sampled within Ecoregion 6 (Southern and Central California Chaparral and Oak Woodlands; Omernik, 1987), and noted that concentrations may be sufficiently high that nutrients are not limiting growth. They also noted:

> *It is possible neither nitrogen nor phosphorus ever becomes limiting in the Laguna due to the availability of these nutrients released from the sediments. It would be necessary to further control N and P loadings to begin to address excess algal and macrophyte growth in the Laguna. However, other risk cofactors including shallow water depth, lack of riparian cover, low flow, altered flow regime, and high water*

> *temperature also contribute to excess algal and macrophytes growth. A nutrient management strategy will have limited success in controlling excess algal growth without also addressing other risk cofactors.*

Four compliance stations on the shallow, lake-like Laguna mainstem and downstream on Mark West Creek were established as a result of the WRS (Morris, 1995): the Laguna at Stony Point Road (LSP), the Laguna at Occidental Road (LOR), the Laguna at Guerneville Road (LGR), and Mark West Creek at Trenton-Healdsburg Road (LTH), as well as a station on Santa Rosa Creek at Willowside Road (SRCWR) (Figure 3-1). These stations were sampled regularly by Regional Board staff between 1995 and 2001 according to complied data supplied by David Kuszmar, NCRWQCB in 2015. Phosphorus monitoring at LSP and LOR goes back to 1973. Water quality sampling within the Laguna de Santa Rosa after 2001 has been more limited but does include efforts at all the compliance stations in 2008 and 2013, plus samples at LOR (only) in 2005. Nutrient samples for N (nitrogen), P (phosphorus), Chl-*a* (chlorophyll a), total organic carbon (TOC), and the 5-day biochemical oxygen demand (BOD-5) for 2000 through 2008 are summarized in Table 3-1.

Table 3-1. Summary of Nutrient Samples Collected by Regional Board Staff at Laguna de Santa Rosa Compliance Stations, 2000-2008

	Total NH3-N (mg/l)	TN (mg/l)	TP (mg/l)	Dissolved P (mg/l)	Chl-*a* (µg/l)	TOC (mg/l)	BOD-5 (mg/l)
Santa Rosa Creek at Willowside Road (at USGS gage 11466320))							
Count	133	78	115	76	26	45	53
Median	0.050	0.982	0.110	0.100	4.15	5.2	1.0
Mean	0.114	1.818	0.228	0.283	5.79	7.5	1.8
Laguna de Santa Rosa at Stony Point (at USGS gage 22465680)							
Count	212	113	152	69	25	44	135
Median	0.100	1.231	0.477	0.430	18.00	12.0	2.0
Mean	0.190	1.623	0.528	1.150	24.42	14.9	3.0
Laguna de Santa Rosa at Occidental Rd. (adjacent USGS gage 11465750)							
Count	209	110	149	66	38	42	135
Median	0.140	3.147	1.180	1.650	97.20	14.5	5.0
Mean	0.476	4.134	1.378	1.723	286.58	16.4	6.8
Laguna de Santa Rosa at Guerneville Rd.							
Count	123	76	78	0	0	0	84
Median	0.100	1.663	0.462				3.0
Mean	0.209	2.331	0.549				3.5
Mark West Creek at Trenton-Healdsburg Rd. (at USGS gage 11466800)							
Count	147	72	87	8	20	2	135
Median	0.100	1.067	0.341	0.575	11.50	7.4	2.5
Mean	0.125	1.467	0.418	0.620	13.92	7.4	2.7

Note: Censored (non-detect) data included in the calculation of statistics at one-half the detection limit.

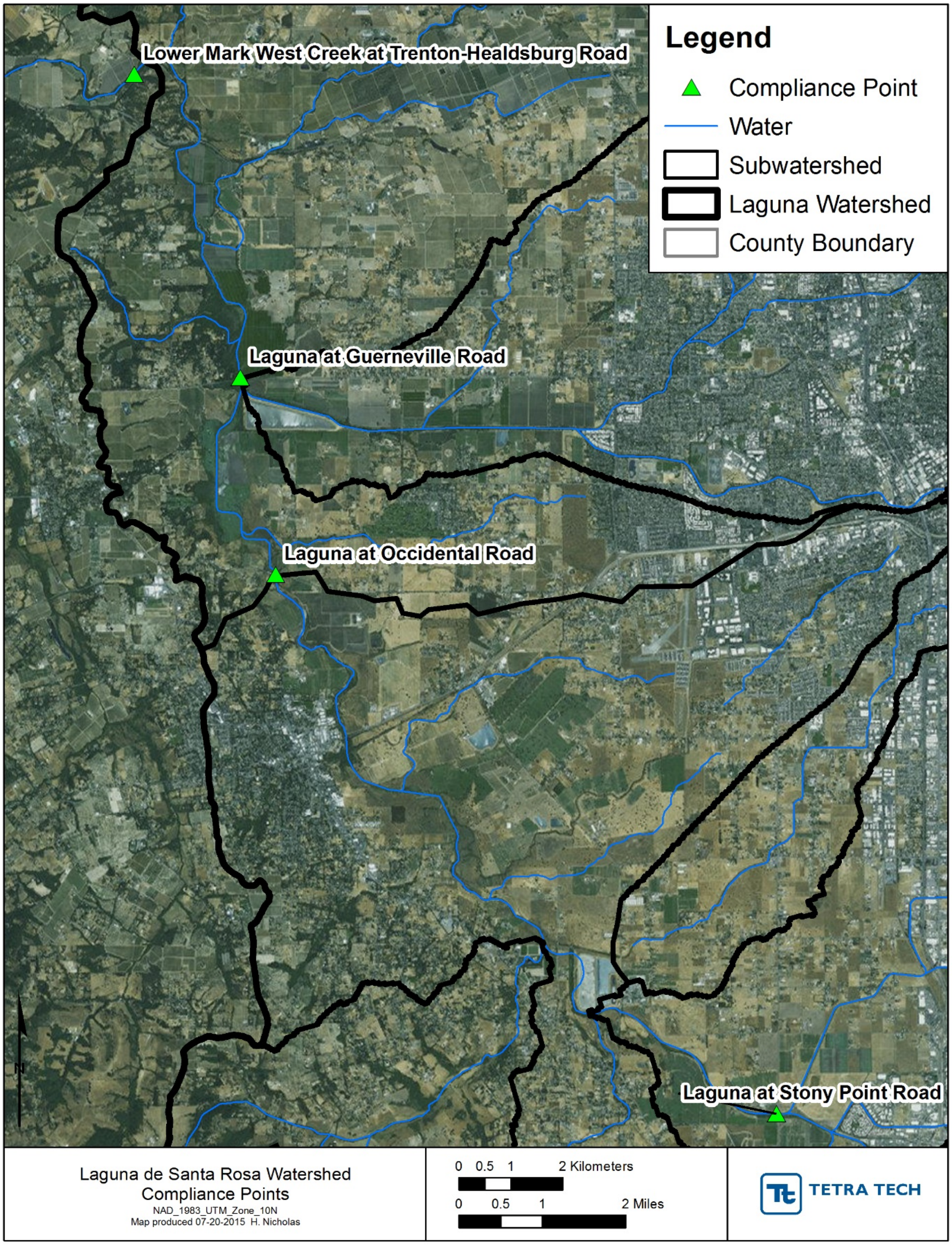

Figure 3-1. Nutrient Compliance Monitoring Points in the Laguna de Santa Rosa

Additional sampling at the Laguna compliance stations as well as other stations previously monitored by Regional Board staff was undertaken by the City of Santa Rosa on a monthly basis from September 2016 through September 2017 (email from Sean McNeil | Deputy Director Environmental Services, Santa Rosa Water to Kelsey Cody, NCRWQCB, 12/23/2019). Sample locations are shown in Figure 3-2 and nutrient sampling results are summarized in Table 3-2.

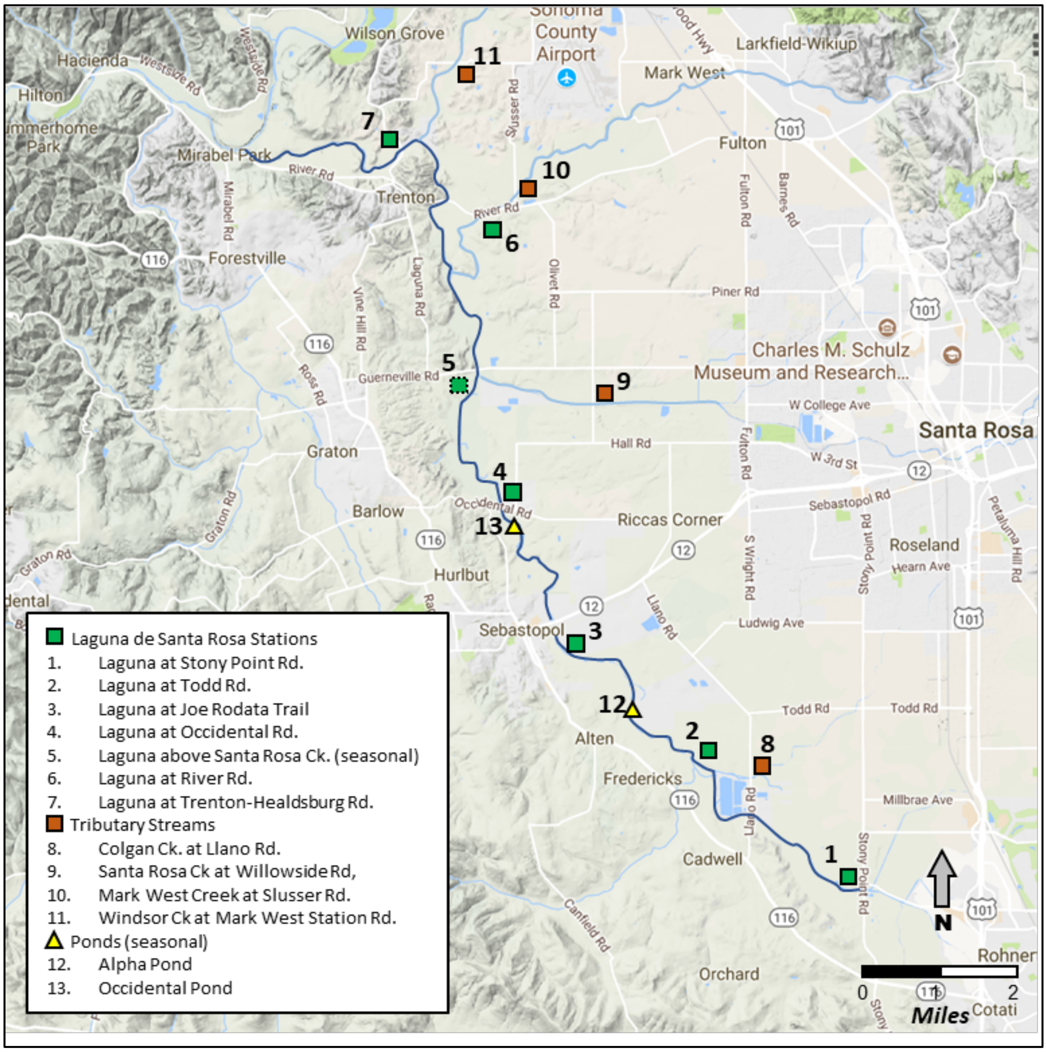

Figure 3-2. Stations Sampled by City of Santa Rosa, 2016-2017

Note: Figure is from map included in presentation by City of Santa Rosa to NCRWQCB, 11/18/2019.

Table 3-2. Summary of Nutrient Data in 2016-2017 Monthly Monitoring by City of Santa Rosa

Station	Ammonia as N (mg/L0		Nitrate as N (mg/L)		Nitrate+ Nitrite as N (mg/L)		Orthophosphate as P (mg/L)		Total Kjeldahl Nitrogen (mg/L)		Total N (mg/L)		Total P (mg/L)	
	mean	median	mean	median	mean	median	mean	median	mean	median	mean	median	mean	median
Colgan Crk., Llano Rd.	0.499	0.260	0.760	0.760	1.244	1.400	0.277	0.250	1.162	1.100	2.436	2.400	0.400	0.410
Laguna at Joe Rodata Trail	0.418	0.170	0.305	0.305	0.804	0.915	0.454	0.465	1.150	1.300	2.008	2.000	0.616	0.585
Laguna at Occidental Rd.	0.392	0.180	-	-	0.439	0.510	0.437	0.440	1.492	1.400	1.873	1.700	0.619	0.645
Laguna at River Rd.	0.293	0.190	0.545	0.545	0.354	0.230	0.395	0.380	0.912	1.000	1.465	1.300	0.518	0.560
Laguna at Stony Point Rd.	0.636	0.600	0.640	0.640	0.803	0.830	0.291	0.270	1.334	1.200	1.986	2.050	0.443	0.450
Laguna, Trenton-Healdsburg Rd.	0.321	0.185	0.358	0.358	0.364	0.225	0.411	0.385	0.865	0.855	1.303	1.300	0.553	0.590
Laguna at Todd Rd.	0.438	0.150	0.338	0.338	0.677	0.630	0.591	0.445	1.248	1.350	1.950	1.950	0.728	0.545
Mark West Crk., Slusser Rd.	0.236	0.100	0.163	0.163	0.224	0.140	0.151	0.083	0.440	0.400	0.715	0.620	0.108	0.096
Santa Rosa Crk., Willowside Rd.	0.242	0.100	0.400	0.400	0.508	0.460	0.135	0.076	0.533	0.505	0.988	0.880	0.143	0.110
Windsor Crk., Mark West Station Rd.	0.124	0.100	0.990	0.990	0.569	0.395	0.139	0.110	0.637	0.700	1.317	1.200	0.197	0.170

There has been less systematic data collection at individual stations over the last decade (defined here as 2009 through 2018); however, various programs have collected data at multiple stations in the Laguna and its tributaries (Table 3-3 and Figure 3-3). These more recent data are available through the California Environmental Data Exchange Network (CEDEN) and include another round of Laguna de Santa Rosa trend sampling in 2013 (only) as well as samples associated with the Statewide Perennial Streams Assessment (2012), Statewide Pollution Trends Study (2014), Regional Board Russian River Monitoring and Bioassessment (2009-2011, 2016), Regional Board Russian River Pathogen Indicator TMDL (2009-2013), Regional Board Irrigated Lands Monitoring (2013-2014), and Regional Board Post-Fire Sampling (2017-2018).

A summary of water column monitoring data collected since 1/1/2009 is provided in Table 3-4 (for nitrogen species) and Table 3-5 (for phosphorus species and chlorophyll *a*.

Table 3-3. Laguna de Santa Rosa Water Column Monitoring Stations in CEDEN, 2009-2018

1 Blucher Creek at Lone Pine Road (114BL1999)
3 Colgan Creek at Meda Lane-(114CL9596)
5 Copeland Creek at Petaluma Hill Road-(114CO3423)
6 Copeland Creek at Redwood Drive-(114CO0584)
7 Laguna de Santa Rosa at Benson Road-(114LG9440)
8 Laguna de Santa Rosa at Cunningham Pond-(114LG4844)
9 Laguna de Santa Rosa at Guerneville Road-(114LG0916)
10 Laguna de Santa Rosa at Joe Rodata Trail-(114LG3704)
11 Laguna de Santa Rosa at Llano Road-(114LG6367)
12 Laguna de Santa Rosa at Lower Occidental Pond (114LG2577)
14 Laguna de Santa Rosa at Mirabel (114LAGMIR)
15 Laguna de Santa Rosa at Occidental Road-(114LG2320)
16 Laguna de Santa Rosa at Redwood Drive-(114LG8693)
17 Laguna de Santa Rosa at Santa Rosa Creek-(114LG0958)
18 Laguna de Santa Rosa at Sebastopol Community Center (114LG3411)
19 Laguna de Santa Rosa at Stony Point Road (114LG7508)
20 Laguna de Santa Rosa at Todd Road (114LG5615)
21 Laguna de Santa Rosa at Upper Occidental Pond-(114LG2850)
22 Laguna de Santa Rosa downstream Guerneville Road-(114LG0877)
24 Laguna de Santa Rosa downstream of Occidental Road-(114LG2125)
27 Laguna de Santa Rosa upstream of Santa Rosa Creek-(114LG1059)
28 Laguna de Santa Rosa upstream of Wohler Street Bridge (114LAGWOH)
29 Mark West Creek ~1.2mi above Van Buren Cr. (114MW8747)
30 Mark West Creek at River Road (114MW2583)
31 Mark West Creek at Slusser Road-114MW2687 (114MW2687)
32 Mark West Creek at St. Helena Road-(114MW8405)
33 Mark West Creek at Trenton Healdsburg Road (114MW0930_SWAMP)
34 Mark West Creek at Wohler Road-(114MW0211)
35 Mark West Creek downstream of Trenton Healdsburg Road-(114MW0908)
36 Matanzas Creek ~0.5mi above Hoen Ave. (114PS0149)
38 Outfall on north bank of Santa Rosa Creek west of Pierson Bridge-(114OFNWPB)
39 Outfall on north bridge abutment of Matanzas Creek under Brookwood Ave-(114OFNUBA)
42 Santa Rosa Creek at Willowside Road (114SR0761_SWAMP)
44 Santa Rosa Creek upstream of the Laguna de Santa Rosa-(114SR0082)
46 Unnamed stream at Laguna Road-(114UL3708)
47 Unnamed Stream at Occidental Road (114USOCCI)
48 Unnamed stream at Windsor Road-(114UW2221)
49 West outfall on north bank of Santa Rosa Creek west of First Street-(114OFWWFS)
50 Windsor Creek at Mark West Station (114WC1630)

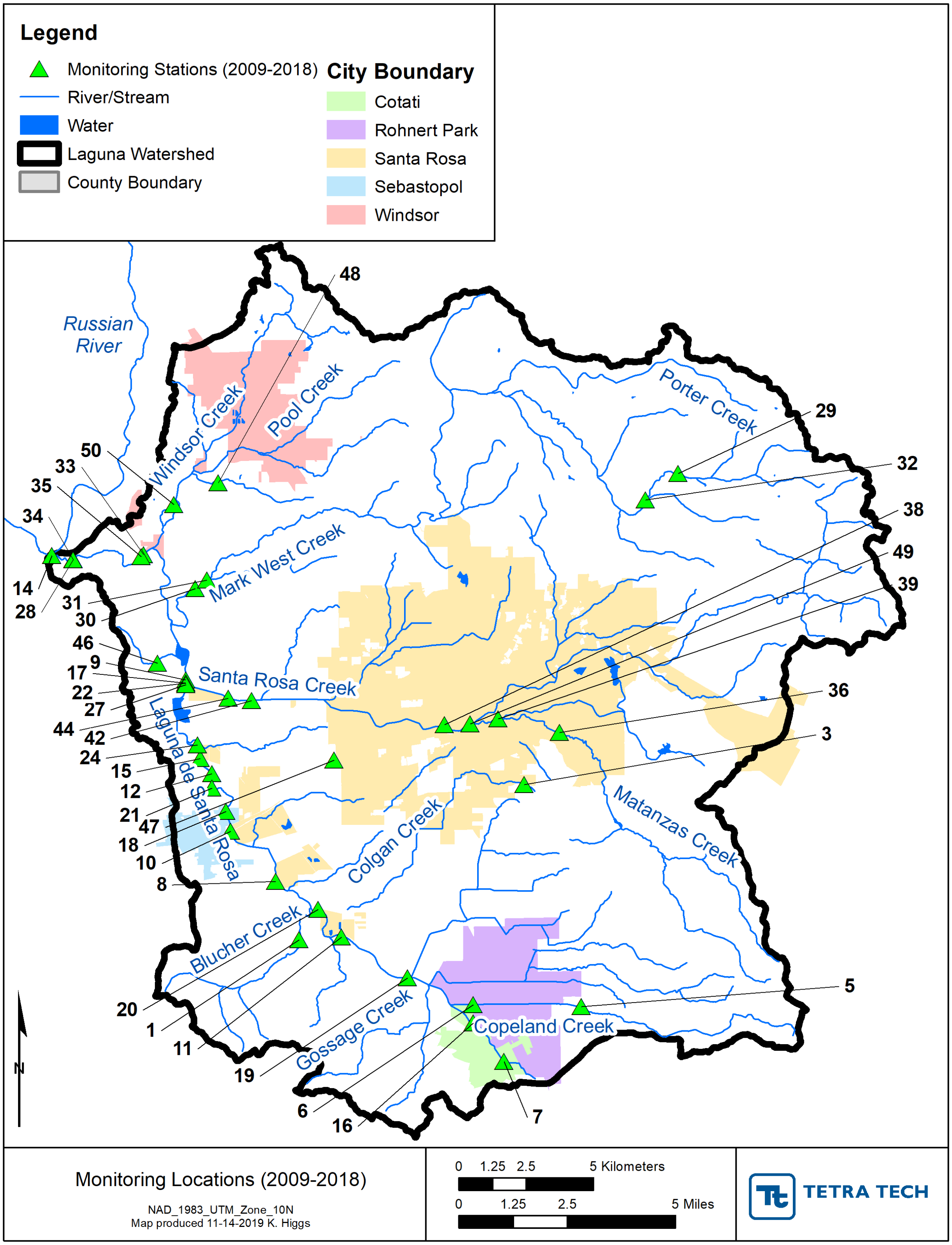

Figure 3-3. CEDEN Water Column Monitoring Locations since 1/1/2009

Table 3-4. Monitoring Since 1/1/2009 for Nitrogen Species in CEDEN

		Total Ammonia as N (mg/L)			Nitrite + Nitrate as N (mg/L)			Total Kjeldahl Nitrogen (mg/L)			Total Nitrogen (mg/L)		
		Count	Mean	Median	Count	Mean	Median	Count	Mean	Median	Count	Mean	Median
1	Blucher Creek at Lone Pine Road	1	0.047	0.047	1*	0.754	0.754		-	-	1	1.40	1.40
3	Colgan Creek at Meda Lane-114CL9596	4	0.072	0.069	4	-	-		-	-	4	0.596	0.722
5	Copeland Creek at Petaluma Hill Road-114CO3423	11	0.058	0.051	11	-	-		-	-	9	0.596	0.507
9	Laguna de Santa Rosa at Guerneville Road-114LG0916	3	0.062	0.060	3*	0.025	0.025	3	0.554	0.641	0		
11	Laguna de Santa Rosa at Llano Road-114LG6367	5	0.050	0.050	5*	0.075	0.075		-	-	0		
14	Laguna de Santa Rosa at Mirabel	0	-	-	0*	-	-	3	0.734	0.531	0		
15	Laguna de Santa Rosa at Occidental Rd	3	0.083	0.070	3*	0.025	0.025	3	1.059	0.878	0		
19	Laguna de Santa Rosa at Stony Point Road-114LG7508	3	0.123	0.150	3*	0.0367	0.025	3	0.764	0.755	0		
20	Laguna de Santa Rosa at Todd Road	1	0.011	0.011	1*	0.219	0.219		-	-	1	0.758	0.758
29	Mark West Creek ~1.2mi above Van Buren Cr.	0	-	-	0*	-	-	1	0.274	0.274	0		
30	Mark West Creek at River Road	2	0.003	0.003	2*	0.0025	0.0025		-	-	2	0.112	0.112
32	Mark West Creek at St. Helena Road-114MW8405	3	0.057	0.046	3	-	-		-	-	3	0.288	0.204

		Total Ammonia as N (mg/L)			Nitrite + Nitrate as N (mg/L)			Total Kjeldahl Nitrogen (mg/L)			Total Nitrogen (mg/L)		
		Count	Mean	Median	Count	Mean	Median	Count	Mean	Median	Count	Mean	Median
33	Mark West Creek at Trenton Healdsburg Road	10	0.035	0.032	2*	0.322	0.322	1	0.693	0.693	12	0.553	0.477
35	Mark West Cr ds of Trenton Healdsburg Road-114MW0908	3	0.032	0.040	3*	0.0367	0.025	3	0.769	0.822	0		
36	Matanzas Creek ~0.5mi above Hoen Ave.	1	0.020	0.020	0*	-	-		-	-	1	0.245	0.245
38	Outfall on north bank of Santa Rosa Creek west of Pierson Bridge-114OFNWPB	5	0.040	0.042	5	-	-		-	-	5	0.949	0.873
39	Outfall on north bridge abutment of Matanzas Creek under Brookwood Ave-114OFNUBA	3	0.115	0.115	3	-	-		-	-	3	0.576	0.706
42	Santa Rosa Creek at Willowside Road	9	0.017	0.012	3	0.208	0.111	5	0.780	0.449	9	0.665	0.416
46	Unnamed stream at Laguna Road-114UL3708	9	0.071	0.056	9	-	-		-	-	9	0.726	0.709
47	Unnamed Stream at Occidental Road-114USOCCI	6	0.093	0.089	6	-	-		-	-	6	1.50	1.36
48	Unnamed stream at Windsor Road-114UW2221	5	0.120	0.160	5	-	-		-	-	5	0.640	0.639
49	West outfall on north bank of Santa Rosa Creek west of First Street-114OFWWFS	5	0.052	0.032	5	-	-		-	-	5	1.74	0.843
50	Windsor Creek at Mark West Station	1	0.013	0.013	1*	0.357	0.357		-	-	1	0.850	0.850

* Samples for nitrate only.

Table 3-5. Monitoring Since 1/1/2009 for Phosphorus Species and Chlorophyll *a* in CEDEN

		Dissolved PO_4 as P (mg/L)			Total PO_4 as P (mg/L)			Total Phosphorus (mg/L)			Chlorophyll a (µg/L)		
		Count	Mean	Median	Count	Mean	Median	Count	Mean	Median	Count	Mean	Median
1	Blucher Creek at Lone Pine Road	1	0.420	0.420	0	-	-	1	0.481	0.481	1	12.0	12.0
3	Colgan Creek at Meda Lane-114CL9596	0	-	-	4	0.128	0.104	4	0.153	0.121	0	-	-
5	Copeland Creek at Petaluma Hill Road-114CO3423	0	-	-	11	0.089	0.080	11	0.192	0.097	0	-	-
9	Laguna de Santa Rosa at Guerneville Road-114LG0916	0	-	-	0	-	-	3	0.465	0.410	0	-	-
14	Laguna de Santa Rosa at Mirabel	3	0.331	0.200	0	-	-	3	0.420	0.379	3	10.5	1.2
15	Laguna de Santa Rosa at Occidental Rd	0	-	-	0	-	-	3	0.386	0.361	6	70.7	48.0
19	Laguna de Santa Rosa at Stony Point Road-114LG7508	0	-	-	0	-	-	3	0.595	0.587	0	-	-
20	Laguna de Santa Rosa at Todd Road	1	0.349	0.349	0	-	-	1	0.417	0.417	1	12.0	12.0
29	Mark West Creek ~1.2mi above Van Buren Cr.	1	0.044	0.044	0	-	-	1	0.053	0.053	0	-	-
30	Mark West Creek at River Road	2	0.109	0.109	0	-	-	2	0.086	0.086	2	12.0	12.0
32	Mark West Creek at St. Helena Road-114MW8405	0	-	-	3	0.048	0.050	3	0.051	0.045	0	-	-
33	Mark West Creek at Trenton Healdsburg Road	12	0.287	0.275	0	-	-	12	0.334	0.321	12	15.7	22.0
35	Mark West Cr ds of Trenton Healdsburg Road-114MW0908	0	-	-	0	-	-	3	0.434	0.431	0	-	-

		Dissolved PO_4 as P (mg/L)			Total PO_4 as P (mg/L)			Total Phosphorus (mg/L)			Chlorophyll a (µg/L)		
		Count	Mean	Median	Count	Mean	Median	Count	Mean	Median	Count	Mean	Median
36	Matanzas Creek ~0.5mi above Hoen Ave.	1	0.336	0.336	0	-	-	1	0.291	0.291	0	-	-
38	Outfall on north bank of Santa Rosa Creek west of Pierson Bridge-114OFNWPB	0	-	-	5	0.078	0.077	5	0.128	0.101	0	-	-
39	Outfall on north bridge abutment of Matanzas Creek under Brookwood Ave-114OFNUBA	0	-	-	3	0.081	0.090	3	0.212	0.211	0	-	-
42	Santa Rosa Creek at Willowside Road	11	0.132	0.126	0	-	-	15	0.209	0.138	11	14.0	22.0
46	Unnamed stream at Laguna Road-114UL3708	0	-	-	9	0.127	0.122	9	0.288	0.203	0	-	-
47	Unnamed Stream at Occidental Road-114USOCCI	0	-	-	6	0.150	0.119	6	0.247	0.191	0	-	-
48	Unnamed stream at Windsor Road-114UW2221	0	-	-	5	0.256	0.243	5	0.361	0.340	0	-	-
49	West outfall on north bank of Santa Rosa Creek west of First Street-114OFWWFS	0	-	-	5	0.097	0.092	5	0.095	0.089	0	-	-
50	Windsor Creek at Mark West Station	1	0.164	0.164	0	-	-	1	0.228	0.228	1	12.0	12.0

The history and trends in nutrient concentrations at the primary long-term monitoring stations in the Laguna de Santa Rosa and tributaries are summarized briefly and graphically in Figure 3-4 (for N) and Figure 3-5 (for P). The blue circles show individual observations, while the orange circles and lines show half-decadal medians and trends. In general, the medians for one time period are not significantly different from those of other time periods at a 95% confidence level. It is difficult to draw firm conclusions due to the sparse data after 1998, but total N concentrations look to have remained relatively stable over time, with no evident positive or negative trends. Total P concentrations do appear to show a downward trend over time at Occidental Road, perhaps due to point source discharge limitations. However, this pattern is not seen downstream at Guerneville Road or in Mark West Creek at Trenton-Healdsburg Road.

Medians of the post-2009 total N and total P data are compared to medians from 2000-2004 and 2005-2008 in Figure 3-6 and Figure 3-7. The total N results again do not show strong trends. For total P, median concentrations at SRCWR, LSP, and LOR appear to have been relatively stable over time, while median concentrations at LGR appear to have decreased since the 1990s.

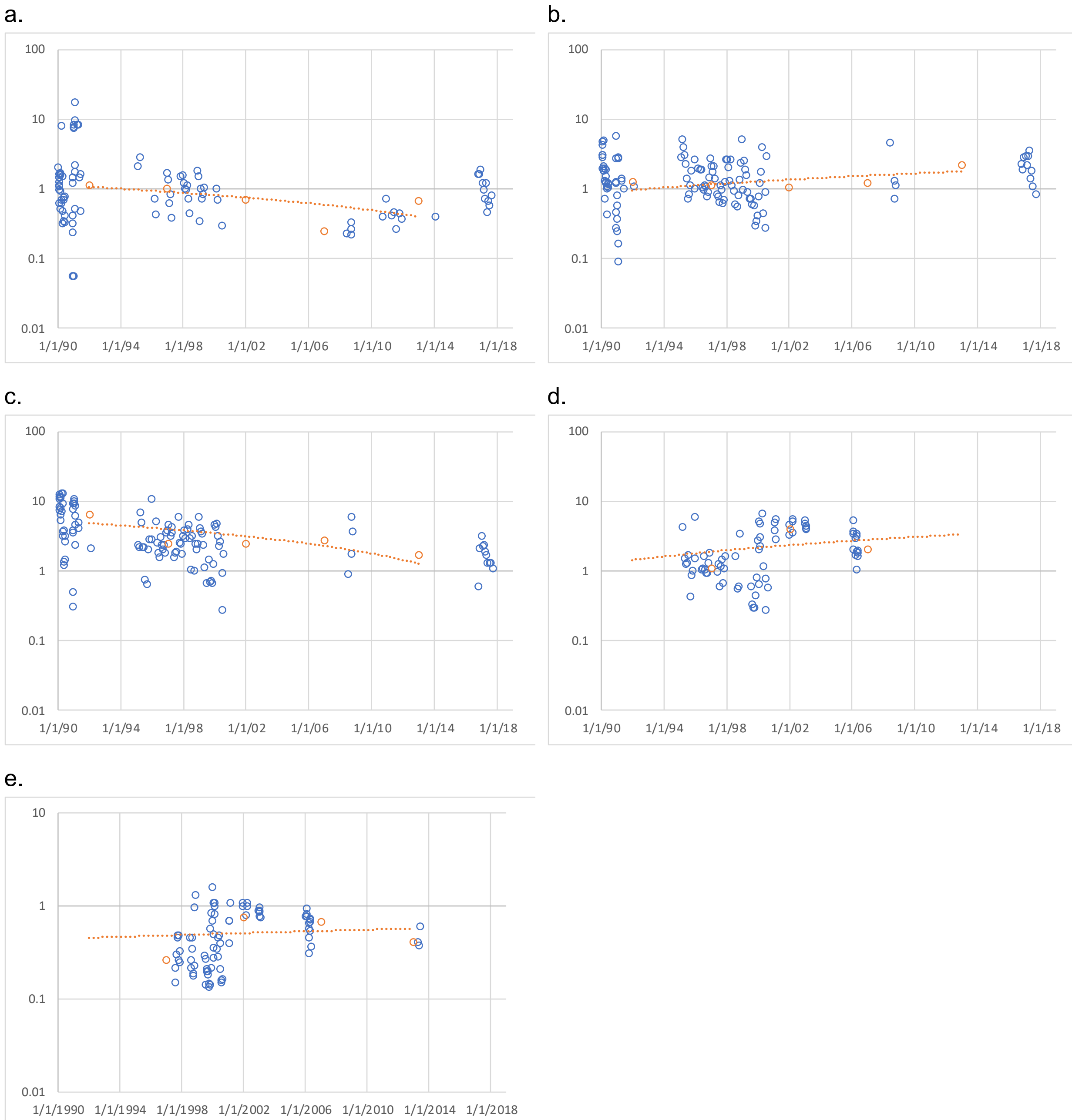

Figure 3-4. Trends in Total N Concentrations, 1990-2017

Note: Stations (a): Santa Rosa Creek at Willowside Road, (b), Laguna de Santa Rosa at Stony Point, (c) Laguna de Santa Rosa at: Occidental Road, (d) Laguna de Santa Rosa at Guerneville Road, (e) Mark West Creek at Trenton-Healdsburg Road. Blue open circles show individual observations. Orange points and lines show half-decadal medians and linear trend.

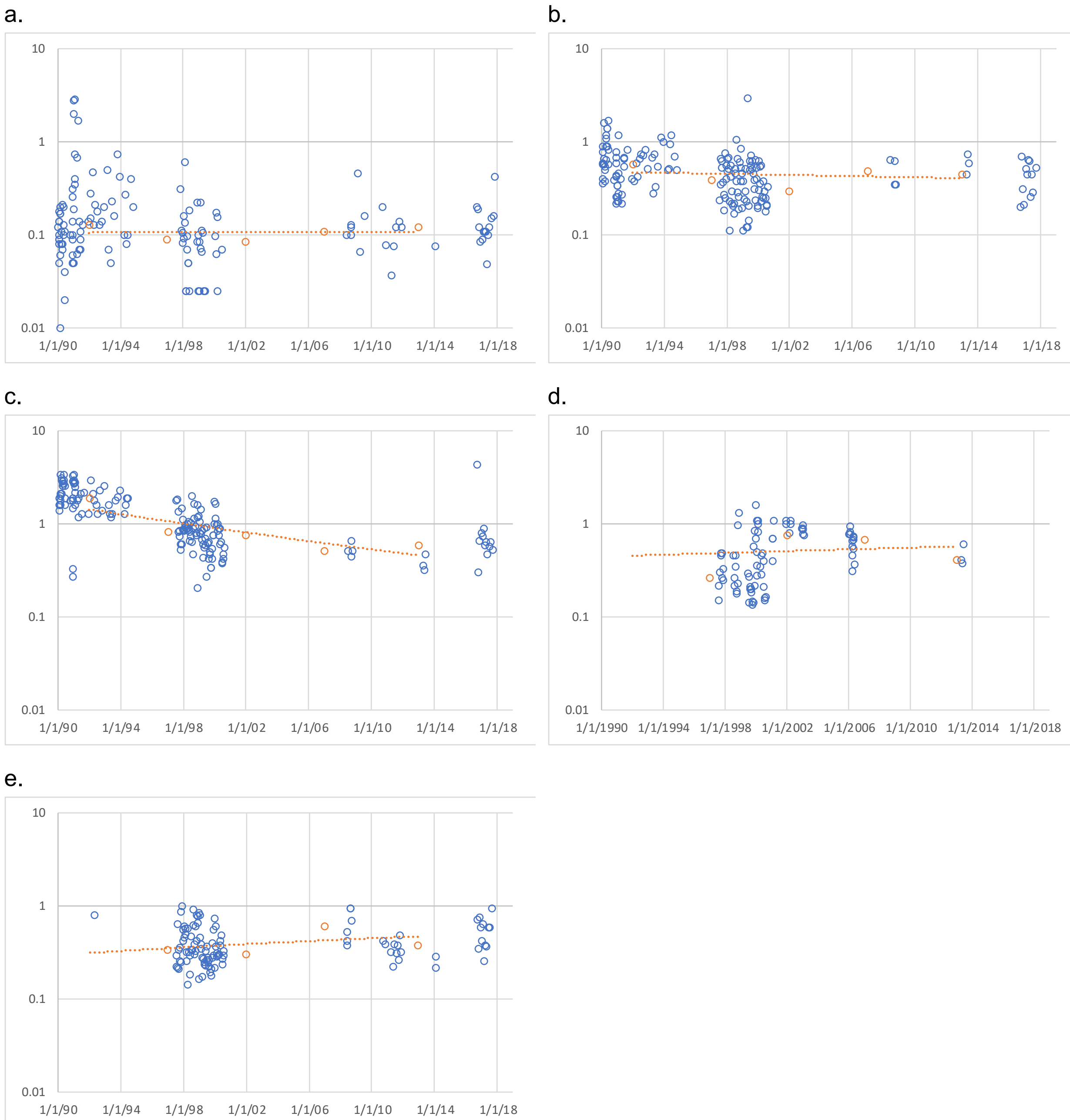

Figure 3-5. Trends in Total P Concentrations, 1990-2017

Note: Stations (a): Santa Rosa Creek at Willowside Road, (b), Laguna de Santa Rosa at Stony Point, (c) Laguna de Santa Rosa at: Occidental Road, (d) Laguna de Santa Rosa at Guerneville Road, (e) Mark West Creek at Trenton-Healdsburg Road. Blue open circles show individual observations. Orange points and lines show half-decadal medians and linear trend.

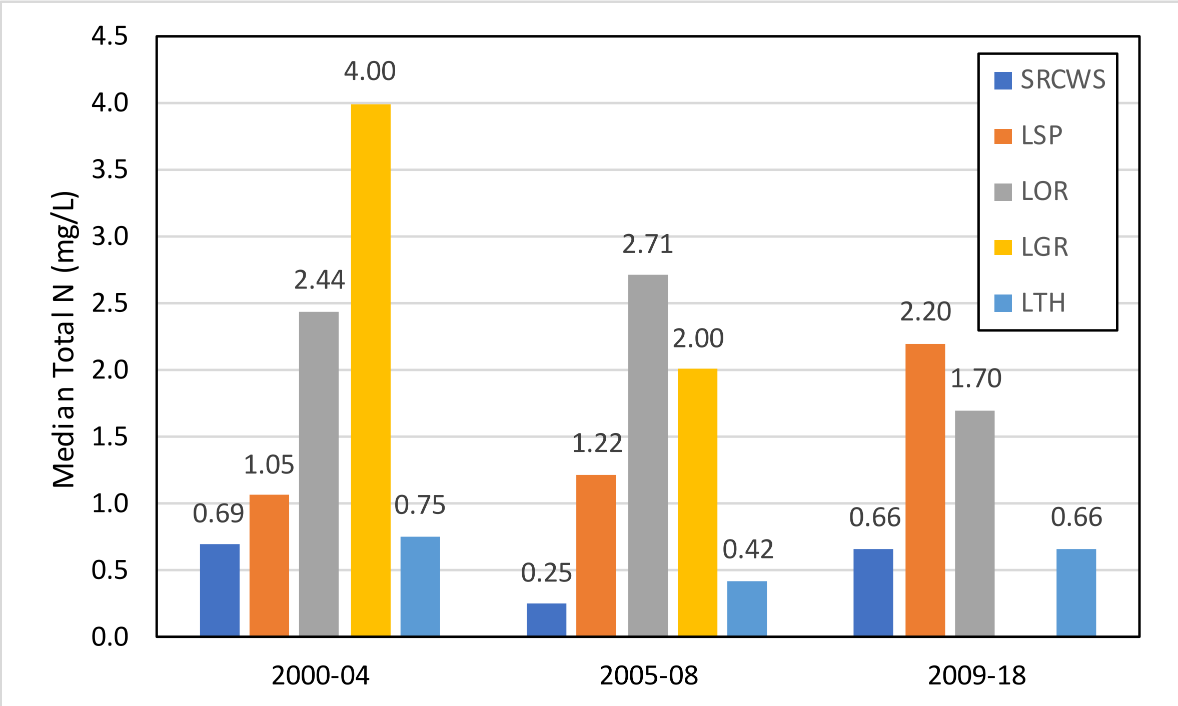

Figure 3-6. Comparison of post-2009 to 2000-2008 Median Total Nitrogen Concentrations at Compliance Monitoring Points

Note: Total N estimates at LSP, LOR, and LGR estimated from sum of TKN and Nitrite plus Nitrate N.

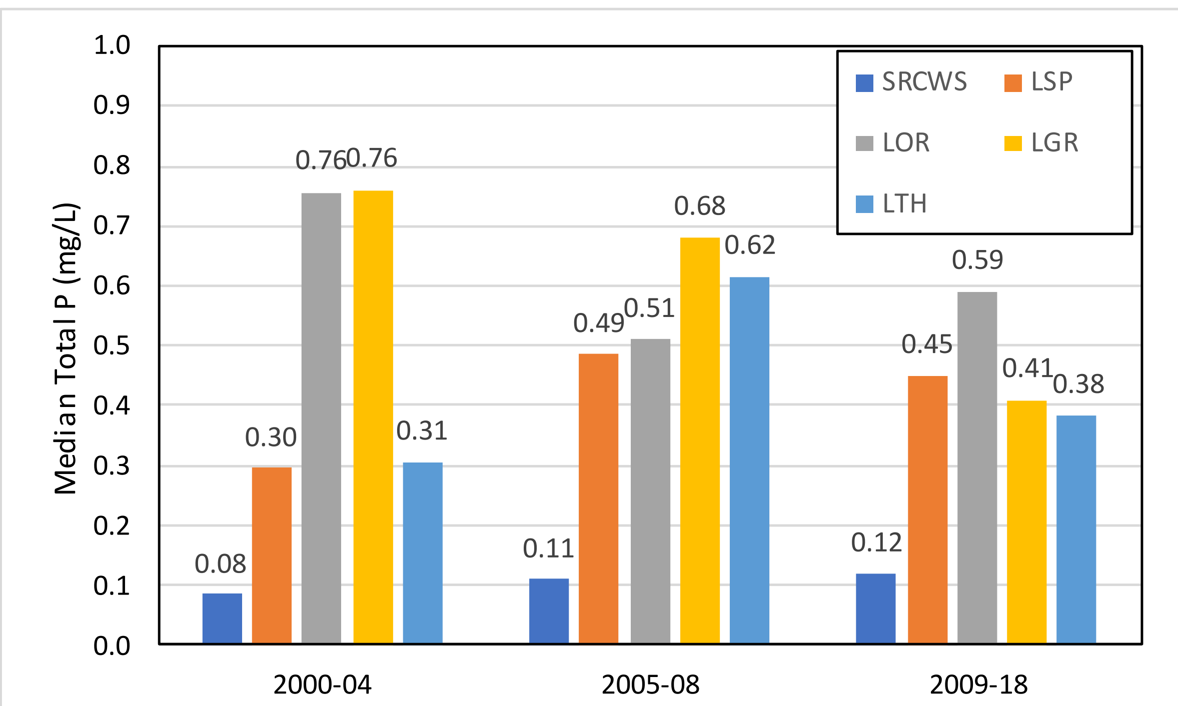

Figure 3-7. Comparison of post-2009 to 2000-2008 Median Total Phosphorus Concentrations at Compliance Monitoring Points

Another source of nutrient data is available for Santa Rosa Creek. The Sonoma County Water Agency (SCWA) has collected nutrient samples in Santa Rosa Creek at Fulton Road since 1997 in accordance with its municipal separate storm sewer system (MS4) stormwater permit. From 1997 to 2009 samples were collected on an annual basis during storm events. Since 2010, SCWA has collected samples on a monthly basis at a variety of flow conditions. The samples prior to 2010 are primarily of value for quantifying nitrogen species as there appears to have been a high detection limit for phosphorus (1 mg/L) between 1999 and 2009. Data (which are not in CEDEN) were provided by SCWA through January 16, 2019 (Table 3-6).

Table 3-6. SCWA Nutrient Sampling, Santa Rosa Creek at Fulton Road

Constituent	Statistic	1999-2008	2009-1/16/2019
Ammonia as N	Count	11	48
	Mean	0.42	0.15
	Median	0.38	0.17
Total Kjeldahl N	Count	27	51
	Mean	1.88	0.44
	Median	1.30	0.46
Total Phosphorus	Count	1	52
	Mean	1.20	0.12
	Median	1.20	0.10
Nitrate-N	Count	21	51
	Mean	0.45	0.26
	Median	0.37	0.25
Total N (Total Kjeldahl N plus Nitrate-N)	Count	21	52
	Mean	2.15	0.68
	Median	1.82	0.70

Note: Phosphorus samples reported as less than 1 mg/L prior to 2009 are eliminated from the tabulation.

The SCWA samples provide a relatively large and recent dataset. Unfortunately, flow, which is needed to convert concentration to load, is not monitored directly at Fulton Road. The USGS gage on Santa Rosa Creek is located a short distance downstream, at Willowside Road; however, Piner Creek, which drains a significant portion of the western part of the City of Santa Rosa, enters between these two locations. This limits our ability to evaluate loads from the SCWA monitoring. An approximate estimate was made by combining the monitoring with USGS gaging of flows in Santa Rosa Creek at Willowside Road, prorated for the difference in drainage area (factor of 0.9579), to evaluate correlations between concentration and flow (Figure 3-8).

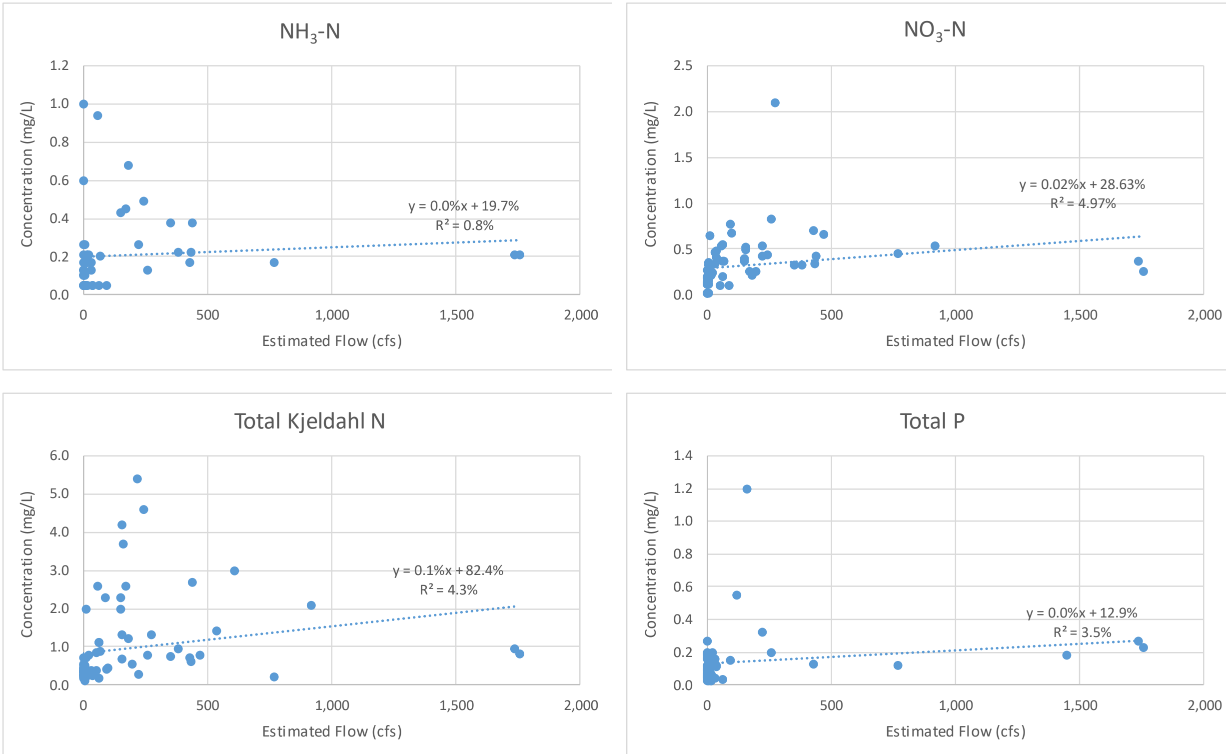

Figure 3-8. SCWA Nutrient Sampling, Santa Rosa Creek at Fulton Rd., Compared to Prorated Daily Flows from Santa Rosa Creek at Willowside Rd.

Additional water column data in the Laguna de Santa Rosa near Stony Point Road and in upstream tributaries has been collected since 2014 as part of student projects at Sonoma State University (SSU) with funding from Sonoma Water. These data were provided by Dr. Jackie Guilford of SSU and the sampling efforts are partially described in Accacain et al. (2018), Adams et al. (2018), and Rai et al. (2017). Global positioning unit (GPS) coordinates were not available for all samples, and site descriptions are not always informative. In addition, detection limits are missing for censored data, so these results must be used with caution. Despite these qualifications, these data do provide additional spatial and temporal coverage that will be used to help refine loading estimates in Section 5.3. The medians and ranges are presented in Table 3-7 for those samples with clearly identified locations, combining all samples for a given waterway. For the Laguna near Stony Point Road, the median total P of the SSU samples is 0.27 mg/L, which is 40 percent less than the median of the post-2009 CEDEN and City of Santa Rosa samples at this station (0.45 mg/L), although the range of the SSU samples covers the median shown in Figure 3-7. Total N results are also lower than the median in Figure 3-6 and consisted primarily of organic N.

Table 3-7. Water Column Concentrations from Sonoma State University Sampling, 2014-2018

Station	Total N (mg/L)			Total P (mg/L)		
	Count	Median	Range	Count	Median	Range
Coleman Crk	1	2.1	2.1-2.1	2	0.426	0.26-0.592
Copeland Crk	29	0.87	0.0038-8.1	33	0.25	0.047-1.4
Crane Crk	1	1.4	1.4-1.4	2	0.193	0.12-0.266
Five Crk	1	1.9	1.9-1.9	2	0.6655	0.427-0.904
Hinebaugh Crk	2	1.5	1.4-1.6	3	0.234	0.16-0.291
Laguna nr Stony Point Rd.	10	0.375	0.017-15	13	0.27	0.16-0.988

3.2 SEDIMENT SAMPLING

Recent monitoring data entered in CEDEN also include 27 sediment samples for total phosphorus, mostly as single samples per site Table 3-8). Of these, 22 are bank samples at 0.1 m depth and only 5 are channel samples, mostly at 2 cm depth. The channel samples ranged from 240 to 687 mg-P/kg of dry weight sediment, or up to about 0.07% by weight, with an average of 488 and median of 531 mg/lg. The bank samples ranged from 114 to 367 mg-P/kg with an average of 248 and median of 250 mg/kg. The bank samples have lower concentrations and do not appear to be representative of in-channel conditions. However, even the limited channel samples have concentrations that appear to be low compared to the stream sediment samples for the region contained in the National Geochemical Survey Database (Grossman et al., 2008). Five individual channel samples reported by Grossman et al. from the Laguna de Santa Rosa watershed range from 500 mg/kg to 1,290 mg/kg P by weight, with a median of 895 mg/kg. The average of stream channel samples reported by Grossman et al. for Sonoma County as a whole is 700 mg/kg.

Table 3-8. Sediment Phosphorus Concentrations from CEDEN, 2010 – 2013 (mg/kg dry weight)

		Count	Mean	Median
6	Copeland Creek at Redwood Drive-114CO0584 (bank)	1	327	327.
7	Laguna de Santa Rosa at Benson Road-114LG9440 (bank)	1	249.	249.
8	Laguna de Santa Rosa at Cunningham Pond-114LG4844 (bank)	1	203.	203.
9	Laguna de Santa Rosa at Guerneville Road-114LG0916 (bank)	1	193.	193.
10	Laguna de Santa Rosa at Joe Rodata Trail-114LG3704 (bank)	1	346.	346.
11	Laguna de Santa Rosa at Llano Road-114LG6367 (bank)	1	367.	367.
12	Laguna de Santa Rosa at Lower Occidental Pond-114LG2577 (bank)	1	114.	114.
14	Laguna de Santa Rosa at Mirabel-114LAGMIR (channel)	2	410.	410.
15	Laguna de Santa Rosa at Occidental Rd-114LG2320 (bank)	1	251.	251.
16	Laguna de Santa Rosa at Redwood Drive-114LG8693 (bank)	1	294.	294.
17	Laguna de Santa Rosa at Santa Rosa Creek-114LG0958 (bank)	1	269.	269.
18	Laguna de Santa Rosa at Sebastopol Community Center-114LG3411 (bank)	1	215.	215.
19	Laguna de Santa Rosa at Stony Point Road-114LG7508 (bank)	1	311.	311.
20	Laguna de Santa Rosa at Todd Road-114LG5615 (bank)	1	154.	154.
21	Laguna de Santa Rosa at Upper Occidental Pond-114LG2850 (bank)	1	231.	231.
22	Laguna de Santa Rosa downstream Guerneville Road-114LG0877 (bank)	1	217.	217.
24	Laguna de Santa Rosa downstream of Occidental Road-114LG2125 (bank)	1	138.	138.
27	Laguna de Santa Rosa upstream of Santa Rosa Creek-114LG1059 (bank)	1	198.	198.
28	Laguna de Santa Rosa upstream of Wohler Street Bridge-114LAGWOH (channel)	3	539.4	531.
30	Mark West Creek at River Road-114MW1361 (bank)	1	275.	275.
31	Mark West Creek at Slusser Road-114MW2687 (bank)	1	194.	194.
34	Mark West Creek at Wohler Road-114MW0211 (bank)	1	266.	266.
35	Mark West Creek downstream of Trenton Healdsburg Road-114MW0908 (bank)	1	307.	307.
44	Santa Rosa Creek upstream of the Laguna de Santa Rosa-114SR0082 (bank)	1	327.	327.

Many additional measurements of sediment nutrient concentrations have been collected in the Stony Point – Copeland Creek area as part of the work by students at Sonoma State University described above (Table 3-9). These include both surface sediment samples and cores with results reported by depth range (September 2017 samples only). For total phosphorus, the medians reported here for Copeland Creek and Laguna de Santa Rosa near Stony Point Road (multiple stations) are within the range reported by Grossman et al. (2008). Accacain et al. (2018) report “Surface values of phosphorus in sediment (707-1160 mg/kg) were generally higher than depth samples (553-791 mg/kg).”

Table 3-9. Sediment Concentrations from Sonoma State University Sampling, 2014-2018

Station	Total N (mg/kg dry weight)			Total P (mg/kg dry weight)		
	Count	Median	Range	Count	Median	Range
Brush Crk	1	230	230-230	1	770	770-770
Coleman Crk	2	570	350-790	2	520	335-705
Cook Crk	1	580	580-580	1	828	828-828
Copeland Crk	11	640	240-1,700	11	627	567-851
Crane Crk	4	760	0.26-1,900	5	568	482-786
Five Crk	3	260	140-290	3	429	266-447
Hinebaugh Crk	8	360	78-3,100	11	500	218-1,090
Laguna nr Stony Point Rd	74	2800	960-6,100	74	709	250-1,160

Recently, SCWA analyzed nutrient concentrations in six composite cores obtained from the area of the Laguna 1 and Laguna 2 Nutrient Offset Project Proposal, located downstream and upstream of the Stony Point Road bridge (Lassettre, 2019). The total phosphorus analyses ranged from 900 to 4,600 mg/kg, with an average of 2,630 mg/kg, while total N concentrations ranged from 4,600 to 9,900 mg/kg.

The reasons for the range of results from the different sediment sampling efforts are uncertain at this time but could be related to a number of factors related to sampling protocols or other activities in the channel or surrounding watershed. Sufficient information is not available at this time to fully understand the causes of the differences.

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4.0 WASTEWATER DISCHARGES

The Town of Windsor and City of Santa Rosa both operate wastewater treatment plants (WWTPs) in the watershed. As of the 1975 Basin Plan, discharges directly to the Russian River and its tributaries including the Laguna de Santa Rosa, were allowed only between October 1 and May 14, and were further limited by the implementation of the Waste Reduction Strategy in 1995. Prior to these efforts, these dischargers were significant sources of nutrient loading to the Laguna de Santa Rosa (although Windsor's discharge is at the very downstream end of the Laguna, as discussed below); however, in recent decades the majority of the effluent from these plants is reclaimed and used for irrigation, with discharges to the Laguna only during wet weather conditions when storage capacity for reclaimed water is exceeded.

While past WWTP discharges contributed to elevated concentrations of phosphorus and other substances in the sediment of the Laguna de Santa Rosa, those discharges have been largely controlled. For the nutrient mass balance, we therefore focus on the ongoing discharges from WWTPs under recent management conditions. As the amount of effluent that is discharged varies considerably from year to year based on precipitation patterns, we use available data from the last 15 years to develop long-term average estimates of direct nutrient loads from the WWTPs. Any indirect nutrient loading from the WWTPs associated with the use of reclaimed water for irrigation is not included in this total. Irrigation protocols in the WWTP permits prohibit irrigation with reclaimed water when soil conditions (saturation) or climate conditions (rain) could result in runoff to surface water.

4.1 TOWN OF WINDSOR

The Windsor Water District operates the Windsor Wastewater Treatment, Reclamation, and Disposal facility, which serves approximately 28,000 residential, industrial, and commercial customers within the Town of Windsor. The facility is a tertiary treatment plant that provides reclaimed water for irrigation and groundwater recharge but also discharges to Mark West Creek. Details of the history and operations of the facility are provided at length in the 2013 permit for the facility from the NCRWQCB (Order No. R1-2013-0042, NPDES NO. CA0023345) and the draft 2020 Waste Discharge Requirements (WDR) (Order No. R1-2020-0010).

Windsor has a permitted stream outfall that enters Mark West Creek via a ditch a short distance downstream of the Trenton-Healdsburg Road Bridge and just upstream of USGS gage 11466800 (see Figure 1-2). The area of interest for this study is defined as ending at that USGS gage, and the Windsor discharges will not affect most of the Laguna de Santa Rosa during normal flow conditions; however, when the Russian River backs up into the Laguna during high flow conditions, discharges from Windsor as well as sediment containing nutrients derived from those discharges could be transported upstream into the Laguna.

Windsor has a dry weather design flow of 2.25 million gallons per day (MGD), a permitted dry weather flow of 1.9 MGD, and a permitted wet-weather weekly peak flow of 7.2 MGD. Reclaimed water generated by the facility goes in large part to irrigation and groundwater recharge uses, with temporary storage in effluent ponds. For discharges to Mark West Creek, the plant has an effluent limit of 10.5 mg/L total N and an interim effluent limit of 7.5 mg/L total P and is also generally directed to limit the total discharge flow to less than 10% of the flow in Mark West Creek.

Since Fall 2007, Windsor has typically discharged to Mark West Creek for two to four days per year during the allowed discharge window, although there were no discharges in water year 2014. Effluent monitoring includes total P and various N species. The total N load is about 83 percent nitrate N. Estimated loads by water year are shown in Table 4-1.

Table 4-1. Annual Nutrient Loads Discharged by Windsor Wastewater Facility

Water Year	Discharge Months	Total P (kg/yr)	Total N (kg/yr)
2007/08	4	2,439	3,890
2008/09	3	2,822	3,905
2009/10	4	3,800	7,942
2010/11	4	3,146	11,490
2011/12	2	810	2,489
2012/13	3	1,084	3,485
2013/14	0	0	0
2014/15	4	257	667
2015/16	2	508	3,426
2016/17	6	560	7,696
2017/18	5	409	2,252
2018/19	5	387	3,433
Average (2008 – 2019)	3.5	1,352	4,223

Note: Loads (provided by Regional Board staff) are calculated from monthly discharge totals and a single concentration sample for that month.

4.2 CITY OF SANTA ROSA

The City of Santa Rosa operates the Laguna Subregional Water Reclamation System, which serves approximately 230,000 residents in Santa Rosa, Rohnert Park, Cotati, Sebastopol, and unincorporated areas of Sonoma County. This plant is a tertiary treatment system that provides reclaimed water for irrigation and groundwater recharge but also discharges to the Laguna. Detailed information on the facility is provided in the 2013 WDR (Order No. R1-2013-0001; NPDES No. CA0022764; WDID No. 1B830990S0N) as well as in the 2020 draft of proposed Waste Discharge Requirements.

Santa Rosa has five discharge points in the Laguna watershed, three to the Laguna de Santa Rosa at the confluence with Colgan Creek near Meadow Lane Pond D (006A, 006B, and 015), one near the upstream end of the Upper Floodplain subwatershed, and two to Santa Rosa Creek near Delta Pond (012A and 012B), just upstream of the confluence of Santa Rosa Creek with the Laguna (see Figure 1-2). With the exception of the wet period of February 2017, discharges to Laguna and its tributaries have been primarily through discharge point 012B.

The facility has an average dry weather design flow of 21.34 MGD, a permitted dry weather average weekly flow of 25.9 MGD, and a peak weekly wet weather design flow of 64 MGD. Much of the reclaimed water produced by the facility goes either to the Geysers Recharge Project, where it is used to replenish water used in geothermal energy generation, or to an irrigation distribution system.

Per the 2013 WDR, nutrient effluent limitations for this facility include a maximum average monthly total N concentration of 10.6 mg/L and "no net loading of total phosphorus to the water bodies of the greater Laguna de Santa Rosa watershed." The no net loading provision is described in Section VII.N of the 2013 WDR: "For each discharge season (i.e., October 1st through May 14th), the Permittee shall calculate the mass of total phosphorus discharged to the Laguna de Santa Rosa (and tributaries) from the Subregional System and the mass of total phosphorus that was controlled during the same season through approved nutrient offset projects. If the mass discharged is equal to or less than the mass controlled, then the Permittee shall be deemed in compliance with the effluent limitation."

Records of total phosphorus and total nitrogen loads discharged by the Santa Rosa Water Reclamation System to Santa Rosa Creek and the Laguna de Santa Rosa from water years 2008 – 2019 were recalculated from flows and concentrations by discharge point (Table 4-2), and differ somewhat from the summary provided by Burke (2019). Loads prior to 2008 were often larger (up to 27,000 kg-P/yr in water year 2002), but do not represent current operating conditions.

Table 4-2. Annual Nutrient Loads Discharged by City of Santa Rosa Wastewater Facility

Water Year	Discharge Months	Total P (kg/yr)		Total N (kg/yr)	
		Upper	Lower	Upper	Lower
2007/08	1	0	1,621	0	6,122
2008/09	0	0	0	0	0
2009/10	1	0	595	0	3,293
2010/11	4	0	5,027	0	25,731
2011/12	1	0	59	0	0
2012/13	0	0	0	0	0
2013/14	0	0	0	0	0
2014/15	0	0	0	0	0
2015/16	1	0	52	0	163
2016/17	3	2,622	5,260	10,908	24,418
2017/18	0	0	0	0	0
2018/19	2	1,330	2,316	6,564	11,607
Average, 2008-2019	1	329	1,244	1,456	5,944

Note: The City of Santa Rosa Wastewater Facility discharges at multiple locations. There are seven discharge sites (many no longer in use) located near the confluence of Colgan Creek and the Laguna de Santa Rosa near Meadow Lane D Pond. These are combined to produce the "Upper" load. There is another discharge from the Delta Pond to Santa Rosa Creek, just above the confluence with the Laguna (the "Lower" loads. Loads are calculated from daily discharge flows and monthly average concentrations by site. TN for water years 2008-2015 is taken from a spreadsheet supplied by NCRWQCB staff in 2016 as the original TN concentration data for this period have not been supplied.

5.0 LANDSCAPE NUTRIENT LOADING SOURCES

A process-based watershed model that is calibrated and validated for nutrients is not available for the Laguna de Santa Rosa watershed – in large part due to limitations in data available for model development and calibration. Potter and Hiatt (2009) did develop a Soil and Water Assessment Tool (SWAT) model of watershed runoff and sediment loading; however, the comparison of model predicted sediment loads and concentrations to observed data was poor (monthly Nash-Sutcliffe coefficients of model fit efficiency less than zero and a large percent low bias relative to observed values). That model has not been further developed for nutrients, and such development is not recommended unless a better sediment calibration can be achieved due to the importance of sediment transport in the delivery of phosphorus loads.

Lacking a process-based watershed model that can simulate nutrient loading, Regional Board staff developed an empirical, data-based model of nutrient loading. This tool, the Land Cover Loading Model (LCLM) is described in Section 5.1. An alternative analysis for phosphorus loading based on association with sediment is presented in Section 5.2. The two analyses provide similar estimates of annual phosphorus load.

5.1 LAND COVER LOADING MODEL

5.1.1 Development of the Land Cover Loading Model

The LCLM was developed by Regional Board staff beginning in 2010. The original memorandum documenting the LCLM (Butkus, 2010) has been revised in draft several times, but a final revised version has not yet been formally released. A revised draft markup (Butkus, 2013) is the most recent version available and is relied on in this discussion.

Butkus (2013) describes the development of the pollutant loading functions in the LCLM as follows:

> *Regional Water Board staff selected nutrient loading rates for each land cover category based on sampling pollutant concentrations in runoff from forest, rangeland, crop and pasture, orchards and vineyards, non-sewered residential, sewered residential, and commercial land covers from 2009-2010 (NCRWQCB, 2010).*
>
> *Samples were collected during both wet and dry periods as identified by federal guidance (USEPA, 1992) and federal regulations (40 CFR 122.21(g)(7)(ii)). The LCLM addresses the distribution of loads between wet and dry periods. Dry period loads were derived from the measured pollutant concentration data and estimates of the base flow at the sampling location. Wet period loads were derived from measured pollutant concentration data and sampling location flows estimated as the combined base flow plus the storm event runoff flow. Statistical hypothesis test results showed significant differences between wet period and dry period concentrations and between the land covers assessed (NCRWQCB, 2010) …*
>
> *Loading rates were estimated from a limited numbers of water samples collected from catchments representing various land covers in the Laguna watershed (NCRWQCB, 2010). Butkus (2010) showed that the samples collecting was biased to larger flows*

> *than the historical distribution of flows. To account the bias from the limited samples, Monte Carlo simulations were conducted to provide estimates of the range of loads across the full range of climatic conditions (extreme dry to extreme wet periods). Monte-Carlo simulation was used to address the potential bias from using only flows observed during sampling events. Monte Carlo simulation is a stochastic method that accounts for the inherent variability of data sets. Monte Carlo simulations rely on repeated random sampling to obtain numerical results as distributions. The probability distributions from the flow, precipitation, and concentration records were applied to the loading models repeatedly until descriptive statistics converged in the resulting loading distribution…*
>
> *Table 3* [in Butkus, 2013 – see Table 5-1 below] *compares the median and mean loading rate values. The central tendency for years with wet days represents the 2-year return period. A 2-year return period storm has a 50% chance of occurring each year and is represented at the center of the x-axis on the load duration curves. The 2-year return period was estimated to be 13.4% wet days per year. The 2-year return period was used to estimate annual loads.*

Sample sites used for land use monitoring were selected randomly from a set of candidate sites with the requirement that at least 50 percent of the drainage area was occupied by the target land use (NCRWQCB, 2010). Sampling was done at road crossings. Drainage areas associated with the individual sample sites are not given; however, the median size appears to have been on the order of 800 acres.

5.1.2 LCLM Results

The summary table of loading rates provided in the LCLM report (Table 5-1) presents dry weather and wet weather loading rates as if each weather type occupied the full year. The annual result is then the mixture of the two types based on the two-year return period (i.e., 13.4% wet days, as noted above).

Table 5-1. Median and Mean Unit Area Loading Rates by Land Cover in the LCLM

Land Cover	Period	Total Phosphorus (lb/ac/yr)		Total Nitrogen (lb/ac/yr)	
		Median	Mean	Median	Mean
Forest	Dry	0.04	0.43	0.25	2.74
	Wet	0.64	1.87	3.86	12.37
	Annual	0.12	0.62	0.73	4.03
Cropland and Pasture	Dry	0.39	5.27	0.23	8.37
	Wet	11.97	57.01	30.60	258.27
	Annual	1.94	12.19	4.29	41.78
Rangeland	Dry	0.10	1.07	0.62	6.37
	Wet	4.73	17.88	15.73	37.93
	Annual	0.72	3.32	2.64	10.59
Residential with Sewer	Dry	0.17	1.65	0.89	8.74
	Wet	9.00	15.28	37.71	70.43
	Annual	1.35	3.47	5.81	16.99
Orchards and Vineyards	Dry	0.29	4.40	0.59	5.27
	Wet	6.24	15.53	19.85	48.77
	Annual	1.09	5.89	3.16	11.08
Residential without Sewer	Dry	0.19	2.27	0.48	6.32
	Wet	10.13	30.19	40.65	73.69
	Annual	1.51	6.00	5.85	15.33
Commercial	Dry	0.09	0.98	0.57	7.25
	Wet	7.14	12.74	43.35	66.08
	Annual	1.03	2.55	6.29	15.12
Other Land Uses	Dry	0.18	2.30	0.52	6.44
	Wet	7.12	21.50	27.39	81.08
	Annual	1.11	4.86	4.11	16.42

Note: Table from Butkus (2013). Analyses omitted one “Residential without Sewer” sample from 10/15/2009 due to quality assurance/quality control (QA/QC) concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015). Annual loading rates are based on a 2-year return period (50% probability to exceed).

Table 5-1 gives both mean (average) and median (50th percentile) results. The data distributions shown in Butkus (2013) exhibit a strong skew, with mean concentrations often higher than the 75th percentile load. To protect against undue influence by outliers, Butkus (2013) recommended use of the median load rates as the best indicator of the central tendency of the distribution. Estimated total phosphorus loads by this method are summarized in Table 5-2, and, not surprisingly, are dominated by wet period loads. Estimated total nitrogen loads are shown in Table 5-3 and are about three times greater than the phosphorus loads.

On the whole (i.e., per unit acre), LCLM results indicated that "Cropland and Pasture" had the highest total phosphorus loading rates during wet and dry periods. The highest total nitrogen loading rate during the dry period was for "Residential with Sewer," and the highest total nitrogen loading rate during the wet period was "Commercial". Wet period loading rates are always higher than dry period loading rates for all land use classes. When total annual loads by land use area are tabulated, the highest total phosphorus loads (Table 5-2) and total nitrogen loads (Table 5-3) are attributed to Cropland and Pasture. An analysis of the Cropland Data Layer for 2013 reveals that vineyards cover approximately 7% of the entire watershed area, while other crop types cover less than 1%. As the LCLM created a separate land cover class for "Orchards and Vineyards," the "Cropland and Pasture" land cover class is about 99% Pasture and 1% Cropland.

Table 5-2. LCLM Estimates of Typical Total Phosphorus Loads by Land Cover in Butkus (2013)

Land Cover	Laguna Watershed Land Cover Area (acres)	Median Wet Period Load (lb/yr)	Median Dry Period Load (lb/yr)	Median Annual Load (lb/yr)
Forest	48,315	4,150	1,734	5,884
Cropland & Pasture	44,458	71,130	14,903	86,032
Rangeland	21,767	13,777	1,949	15,726
Residential with Sewer	15,348	18,474	2,255	20,729
Orchards and Vineyards	12,825	10,699	3,239	13,938
Residential without Sewer	9,857	13,346	1,580	14,926
Commercial	8,577	8,191	682	8,873
Other Land Uses	1,461	1,391	230	1,622
Total Watershed	162,608	141,159	26,571	167,730

Note: Table from Butkus (2013). Analyses omitted one "Residential without Sewer" sample from 10/15/2009 due to QA/QC concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015). Annual loading rates are based on a 2-year return period (50% probability to exceed). Note that land use categories and acreages reported here differ somewhat from Tetra Tech's analyses.

Table 5-3. LCLM Estimates of Typical Total Nitrogen Loads by Land Cover in Butkus (2013)

Land Cover	Laguna Watershed Land Cover Area (acres)	Median Wet Period Load (lb/yr)	Median Dry Period Load (lb/yr)	Median Annual Load (lb/yr)
Forest	48,315	24,927	10,271	35,198
Cropland & Pasture	44,458	181,867	8,745	190,611
Rangeland	21,767	45,779	11,742	57,520
Residential with Sewer	15,348	77,378	11,821	89,199
Orchards and Vineyards	12,825	34,032	6,542	40,575
Residential without Sewer	9,857	53,579	4,128	57,706
Commercial	8,577	49,708	4,241	53,948
Other Land Uses	1,461	5,351	656	6,006
Total Watershed	162,608	472,620	58,145	530,764

Note: Table from Butkus (2013). Analyses omitted one "Residential without Sewer" sample from 10/15/2009 due to QA/QC concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015). Annual loading rates are based on a 2-year return period (50% probability to exceed). Note that land use categories and acreages reported here differ somewhat from Tetra Tech's analyses.

Examination of the Regional Board staff's calculation sheets demonstrates that selection of the mix of wet and dry periods at the 50th percentile year provides a reasonable approximation of average hydrologic conditions across all years analyzed for the wet-dry distribution (1931 – 2009); however, the interquartile range on the Monte Carlo analysis for nutrient loading conditions is large (for example, the median annual loading rate for total phosphorus from cropland has an interquartile range of 0.7 to 6.2 lb/ac/yr). An important source of uncertainty is the use of the median load results from the Monte Carlo analysis for nutrient loading conditions rather than the mean (average). The median is appropriate for the stated goal of estimating "typical" loads during a "typical" year; however, the bulk of sediment and phosphorus loading may occur during large events. In addition, it is possible that the monitoring on which the LCLM is based could be biased low for more intensive land uses because the selection requirement was that the drainage area contain at least 50 percent of the target land use. Thus, sampling for a vineyard site could represent a mix of relatively high loads from vineyards with lower loads derived from vacant rangeland. Tetra Tech (2015a) recalculated LCLM loading estimates based on average, rather than median loading rates; however, the resulting loading rate estimate are uniformly higher than and outside the range of the corroborating load estimates discussed in Section 5.1.3 through 5.3 and were therefore rejected.

An issue with the LCLM analyses presented in Butkus (2013) is that the total load estimates are based on the land cover distribution from the 2006 National Land Cover Database satellite-based classification, which attributes 44,468 acres in the watershed to a combined cropland and pasture category. The detailed coverages produced by Sonoma VegMap (2018), based on 2013 satellite data with ground-truthing, show a much smaller land area in these land uses (812 acres in row-crop agriculture and 3,837 acres in pasture/hay), with a correspondingly larger area in unmanaged herbaceous and rangeland cover (see Table **1-1** and Figure 1-1). Therefore, the total load estimates in Butkus (2013) are likely too high and need to be adjusted based on revised land use data.

Total nutrient load estimates by subbasin produced by the LCLM, based on loading rates per acre of a given land use but using the updated land use from the Sonoma VegMap as discussed in Tetra Tech (2019), are provided in Table 5-4., using the sub-watersheds shown in Figure 1-2. For Southeast Santa Rosa, totals are shown with and without excluding the area above Matanzas and Ilsanjo Reservoirs. As summarized in the sediment linkage analysis (Tetra Tech, 2019, Section 5.3) bathymetric studies have shown that Matanzas Reservoir is an effective sediment trap, and the same is expected for Ilsanjo. As phosphorus tends to be sediment-associated, it is likely that these reservoirs also trap a large proportion of incoming phosphorus, but a much smaller fraction of nitrogen, which has higher solubility.

Figure 5-1 shows the attribution of upland loads by land use obtained by combining the LCLM loading rates with the updated Sonoma VegMap land use tabulations. Note that these attributions are noticeably different from those presented by Butkus (2013) due to the revisions in land use tabulation that substantially reduced the estimated area of agricultural land (see discussion in Tetra Tech, 2019).

Table 5-4. LCLM Estimates of Nutrient Loads by Subbasin (Revised Land Use)

Subbasin	TP (kg/yr)	TN (kg/yr)
Copeland	1,438	5,918
Upper Laguna	9,747	37,568
Blucher	1,551	5,805
Colgan	1,881	7,643
Upper Floodplain	6,512	24,040
NE Santa Rosa	2,578	11,346
SE Santa Rosa	3,856	16,040
SE Santa Rosa (excluding area above reservoirs)	1,986	8,953
Lower Santa Rosa	9,225	38,886
Upper Mark West	2,992	12,926
Lower Mark West	1,080	4,819
Windsor	4,621	18,705
Lower Floodplain	7,781	27,341
Total	*53,262*	*211,037*
Total excluding area above reservoirs	*51,392*	*203,950*

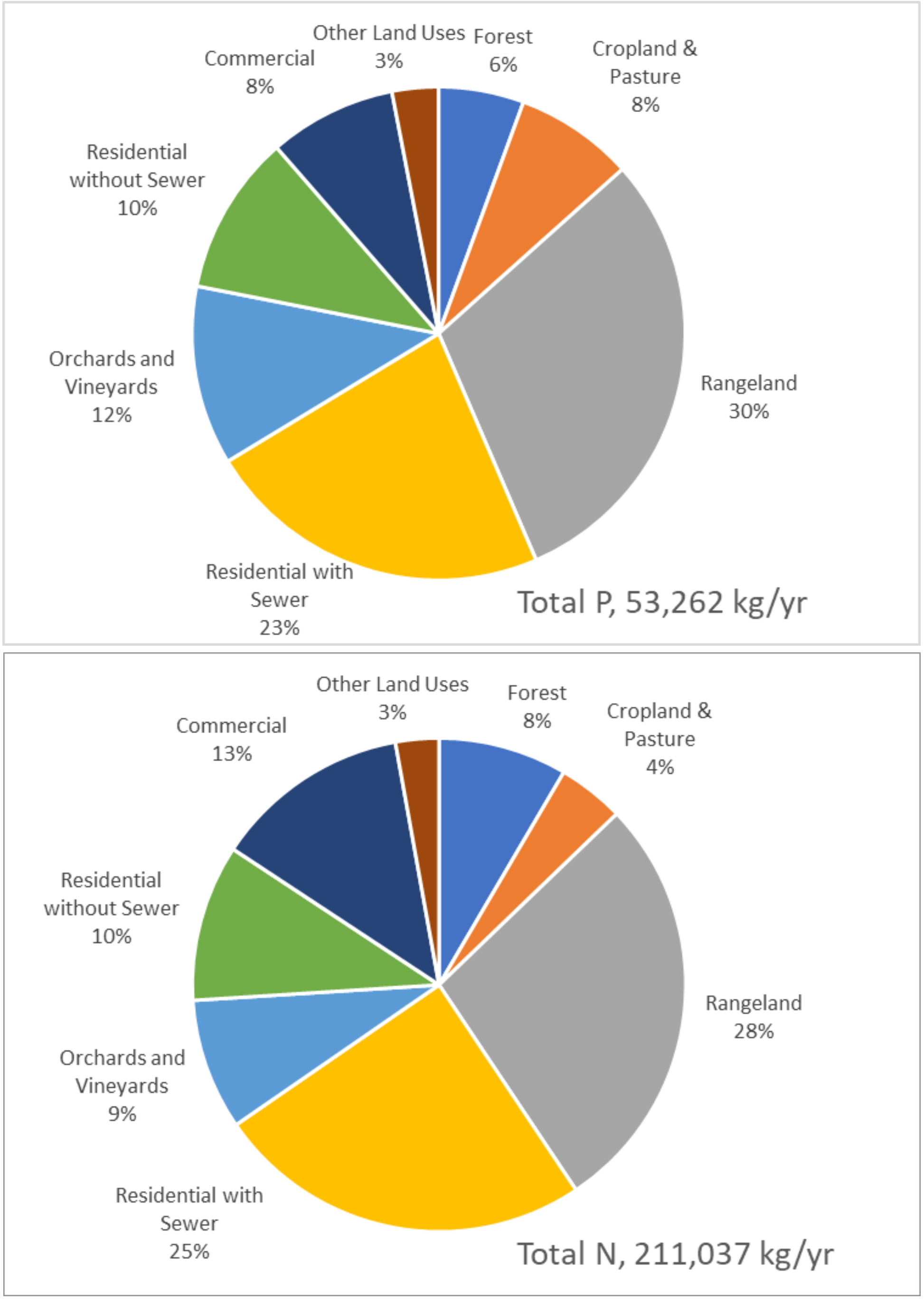

Figure 5-1. Source of Upland Nutrient Loads from LCLM with Sonoma VegMap Land Use

5.1.3 LCLM Corroboration

How reasonable are LCLM estimates of average annual nutrient loads? The strongest lines of evidence for corroboration of the performance of the LCLM are comparisons to two other methods of estimating nutrient loads in the Laguna watershed. Those comparisons are provided below in Sections 5.2 through

5.4. Additionally, Butkus (2013) presented a number of lines of evidence to corroborate LCLM results. These are summarized immediately below along with some supplementary comparisons developed by Tetra Tech.

5.1.3.1 Staff Literature Review

As reported in Butkus (2013), Regional Board staff conducted a literature review to compare published land use-based loading rates with the results of the LCLM. Unit area nutrient loading rates for total nitrogen and total phosphorus were obtained from some fifteen different published sources as they specifically applied to the land use categories of forest, rangeland, cropland and pasture, orchard and vineyard, sewered residential, non-sewered residential, and commercial lands. Literature values used for comparison were assumed to represent a median hydrologic year, and can vary widely depending on precipitation, source activity, and soils. The LCLM memorandum (Butkus, 2013) does not compute statistics on the literature values, but rather compares results visually by plotting mean values alongside LCLM results. Visual inspection of the literature values plotted against the LCLM results showed general agreement on loading rates by land use. In general, a wider distribution of mean loading values was seen from literature for nitrogen than for phosphorus, with the greatest range seen for commercial lands, orchards and vineyards, and rangeland. The ranges of reported mean loading rates for total phosphorus and total nitrogen are compared to LCLM results in Table 5-5.

Table 5-5. Range of Mean Annual Loading Rates Reported in Published Literature Compared to LCLM Median Annual Loading Rates

Land Use Category	Literature Mean Total Phosphorus (lb/ac/yr)	LCLM Median Total Phosphorus (lb/ac/yr)	Literature Mean Total Nitrogen (lb/ac/yr)	LCLM Median Total Nitrogen (lb/ac/yr)
Forest	0.05 – 0.21	0.12	0.64 – 2.55	0.73
Rangeland	0.09 – 1.01	0.72	0.89 – 14.75	2.64
Cropland and Pasture	0.45 – 1.39	1.94	1.78 – 8.92	4.29
Orchard and Vineyard	0.45 – 1.78	1.09	1.78 – 14.75	3.16
Non-Sewered Residential	0.18 – 1.33	1.51	0.89 – 8.90	5.85
Sewered Residential	0.36 – 1.86	1.35	1.78 – 9.42	5.81
Commercial	0.36 – 3.04	1.03	1.78 – 17.55	6.29

Note: LCLM analyses omitted one “Residential without Sewer” sample from 10/15/2009 due to QA/QC concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015).

The LCLM median annual loading rates recommended for application by Butkus (2013) generally fall within the range of mean loading rates by land use reported in published literature; however, the LCLM total phosphorus loading rates for the cropland and pasture and non-sewered residential land use categories are greater than the upper ends of the literature ranges reported by Butkus.

5.1.3.2 Uncalibrated GWLF Model

Regional Board staff used an uncalibrated application of the Generalized Watershed Loading Functions (GWLF) model (Haith et al., 1992) as another line of evidence to corroborate LCLM results (Butkus, 2013). GWLF is designed to provide scoping level estimates of pollutant loading from mixed land cover watersheds using the Natural Resources Conservation Service curve number and Universal Soil Loss Equation calculations. Staff combined measured concentrations of baseflow nutrients from dry weather samples collected in 2008 in the Laguna de Santa Rosa watershed with an uncalibrated representation of storm runoff and erosion (Butkus, 2010). Staff concluded the LCLM and GWLF models overall produce qualitatively "similar" estimates of annual pollutant loads, with a wide variation between tributary load estimates. Overall, the GWLF model over-estimated both total phosphorus and total nitrogen loads as compared to the LCLM estimates.

5.1.3.3 Comparison to TMDL Analyses

As noted above in Section 2.1, a TMDL for nitrogen was developed for the Laguna de Santa Rosa in 1995 based on an assessment conducted by CH2M Hill (1994). For the 1995 TMDL, pollutant loading rates were estimated for land use categories based on storm and dry weather sampling completed in 1994 for multiple storm events and dry periods. Unit area loading rates for nitrogen differ from those estimated by the LCLM. Nitrogen loads from non-irrigated agriculture, estimated at 13.1 lb/ac/yr, are similar to the LCLM mean estimate for orchards and vineyards of 11.1 lb/ac/yr; however, the estimates for urban/developed land uses (2.4 lb/ac/yr plus 0.7 lb/ac/yr for areas on septic systems) and undeveloped land (0.1 lb/ac/yr) are much lower than the estimates produced by the LCLM. The differences are likely mostly due to the limited sampling data available for the 1994 effort.

Few other nutrient TMDLs that provide nonpoint source nutrient loading rate estimates are available for the immediate region. However, the Central Coast Regional Water Quality Control Board (CCRWQCB) has several completed nutrient TMDLs that provide potentially relevant comparisons to the Laguna de Santa Rosa: Pajaro River, Lower Salinas River, and Santa Maria River. These regional nutrient TMDLs generally address nitrate, low DO, chlorophyll *a*, and orthophosphate (CCRWQCB, 2015; 2013a; 2013b).

The Central Coast nutrient TMDLs used the USEPA's Spreadsheet Tool for Estimating Pollutant Loads, version 4.1 (STEPL; Tetra Tech, 2011), which predicts annual loading based on event mean concentrations for storm runoff events. The assumed nutrient event mean concentrations for each land use category for the Central Coast TMDLs are derived from a variety of literature sources (Table 5-6).

Table 5-6. Nutrient Event Mean Concentrations by Land Use Specified for STEPL Modeling in Central Coast TMDLs (CCRWQCB, 2015; 2013a; 2013b)

Land Use	Santa Maria TMDL		Salinas TMDL		Pajaro TMDL	
	N (mg/L)	P (mg/L)	N (mg/L)	P (mg/L)	N (mg/L)	P (mg/L)
Agriculture	11.4[1,2]	0.64[1]	11.4[1,2]	0.64[1]	11.4[1,2]	0.64[1]
Forest	0.2[3]	0.1[3]	0.2[3]	0.1[3]	0.2[3]	0.1[3]
Rangeland	0.25[4]	0.27[2]	0.25[4]	0.27[2]	0.25[4]	0.21[2]
Urban	1.5-2.5[3]	0.15-0.4[3]	4.0[5]	0.53[1]	1.9-3.62[6]	0.15-0.5[6]

Data sources cited in TMDL documents:

1-Southern California Coastal Water Research Project, Technical Report 335 (Nov. 2000) Appendix C
2-US Dept. of Agriculture's Measured Annual Nutrient loads from AGricultural Environments (MANAGE) database
3-STEPL default values for a specific land use type
4-California Rangeland Watershed Laboratory
5-Average for western cities from Shaver et al., 2007.
6-Natonal Stormwater Quality Database (version 3, 2 Feb 2008)

The resulting annual unit-area nutrient loads reported in each of the Central Coast TMDLs are summarized in Table 5-7 and compared to the LCLM annual median and mean loading rates from Table 5-1. For nitrogen, the Central Coast values tend to fall between the LCLM median and mean loading rates for agricultural and urban land uses but are lower than the LCLM rates for rangeland and forest land uses. LCLM phosphorus loads also appear to be higher than the Central Coast estimates for undeveloped lands. Higher loads in the LCLM are in part related to differences in annual precipitation – Santa Rosa receives about 31 inches per year, whereas Salinas and Santa Maria receive only 15.5 and 14 inches per year, respectively – as well as differences in soils and geology.

Comparison on a concentration basis between the Central Coast STEPL modeling event mean concentration assumptions and wet weather samples from the 2009-2010 Laguna de Santa Rosa watershed intensive monitoring used by Regional Board staff as the basis for the LCLM is shown in Table 5-8. For total phosphorus, the concentrations are in general agreement, except that the Laguna de Santa Rosa monitoring revealed higher average concentrations for runoff from rangeland than the STEPL estimates, which summarize national data. Nitrogen results are more discrepant, with the Laguna de Santa Rosa watershed monitoring yielding lower results for agriculture, and higher results for forest and rangeland. The difference for agriculture seems reasonable, as the Central Coast TMDLs are for areas that grow irrigated salad and fruit crops on land that often has drain tiles, which promote nitrogen export. Higher concentrations for forest and rangeland may reflect the greater rainfall in the Laguna de Santa Rosa area, which both results in more atmospheric deposition of N and greater leaching.

Table 5-7. Comparison of Estimated Unit-Area Nutrient Loads for Central Coast TMDLs to LCLM

Land Use	Santa Maria TMDL		Salinas TMDL		Pajaro TMDL		LCLM		
	N (lb/ac/yr)	P (lb/ac/yr)	N (lb/ac/yr)	P (lb/ac/yr)	N (lb/ac/yr)	P (lb/ac/yr)	Comparable Land Use	Median/ Mean N (lb/ac/yr)	Median/ Mean P (lb/ac/yr)
Agriculture	40.03	2.60	18.25	3.02	19.25	2.10	Cropland and Pasture	4.29/41.78	1.94/12.19
							Orchard & Vineyard	3.16/11.08	1.09/5.89
Urban	10.32	1.59	5.34	0.71	6.10	0.72	Commercial	6.29/15.12	1.03/2.55
							Residential with Sewer	5.81/16.99	1.35/3.47
							Residential no Sewer	5.85/15.33	1.51/6.00
Rangeland	0.83	0.75	1.75	0.66	0.73	0.48	Rangeland	2.64/10.59	0.72/3.32
Forest	0.38	0.19	0.21	0.08	0.24	0.12	Forest	0.73/4.03	0.12/0.62

Source: CCRWQCB, 2015; 2013a; 2013b. LCLM analyses omitted one "Residential without Sewer" sample from 10/15/2009 due to QA/QC concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015).

Table 5-8. Comparison of STEPL Event Mean Nutrient Concentrations from Central Coast Nutrient TMDLs to Average Wet Weather Concentrations from Laguna de Santa Rosa Watershed Monitoring

Land Use	Total Phosphorus (mg/L)		Total Nitrogen (mg/L)	
	Central Coast TMDLs	Laguna de Santa Rosa Monitoring	Central Coast TMDLs	Laguna de Santa Rosa Monitoring
Agriculture	0.64	0.55 – 1.84	11.4	1.73 – 9.14
Forest	0.1 – 0.2	0.08	0.2	0.52
Rangeland	0.21 – 0.27	0.67	0.25	1.41
Urban	0.15 – 0.53	0.19 – 0.93	1.5 – 4.0	1.04 – 2.37

Note: Ranges cover separate land use subcategories (e.g., orchard, vineyard, and cropland within agricultural class.) LCLM analyses omitted one "Residential without Sewer" sample from 10/15/2009 due to QA/QC concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015).

5.1.3.4 Dry Weather Loading from Independent Samples

An additional corroboration test performed by Butkus (2013) was based on samples collected during the summer of 2008 near the mouth of each of the major tributaries draining to the Laguna. These samples were not used in LCLM development. Summer 2008 was a drought period, so the samples were assumed to represent dry weather loading conditions. Weighted average loads based on land use in each tributary and LCLM unit area dry weather loading rates were compared to loads estimated for each tributary using 2008 measured concentrations and flows scaled from the USGS gaging location at Trenton-Healdsburg Road. Statistical tests reported by Butkus did not identify any significant differences in median or mean loads from the two methods in a majority of tests, suggesting that the LCLM estimates are consistent with measured dry-weather loads.

5.2 PHOSPHORUS LOADING AS A FUNCTION OF SEDIMENT LOADING

Inorganic phosphorus loads from the land surface are particle-reactive, and primarily move with sediment. Organic phosphorus loads, which are mostly associated with detrital plant material, also move with sediment. Typically, watershed nonpoint source loads of dissolved phosphorus are small relative to particulate loads on an annual basis[1]. Therefore, a separate line of analysis was developed to relate phosphorus loads to the estimates of upland sediment loading described in the sediment budget report (Tetra Tech, 2019).

5.2.1 Upland Loads

Estimates of sediment loads can be converted to estimates of phosphorus loads through application of sediment potency factors (pounds of phosphorus per ton of sediment). The 2009-2010 land-use monitoring conducted by Regional Board staff included total phosphorus, dissolved phosphorus, and total suspended sediment. For the purposes of the approximate analysis of load based on sediment transport, we assumed that only sorbed phosphorus is associated with sediment load and that the sorbed load transported during larger flow events is the major component of annual phosphorus loading to the Laguna; and further that wet period loads will dominate the total loading process. In many instances within this sampling effort, total suspended solids (TSS) was not fully quantified and was often reported at the detection limit of 15 mg/L[2]. Therefore, in relation to load prediction, we analyzed the phosphorus potency only on wet period samples where the reported TSS concentration was greater than 15 mg/L.

Phosphorus potency was computed for each valid sample, and averages and medians were calculated for land use classes employed in both the LCLM applications (as reported in Table 1 of Butkus, 2013) and the Revised Universal Soil Loss Equation (RUSLE) sediment load modeling (as reported in Table 6-3 of

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[1] Although relatively small on an annual basis, it is worth noting that dissolved phosphorus loads from sources such as agricultural irrigation and recycled water runoff, dry weather MS4 discharges, and leaky septic systems can account for a significant fraction of dry weather nutrient loads. These loads are often discharged during periods of low flow and under critical water quality conditions, when they are most likely to be bioavailable to growing macrophytes and algae.

[2] NCRWQCB (2010) incorrectly reports the TSS detection limit as 0.015 mg/L (personal communication from David Kuszmar, P.E., North Coast Regional Water Quality Control Board, Watershed Protection Division to Jonathan Butcher, Tetra Tech, 12/12/2015).

Tetra Tech, 2019). Given the influence of outliers on the averages and the fact that most sediment moves during storm events, the median wet weather potencies were selected for further analysis.

There is a challenge to matching these two sources of information, especially for agricultural land use: The LCLM combines crop and pasture as one land use class and orchard and vineyard as another land use class. In contrast, the RUSLE sediment analysis groups crop and vineyard as one set and pasture and hay as a separate set. However, given the small amount of row crop area in the watershed, the "crop and pasture" group can be treated as predominantly pasture and hay, while the "crop and vineyard" group can be treated as predominantly vineyard.

Table 5-9. Phosphorus Sediment Potency in Laguna de Santa Rosa Land Use Monitoring Data, 2009 - 2010 Wet Weather Samples with TSS > 15 mg/L

RUSLE Land Use	LCLM Land Use	Average Wet Potency (lb-P/ton-sediment)	Median Wet Potency (lb-P/ton-sediment)
Cropland	Cropland and Pasture	19.51	14.92
Pasture	Cropland and Pasture	19.51	14.92
Grass	Cropland and Pasture	19.51	14.92
Vineyard	Orchard and Vineyard	8.92	8.17
Water/Wetland	N/A	0	0
Forest	Forest	3.36	3.00
Developed	Commercial, Residential with Sewer	8.48	7.69
Developed	Non-Sewered Residential	6.31	6.37
Barren	Rangeland	4.39	3.98
Shrubland	Rangeland	4.39	3.98

Note: Analyses omitted one "Residential without Sewer" sample from 10/15/2009 due to QA/QC concerns (personal communication from Steve Butkus, North Coast Regional Water Quality Control Board, to Jonathan Butcher, Tetra Tech, 12/28/2015).

The phosphorus potencies reported in Table 5-9 appear elevated for land uses affected by human activity. National surveys (Parker et al., 1946; Mills et al., 1985) report that the typical P_2O_5 concentration of surface soils in this part of California should be approximately in the range of 0.10 – 0.19%. As P_2O_5 is 44 percent P, the likely background phosphorus content of soils should be on the order of 0.88 to 1.67 lb/ton. Because phosphorus is preferentially sorbed to fine clay particles, eroded sediment should be enriched relative to the total soil content. The enrichment ratio varies with the intensity of events and is a function of the clay content of the soil; however, for annual analysis enrichment ratios in the range of 2 – 5 are common (Mills et al., 1985; Novotny and Olem, 1994). This suggests that phosphorus potency ought to be in the range of 2 to 8 lb/ton. Both average and median potencies are well above this range for the cropland and pasture land use category.

Applying the median wet weather phosphorus potency factors to the RUSLE delivered sediment estimates in Table 5-3 of Tetra Tech (2019) results in the loading estimates shown below in Table 5-10. .

Table 5-10. Estimated Upland Phosphorus Load based on RUSLE Sediment Yield and Sediment Potency

Land Cover	Pervious Land Cover Area (acres)*	RUSLE Sediment Delivery Rate (t/ac/yr)	RUSLE Sediment Yield (tons/yr)	Median Wet Potency (lb-P/ton Sediment)	P Load from Sediment Delivery (lb-P/yr)	P Load (kg/yr)
Cropland	812	0.521	423	14.92	6,314	2,864
Vineyard	11,860	0.521	6,179	8.17	50,481	22,898
Water/Wetland	3,111	0.006	19	0.00	0	0
Developed - Sewered	13,233	0.103	1,369	7.69	10,530	4,776
Developed - Septic	3,683	0.103	379	6.37	2,416	1,096
Barren	580	2.147	1,244	3.98	4,951	2,246
Forest	48,880	0.130	6,378	3.00	19,133	8,679
Shrub	4,320	0.263	1,137	3.98	4,523	2,052
Pasture/Hay	3,907	0.062	242	14.92	3,605	1,635
Herbaceous	39,358	0.101	3,978	3.98	15,833	7,182
Total	*129,743*				*117,787*	*53,427*

* Excluding drainage area below Ritchurst Knob. Note that the land use tabulations used here (Tetra Tech, 2019) differ from those developed for the LCLM (Butkus, 2013).

The phosphorus load from the entire watershed estimated using the sediment potency approach (53,427 kg/yr, as reported in Table 5-10) is similar to the LCLM load based on median loading rates (51,392 kg/yr, as reported in Table 5-4, but omits dissolved-phase and dry weather loads. In addition, the RUSLE-based analysis does not account for phosphorus associated with sediment that derives from sources other than upland erosion, as discussed in the next section. Analysis of total nitrogen loads using the sediment potency approach was not attempted because a large proportion of the nitrogen load is expected to move in soluble form.

5.2.2 Phosphorus and Other Sources of Sediment Loads

The sediment budget for the Laguna de Santa Rosa watershed (Tetra Tech, 2019) suggests that only about 23% of the total sediment load in the watershed is derived from upland erosion processes described by the RUSLE model. This omits channel degradation, colluvial soil creep, gully formation, and road-related erosion.

The monitoring data described in NCRWQCB (2010) occurred at roads and with contributing drainage areas that appear to be on the order of 800 acres. The monitoring data used to develop LCLM are thus likely, to a large extent, to include sediment load generated from the road drainage network, but likely omits other load sources that contribute to the totals observed at the downstream FLUX stations.

As an approximate and ad hoc adjustment for these additional sources, a phosphorus load was associated with the estimated sediment load derived from colluvial bank erosion shown in Table 7-3 of Tetra Tech (2019). Assuming a sediment potency equal to the median value for forest shown in Table 5-9 of 3 lb/t (1,500 mg/kg) and a colluvial bank erosion rate of 13.62 t/mi/yr over the stream miles identified in Section 7.3 of Tetra Tech (2019), this would account for an additional phosphorus load of 3,965 kg/yr.

Additional insights are available from FLUX analyses of delivered nutrient load after accounting for the phosphorus content of sediment removed from floodways by SCWA (see Section 6.1).

5.3 FLUX ANALYSIS OF NUTRIENT LOADS

Coincident flow and nutrient concentration data are available at four stations to estimate nutrient loads at four of the long-term compliance monitoring locations. In addition, loads can be estimated from the SCWA monitoring from Santa Rosa Creek at Fulton Road by extrapolating flow data from a nearby gage. The load estimates are obtained using the FLUX program, developed by the U.S. Army Corps of Engineers' Waterways Experiment Station (Walker, 1999). FLUX may be used to estimate long-term load estimates or daily series based on relationships between concentration and flow. Data requirements include (1) point-in-time water quality concentration measurements, (2) flow measurements coincident with the water quality samples, and (3) a complete flow record (mean daily flows) for the period of interest.

Estimating constituent mass loads from point-in-time measurements of water-column concentrations presents many difficulties. Load is determined from concentration multiplied by flow, and while measurements of flow are continuous (daily average), only intermittent (e.g., monthly or tri-weekly grab) measurements of concentration are available. Calculating total load therefore requires "filling in" concentration estimates for days without samples and extrapolating point-in-time measurements to whole-day averages. The process is further complicated by the fact that concentration and flow are often highly correlated with one another, and many different types of correlation may apply. For instance, if a load occurs primarily as a result of nonpoint soil erosion, flow and concentration will tend to be positively correlated; that is, concentrations will increase during high flows, which correspond to precipitation-washoff events. On the other hand, if load is attributable to a relatively constant point discharge, concentration will decrease as additional flow dilutes the constant load. In most cases, a combination of processes is found.

Preston et al. (1989) undertook a detailed study of advantages and disadvantages of various methods for calculating annual loads from tributary concentration and flow data. Their study demonstrates that simply calculating load for days when both flow and concentration have been measured and using results as a basis for averaging is seldom a good choice. Depending on the nature of the relationship between flow and concentration, more reliable results may be obtained by one of three approaches:

1. *Averaging Methods:* An average (e.g., yearly, seasonal, or monthly) concentration value is combined with the complete time series of daily average flows;
2. *Regression Methods:* A linear, log-linear, or exponential relationship is assumed to hold between concentration and flow, thus yielding a rating-curve approach; and
3. *Ratio Methods:* Adapted from sampling theory, load estimates by this method are based on the flow-weighted average concentration times the mean flow over the averaging period and performs best when flow and concentration are only weakly related.

No single method provided superior results in all cases examined by Preston et al.; the best method for extrapolating from limited sample data depends on the nature of the relationship between flow and concentration, which is typically not known in detail. Preston et al. show that *stratification* of the sample data and analysis method, however, can reduce error in estimation. Stratification refers to dividing the sample into two or more parts, each of which is analyzed separately to determine the relationship between flow, concentration, and load. Sample data are usually stratified into high- and low-flow portions, allowing a different relationship between flow and load at low-flow (e.g., diluting a constant base load) and high-flow regimes (e.g., increasing load and flow during nonpoint washoff events). Stratification could also be based on time or season to account for temporal or seasonal changes in loading.

The FLUX package implements all three of the general approaches described by Preston et al., including a number of variants on the regression approach, and allows flexible specification of stratification. FLUX also calculates error variances for the estimates. Typically, the best estimation method is selected as the one the produces the lowest coefficient of variation on the annual load estimates.

5.3.1 Long-term Compliance Monitoring Stations

FLUX load estimates for total N and total P were developed at three of four stations using flow gaging data that start at the end of 1998 and continue through the end of 2019. The one exception is Mark West Creek at Trenton-Healdsburg Rd., where flow gaging is not available prior to October 1, 2005. We use the nutrient monitoring data shown above in Figure 3-4 through Figure 3-7 with the addition of SSU sampling results from the Laguna de Santa Rosa at Stony Point (Table 3-7). Results of the FLUX analysis appear in Table 5-11 and Table 5-12.

Table 5-11. FLUX Estimates of Total P Loads at Laguna de Santa Rosa Compliance Monitoring Stations, 1999 - 2019

Station	Method and Stratification	Sample Count	Coefficient of Variation	Load (kg/yr)	Flow-weighted Concentration (mg/L)
Laguna at Stony Point	8(6), unstratified	74	0.011	13,437	0.500
Laguna at Occidental Rd.	4, seasonal (11/15-2/1)	61	0.062	65,719	0.898
Santa Rosa Cr. Willowside	6, unstratified	45	0.190	10,309	0.125
Mark West Crk. Trenton-Healdsburg Rd.	8(6), unstratified	30	0.162	87,740	0.421

Note: Estimates for Mark West Creek at Trenton-Healdsburg Rd. are based on flows starting 10/1/2005. FLUX calculation methods are: 4: C/Q Regression 1, 6: C/Q Regression 3 (daily); 8: Time series with residual interpolation based on method 6. When method 8 is used, the coefficient of variation (CV) reported is for method 6.

Table 5-12. FLUX Estimates of Total N Loads at Laguna de Santa Rosa Compliance Monitoring Stations, 1999 - 2019

Station	Method and Stratification	Sample Count	Coefficient of Variation	Load (kg/yr)	Flow-weighted Concentration (mg/L)
Laguna at Stony Point	2, flow (80 hm^3/yr)	46	0.182	44,389	1.498
Laguna at Occidental Rd.	2, seasonal (11/1-5/1)	35	0.095	176,031	2.487
Santa Rosa Cr. Willowside	2, unstratified	31	0.131	81,251	0.985
Mark West Crk. Trenton-Healdsburg Rd.	4, unstratified	22	0.007	362,952	1.740

Note: Estimates for Mark West Creek at Trenton-Healdsburg Rd. are based on flows starting 10/1/2005. FLUX calculation methods are: 2: Flow-weighted concentration, 4: C/Q Regression 1.

5.3.2 Santa Rosa Creek at Fulton Road

As discussed in Section 3.1, SCWA has collected nutrient samples in Santa Rosa Creek at Fulton Road since 1997 in accordance with its MS4 stormwater permit – on an annual basis during storm events through 2009 and on a monthly basis since 2010 (Table 3-6). This large data set is also useful for evaluating nutrient loads. While flow is not monitored directly at Fulton Road, flow can be approximated by extrapolating flow from the USGS gage on Santa Rosa Creek at Willowside Road (although Piner

Creek, which drains a significant portion of the western part of the City of Santa Rosa, enters between these two locations), as is also described in Section 3.1.

SCWA monitoring, coupled with area-adjusted USGS gage records for Santa Rosa Creek, enables the estimation of annual loads for total phosphorus, TKN, nitrate nitrogen, and ammonium nitrogen. Total nitrogen estimates can be assembled as the sum of Kjeldahl nitrogen and nitrate nitrogen (nitrite nitrogen concentrations are typically minimal in oxygenated waters). For each constituent, a reasonable fit was obtained (based on analysis of the residual coefficient of variation) using FLUX method 6 with stratification at or near median flow. Method 6 is a bias-corrected regression of concentration on flow, implemented on a daily basis.

FLUX analysis for the whole period of record yielded estimates of total nitrogen load that are much greater than provided by the LCLM or the FLUX analysis for Santa Rosa Creek at Willowside Road. However, it also appears that reported concentrations of nitrogen species are much lower at this station after 2008 than prior to 2008 (see Table 3-6). Most notably, the average total nitrogen concentration decreased from 2.15 to 0.68 mg/L, primarily due to a reduction in TKN concentrations. These changes over time are not consistent with observations from Santa Rosa Creek at Willowside Road, where median concentrations were near 0.68 for both 2000-2004 and 2009-2018, with a lower median for 2005-2008 (see Figure 3-6). Experiments with FLUX showed that lower coefficients of variation were obtained for total N, TKN, and ammonium N if the data from this station were stratified at January 1, 2008. No improvement was seen for nitrate N. Therefore, the FLUX load analysis for Fulton Road was rerun using only data from January 1, 2008 onward. The resulting total N load estimate for the period after the start of 2008 of 79,370 kg/yr (Table 5-13i) is very close to the load estimate at Willowside Road of 81,251 kg/yr (Table 5-12). One possibility is that there was some change in analytical methods over time that affected TKN load estimates.

Table 5-13. FLUX Estimates of Annual Nutrient Loads in Santa Rosa Creek at Fulton Road based on SCWA Monitoring for 1999 - 2019

Parameter	Method	Coefficient of Variation	Load (kg/yr)	Flow-weighted Concentration (mg/L)
Total Phosphorus (1999-2019)	6, stratified at 400 cfs	0.14	15,106	0.189
Nitrate-N (1999-2019)	2, unstratified	0.14	35,945	0.450
Total Kjeldahl-N (1999-2019)	4, stratified at 400 cfs	0.14	98,102	1.225
Total Kjeldahl-N (2008-2019)	6, stratified at 400 cfs	0.11	45,930	0.665
Ammonium-N (1999-2019)	2, unstratified	0.099	19,743	0.247
Ammonium-N (2008-2019)	4, unstratified	0.051	14,066	0.051
Total N (1999-2019)	3, stratified at 400 cfs	0.12	120,320	1.51
Total N (2008-2019)	6, unstratified	0.11	79,370	1.06

5.4 COMPARISON OF FLUX AND LCLM LOADING ESTIMATES

The FLUX analyses provide independent estimates of nutrient loads entering the Laguna near the headwaters at Stony Point Road and from Santa Rosa Creek. The FLUX estimates can be compared to estimates using the LCLM (Section 5.1). Results are shown in Table 5-14. For total phosphorus, LCLM and FLUX results are within 15% of one another at both stations. Small differences between upland and instream phosphorus loads are expected due to instream scour and deposition processes. Total nitrogen load estimates are in good agreement at Stony Point; however, the LCLM estimate is much less than FLUX for Santa Rosa Creek at Fulton Road. This may suggest an additional source of Total N load at the Fulton Road site.

Table 5-14. Comparison of Annual Nutrient Loading Rate Estimates from LCLM and FLUX

	Santa Rosa Creek at Fulton Rd.		Laguna de Santa Rosa Creek at Stony Point Road	
	Total P (kg/yr)	Total N (kg/yr)	Total P (kg/yr)	Total N (kg/yr)
LCLM	11,999	46,792	11,002	41,292
FLUX	13,183	79,370	13,437	44,389
Difference (LCLM – FLUX)	-9.0%	-41.0%	-18.1%	-7.0%

Note: LCLM calculations are based on the median annual loading rates in Table 5-1 plus a load associated with colluvial bank erosion as described in Section 5.2.2. LCLM estimates for Total P in Santa Rosa Creek omit land area upstream of Lake Ilsanjo and Matanzas Creek Reservoir; these areas are included in the estimate for Total N. The FLUX estimate for Total N, Santa Rosa Creek at Fulton Road, is the result for 2008-2019 from Table 5-13.

In sum, while estimates of nonpoint source nutrient loading in the Laguna de Santa Rosa watershed are uncertain, the FLUX analyses approximately confirm the LCLM estimates of total phosphorus load at two locations, while the fit for total nitrogen is good at one of the two stations. This suggests that it is reasonable to use LCLM as an estimator of upland nutrient loads throughout the watershed. Additional monitoring in small watersheds with relatively homogenous land use would likely improve the accuracy of the LCLM and would also provide data that could in the future support calibration of a process-based nutrient delivery model.

5.5 ATMOSPHERIC DEPOSITION OF NUTRIENTS

Atmospheric deposition can be an important source of nitrogen load. Deposition occurs in both wet and dry forms. Wet deposition of N is easily measured in rainfall and is monitored by the National Acid Deposition Program (NADP). In contrast, dry deposition is very difficult to measure directly and is usually estimated by combining air concentration with deposition modeling. To address this problem, the NADP has produced estimates of total N deposition by combining NADP monitoring with output from the Community Multi-Scale Air Quality Model (CMAQ), as described in Schwede and Lear (2014).

The net delivery of atmospheric deposition of N to the land surface and to small upstream waterbodies is already implicitly included in LCLM and FLUX estimates of load. However, direct deposition to the surface of the Laguna de Santa Rosa and its adjoining open wetlands is not. Gridded annual data from NADP for total deposition (TDEP) mass of nitrogen oxides (NOx) and ammonium (NH_4) is available for the years 2000-2016 (http://nadp.sws.uiuc.edu/committees/tdep/tdepmaps/). The average over the last three years at the location of the Laguna (from TDEP version 2018.02) is approximately 7 kg/ha/yr. This estimate was multiplied by area in open water and non-forested wetlands in the Laguna and its floodplain to obtain the estimated atmospheric deposition contribution.

Atmospheric deposition of P also occurs, mostly as dust, but few monitoring data are available. McKee and Gluchowski (2011) recommend a total P atmospheric deposition rate of 100 kg/km^2/yr (1 kg/ha/yr) for San Francisco Bay, but note that the estimate is of low accuracy; however, no better local estimates have been identified. Table 5-15 shows the estimated loads.

Table 5-15. Estimated Atmospheric Deposition Flux of Nutrients Direct to the Laguna de Santa Rosa

Constituent	Flux Rate (kg/ha)	Lower Floodplain (kg/yr)	Upper Floodplain (kg/yr)	Upper Laguna (kg/yr)
Total Nitrogen	7	2,300	2,133	1,617
Total Phosphorus	1	329	305	231

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6.0 NUTRIENT SINKS

As a first approximation, phosphorus that enters the Laguna may be sequestered within the Laguna or exported downstream. Nitrogen may also be lost to the atmosphere (primarily through nitrification/denitrification reactions that lead to emission of nitrous oxide and nitrogen gas). There are no significant natural gaseous forms of phosphorus.

6.1 CHANNEL MAINTENANCE ACTIVITIES

As discussed in Tetra Tech (2019), Section 8.2, substantial amounts of sediment are removed from stream channels on the Santa Rosa Plain as part of SCWA's Stream Maintenance Program. The amounts removed vary from year to year; however, the average over the period of available records (2008-2018) amounts to 22,309 tons/yr. This sediment also contains phosphorus.

SCWA has not analyzed or reported the nutrient content of the sediment removed during channel maintenance activities; however, SCWA (Lassettre , 2019) did survey nutrient content in sediment proposed for removal near Stony Point Bridge as discussed in Section 3.2. There is limited additional monitoring data on in situ sediments. To derive an order-of-magnitude estimate of phosphorus removal, the average sediment removal mass is multiplied by four different sediment potency factors, in ascending order, derived from (1) a single sample reported from Santa Rosa Creek in CEDEN, (2) the median of Sonoma State University analyses at and near the Laguna de Santa Rosa at Stony Point Bridge, (3) Grossman et al. (2008), and measurements recently obtained by SCWA (Eurofins Calscience, 2019) in the vicinity of Stony Point Bridge (Table 6-1). This table suggests that channel maintenance activities may remove anywhere from 6,000 to 48,000 kg/yr of phosphorus. The wide range is due to the wide range of estimates of phosphorus concentration in sediment discussed in Section 3.2.

Table 6-1. Estimates of Total Phosphorus Mass Removed during SCWA Channel Maintenance Activities (kg/yr) based on 2008-2018 Removal Data and Different Concentration Assumptions

Sub-basin	CEDEN, Santa Rosa Creek	SSU, Laguna nr Stony Point Rd.	Grossman et al. (2008)	SCWA / Eurofins Calscience (2019)
P Concentration (mg/kg)	327	709	895	2,630
NE Santa Rosa	381	826	1,042	3,062
SE Santa Rosa downstream of Matanzas, Ilsanjo	19	40	51	149
Lower Santa Rosa	972	2,108	2,661	7,818
Windsor	30	65	82	242
Upper Mark West	0	0	0	0
Lower Mark West	0	0	0	0
Blucher	0	0	0	0
Colgan	448	972	1,227	3,607
Copeland	991	2,149	2,713	7,972
Upper Laguna	3,193	6,922	8,738	25,678
Upper Floodplain	40	87	110	324
Lower Floodplain	0	0	0	0
Total	6,074	13,169	16,624	48,851

Nitrogen losses due to channel maintenance activities are less certain due to the high solubility of inorganic N forms. Sediment sampling conducted by Sonoma State University (Table 3-9) showed a median total N concentration in the depositional area in the Laguna de Santa Rosa near Stony Point Rd. of 2,800 mg/kg, with concentrations in upstream tributaries in the 200 – 1000 mg/kg range. Concentrations of sediment N are likely higher at Stony Point Road because this is a depositional area (under the current hydraulic regime) with substantial amounts of *Ludwigia* growth. The SSU data as well as data collected by SCWA (Eurofins Calscience, 2019) suggest most of this sediment N is in the form of organic N, so a significant amount may be removed with sediment, rather than draining back out of the dredge. The SCWA data suggest a much higher total N concentration in sediment, with an average of 6,367 mg/kg dry weight.

Most of the channel maintenance activities take place in floodways, not in the downstream Laguna, so assuming the high concentrations observed at Stony Point is likely not appropriate for estimating the channel maintenance loss of N for other locations. The amounts of total nitrogen removed by channel maintenance activities at four different concentration levels are estimated in Table 6-2.

Table 6-2. Estimates of Total Nitrogen Mass Removed during SCWA Channel Maintenance Activities (kg/yr) based on 2008-2018 Data

Sub-basin	CEDEN, Santa Rosa Creek	SSU, Laguna nr Stony Point Rd.	Grossman et al. (2008)	SCWA / Eurofins Calscience (2019)
N Concentration (mg/kg)	300	575	1,000	6,367
NE Santa Rosa	349	670	1,164	7,414
SE Santa Rosa downstream of Matanzas, Ilsanjo	17	33	57	361
Lower Santa Rosa	892	1,709	2,973	18,927
Windsor	28	53	92	585
Upper Mark West	0	0	0	0
Lower Mark West	0	0	0	0
Blucher	0	0	0	0
Colgan	411	789	1,371	8,732
Copeland	909	1,743	3,031	19,298
Upper Laguna	2,929	5,614	9,763	62,164
Upper Floodplain	37	71	123	783
Lower Floodplain	0	0	0	0
Total	5,572	10,680	18,575	118,265

6.2 SEDIMENTATION LOSSES

6.2.1 Reservoirs

As described in the sediment linkage analysis (Tetra Tech, 2019) significant portions of the Southeast Santa Rosa watershed are upstream of Matanzas Reservoir and Lake Ilsanjo, both of which appear to be efficient sediment traps. There has been little monitoring of water quality immediately downstream of these reservoirs; however, it is likely that they also trap and bury the majority of phosphorus load derived from upstream. The balance of nitrogen species in these reservoirs is unknown, but they may both remove nitrogen (through denitrification reactions) and add nitrogen (through nitrogen-fixing cyanobacteria).

6.2.2 Sedimentation in the Laguna de Santa Rosa

As described in the sediment linkage analysis, approximately 64 percent of sediment loaded from the watershed is retained within the Laguna. The trapped sediment will also sequester substantial amounts of nutrients, although these can be regenerated in dissolved form under the proper redox conditions. An upper limit on nutrient trapping can be obtained by applying a sediment potency (see Section 3.2) to the apparent rate of sediment trapping; however, the net retention rate must be estimated from the overall balance due to lake of direct evidence.

6.2.3 Denitrification Losses

Stagnant portions of the Laguna often exhibit hypoxia, which promotes biological denitrification on nitrate to nitrogen gas and subsequent loss to the atmosphere. While this flux is likely to be significant, there are no quantitative data available. Therefore, it is not possible to separate nitrogen losses to denitrification from retention in the sediment of the Laguna at this time.

6.3 EXPORT TO THE RUSSIAN RIVER

Export from the Laguna is estimated at USGS gage 11466800, Mark West Creek near Mirabel Heights (collocated with sampling station Mark West Creek at Trenton-Healdsburg Road). Nutrient observations at this location are sparse, but do not seem to have changed greatly over time, despite reductions in point source inputs (see Figure 3-4 and Figure 3-5) – likely because of the buffering capacity of the large store of nitrogen and phosphorus present within the sediments in the Laguna. The FLUX analyses reported in Table 5-11 and Table 5-12 yielded estimates of average annual loads of total P (87,740 kg/yr) and total N (362,952 kg/yr) leaving the system. Only a small fraction of this load appears to be attributable to the Town of Windsor wastewater discharge, which enters Mark West Creek directly above this station.

7.0 NUTRIENT BUDGET

The preceding sections provide estimates of most of the components of the nitrogen and phosphorus budgets for the Laguna de Santa Rosa – with the notable exception of net exchanges with sediment in the Laguna due to deposition to and regeneration of nutrients from the sediments. This last component is obtained as the difference required to achieve balance after adjusting the tabulations to approximately match FLUX estimates of loads at four points in the system. The solution is not unique as all the components are subject to uncertainty and year-to-year variability. Uncertainty in estimates of upstream loads are implicitly contained within the estimates of net exchanges with the sediment. Nonetheless, the nutrient balances shown in Table 7-1 and Table 7-2 provide credible estimates that are consistent with the available data, especially the FLUX estimates of annual nutrient loads described in Section 5.3.

In calibration adjustments at the FLUX stations, net exchange with the sediment was set to the nearest 500 kg/yr. The resulting fit is summarized in Figure 7-1, which shows a near 1:1 relationship between the mass balance and the FLUX estimates at four stations. As negative exchange with the sediment is a net load to the water column, the nutrient budget suggests that on the order of 35 – 40 percent of the nutrient mass in the water column of the Laguna under current conditions may be attributable to regeneration of nutrients from the sediment by rooted macrophytes.

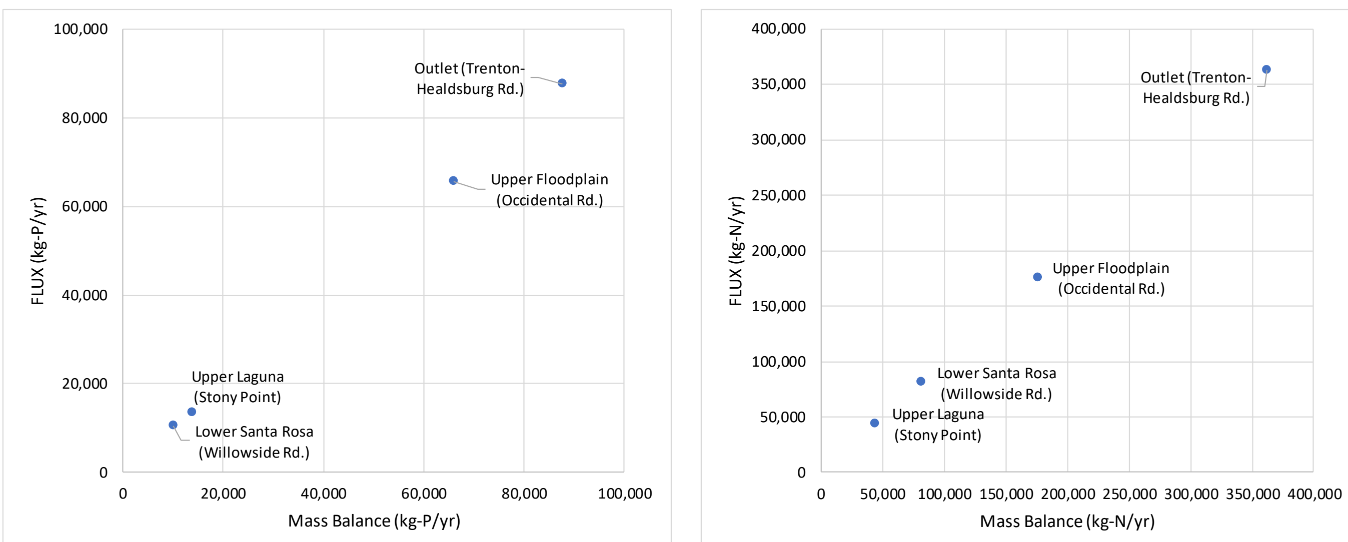

Figure 7-1. Calibration of Nutrient Mass Balance for TP and TN to FLUX Load Estimates

Table 7-1. Estimated Average Annual Total Phosphorus Budget for the Laguna de Santa Rosa (kg/yr)

	Inputs						I/O	Outputs		
Subbasin	Upland (LCLM)	Colluvial Bank Erosion	Upstream	Point Source	Atmospheric Deposition	Total In	Exchange with Sediment	Outflow	Channel Maintenance	Total Out
Copeland	1,438	125	0			1,438	0	573	991	1,564
Upper Laguna	9,747	336	447		231	16,425	-6,000	13,694	3,193	16,887
Blucher	1,551	128	0			1,551	0	1,679	0	1,679
Colgan	1,881	37	0			1,881	0	1,470	448	1,918
Upper Floodplain	6,512	6	16,217	329	305	65,863	-42,000	65,955	40	65,995
NE Santa Rosa	2,578	722	0			2,578	0	2,918	381	3,299
SE Santa Rosa	1,986	137	0			1,986	0	2,103	19	2,122
Lower Santa Rosa	9,225	348	4,163			13,388	3,500	10,123	972	14,595
Upper Mark West	2,992	1,038	0			2,992	0	4,029	0	4,029
Lower Mark West	1,080	293	2,992			4,072	0	5,402	0	5,402
Windsor	4,621	327	0			4,621	0	4,918	30	4,948
Lower Floodplain	7,781	56	86,902	2,596	329	97,160	9,500	87,660	0	97,160
Total	*51,392*	*3,553*		*2,925*	*865*	*93,734*	*-35,000*	*87,660*	*6,074*	*93,734*
Percent of Total	54.83%	3.79%		3.12%	0.92%		37.34%	93.52%	6.48%	

Note: For Total P, the upland load for SE Santa Rosa excludes the area upstream of Matanzas and Ilsanjo Reservoirs. Colluvial erosion loads are estimated as described in Section 5.2.2. For "Exchange with Sediment", negative values indicate a load from sediment to water column and are tabulated as inputs; positive values are losses to the sediment. Entries in the "Outflow" column in red are calibrated to FLUX estimates of load. Total line for "Total In" represents the sum of upland, point source, and atmospheric deposition loads plus the net exchange from sediment to the water column; total for "Outflow" is the estimated amount exiting via Mark West Creek. Several of the City of Santa Rosa discharge points are technically at the downstream end of Upper Laguna but are downstream of the Stony Point gage; they are thus assigned to the Upper Floodplain subbasin to allow comparison to the FLUX estimate at Stony Point. Similarly, the City of Santa Rosa Delta Pond discharge is at the downstream end of Santa Rosa Creek, below the Willowside gage, and is thus assigned to Lower Floodplain along with the Windsor discharge.

Table 7-2. Estimated Average Annual Total Nitrogen Budget for the Laguna de Santa Rosa (kg/yr)

	Inputs					I/O	Outputs		
Subbasin	Upland (LCLM)	Upstream	Point Source	Atmospheric Deposition	Total In	Exchange with Sediment	Outflow	Channel Maintenance	Total Out
Copeland	5,918	0			5,918	0	5,009	909	5,918
Upper Laguna	37,568	5,009		1,617	47,194	-3,000	44,265	2,929	47,194
Blucher	5,805	0			5,805	0	5,805	0	5,805
Colgan	7,643	0			7,643	0	7,232	411	7,643
Upper Floodplain	24,040	57,302	1,456	2,133	175,931	-91,000	175,894	37	175,931
NE Santa Rosa	11,346	0			11,346	0	10,997	349	11,346
SE Santa Rosa	16,040	0			16,040	0	16,023	17	16,040
Lower Santa Rosa	38,886	27,020			82,406	-16,500	81,514	892	82,406
Upper Mark West	12,926	0			12,926	0	12,926	0	12,926
Lower Mark West	4,819	12,926			17,744	0	17,744	0	17,744
Windsor	18,705	0			18,705	0	18,677	28	18,705
Lower Floodplain	27,341	293,830	10,167	2,300	361,638	-28,000	361,638	0	361,638
Total	*211,037*		*11,623*	*6,050*	*367,210*	*-138,500*	*361,638*	*5,572*	*367,210*
Percent of Total	57.47%		3.17%	1.65%		37.72%	98.48%	1.52%	

Note: For Total N, the upland load for SE Santa Rosa includes the area upstream of Matanzas and Ilsanjo Reservoirs. For "Exchange with Sediment", negative values indicate a load from sediment to water column and are tabulated as inputs; positive values are losses to the sediment. Entries in the "Outflow" column in red are calibrated to FLUX estimates of load. Total line for "Total In" represents the sum of upland, point source, and atmospheric deposition loads plus the net exchange from sediment to the water column; total for "Outflow" is the estimated amount exiting via Mark West Creek. Several of the City of Santa Rosa discharge points are technically at the downstream end of Upper Laguna but are downstream of the Stony Point gage; they are thus assigned to the Upper Floodplain subbasin to allow comparison to the FLUX estimate at Stony Point. Similarly, the City of Santa Rosa Delta Pond discharge is at the downstream end of Santa Rosa Creek, below the Willowside gage, and is thus assigned to Lower Floodplain along with the Windsor discharge.

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8.0 NUTRIENT BUDGET PRIOR TO EUROPEAN SETTLEMENT

Regional Board staff performed a detailed analysis to estimate land use coverage in the watershed prior to European settlement (Butkus, 2011). Under pre-settlement conditions, about 18 percent of the watershed area was in oak savanna. Representative nutrient loading rates for this land use were assigned by Butkus (2010) based on data from an un-grazed watershed near the town of Hopland in 1999-2000 reported by Dahlgren et al. (2001).

Using pre-settlement land use coverage provided by Butkus (2011) we recalculated nutrient loads for pre-settlement conditions using both the median and average annual load rates (Table 8-1). The median loads differ slightly from those presented by Butkus (2013) but continue to predict that pre-settlement loads were likely an order of magnitude less than those under current conditions.

Table 8-1. Nutrient Loads for Conditions prior to European Settlement Estimated by the LCLM

Pre-Settlement Land Cover	Land Cover Area (acres)*	Median Annual P Load (lb/yr)	Median Annual N Load (lb/yr)
Open Water	2,963	0	0
Perennial Wetland	16,964	0	0
Riverine Wetland	5,058	0	0
Rangeland	24,182	17,471	63,902
Oak Savanna	28,832	2,499	11,831
Forest	83,076	10,118	60,522
Total (lb/yr)	*161,075*	*30,088*	*136,255*
Total (kg/yr)		*13,648*	*61,804*

* Excluding drainage area below Ritchurst Knob.

Butkus (2013) speculated that loads of nutrients from the watershed that were actually delivered to the Laguna de Santa Rosa under conditions prior to European settlement were likely much less than the loads estimated by the LCLM. In contrast to current conditions in which flood control channels are designed to move water off the Santa Rosa Plain, the pre-settlement land coverage (Butkus, 2011) contained many disconnected channels that discharged into seasonal wetlands on alluvial fans, and there were extensive amounts of both riparian and permanent wetlands.

Regional Board staff estimated that a total of 73 percent of the upland phosphorus load and 87 percent of the upland nitrogen load was likely “assimilated” in wetlands prior to reaching the Laguna mainstem under pre-settlement conditions (Butkus, 2013). These estimates appear highly speculative as they are based on estimates reported in USEPA compilations of the median removal efficiency of riparian wetland buffers for nitrogen (USEPA, 2005) and riparian buffers in general for phosphorus (USEPA, 1993), along with application of the simple Pollutant Removal Estimates for Wetlands (PREWet) model of nutrient removal in perennial wetlands (Dortch and Gerald, 1995). These references primarily address removal efficiencies through managed riparian buffers and constructed wetlands in a modern landscape and may differ significantly from the performance of the natural system that existed pre-settlement. Removal efficiencies are likely to have been lower because the source strength in runoff was lower. Reported percent removal in Best Management Practices (BMPs) is strongly dependent on source water concentration, and many treatments exhibit an “irreducible concentration” below which net removal is essentially non-existent (Wright Water Engineers and Geosyntec Consultants, 2007). In addition, trapping of nutrients in wetlands is in large part not permanent as nutrients that settle out or are converted to biomass can later be remobilized in large flow and scour events or converted back to dissolved form in hypoxic sediments. The only pathways for permanent removal in a wetland or riparian area would be through removal of sediment or biomass (which would by definition be non-existent or minor under pre-settlement conditions) or denitrification that converts nitrogen compounds to nitrogen gas. It appears clear that the large area of wetlands present under pre-settlement conditions would reduce the rate of nutrient transport into the Laguna mainstem, but the net effect would likely be smaller than the estimates provided above, which can be considered to provide an approximate upper bound on removal.

Point sources of nutrient loads were not present prior to European settlement, and rates of atmospheric deposition and colluvial bank erosion would be lower. Under current conditions, the nutrient budgets presented in Section 7.0 include substantial amounts of nitrogen and phosphorus estimated to be regenerated from legacy sediment deposits within the Laguna. For pre-settlement conditions we assume that the Laguna and its watershed were in a quasi-steady state equilibrium such that nutrient regeneration from the sediment does not constitute a source that is in addition to ongoing watershed loads. We thus assume as a first approximation that the total nutrient loading to the Laguna under pre-settlement conditions is equal to the upland load estimates given in Table 8-1. With these simplifying assumptions the pre-settlement load of phosphorus is estimated to be 15 percent of present-day loads (using the LCLM median-basis analysis), while the pre-settlement load of nitrogen is estimated to be 17 percent of present-day loads.

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