Water Quality 5

5.1 Overview of water quality conceptual models

The purpose of the water quality conceptual model is to identify the probable linkages between key stressors (e.g., nutrients) and impacts on selected outcomes (e.g., support of Beneficial Uses). Conceptual models are used in other portions of this report to describe specific processes that are occurring in the Laguna. The water quality overview conceptual model (Figure 5-1) is an overarching illustration that incorporates most key water quality components and linkages to other ecosystem elements (e.g., hydrology and terrestrial ecosystem). The water quality overview conceptual model can also be used to identify key linkages within the Laguna that would be simulated using a dynamic model to support development of management strategies to protect and restore the Laguna.

In general we organized the conceptual model into a series of categories beginning with external loading stressors and other exogenous risk cofactors (A) that progress through a series of response categories (B-F) to beneficial uses (G). The model illustrates potential linkages between categories. The primary response category (B) responds to stressors and exogenous risk cofactors (A) that is linked to changes in the descending categories for physical habitat and water chemistry changes. The changes could potentially impact the integrity of biological community and other use categories. The Beneficial Uses assigned to the LSR represent a broad spectrum of ecosystem attributes that are included in the mission of Laguna Foundation to maintain, protect and restore the Laguna.

This initial conceptual model is not a complete representation but it will identify key linkages among processes that might be measured to evaluate trends within the Laguna which affect the goal of ecosystem restoration. The purpose of this model is not to describe the internal dynamics of the Laguna, rather it is to describe the linkages between those components in a generalized form. With this approach, we can identify those primary processes and linkages that require further investigation and will need to be represented more completely in any future modeling effort. Improving management of primary stressors and selective risk cofactors can improve conditions in key response categories and thus lead to restoration of the beneficial uses.

Nutrients and organic matter were identified as the primary external stressors for this conceptual model due to high concentrations and external loadings of nitrogen, phosphorus, and organic matter to the Laguna ecosystem as discussed below in Section 5.2 and as identified in previous studies (Smith, 1990; Otis, 2006). Risk cofactors (such as channel modification) are also stressors that in combination with nutrients can result in degraded conditions for the impact of assessment variables. The impact assessment variables that have been identified for the conceptual model are most of the beneficial uses listed in the North

Coast Regional Water Quality Control Board Basin Plan and represent most elements of the comprehensive Laguna ecosystem. Not all known processes and linkages have been included in the conceptual model illustration. Rather, those linkages that are believed at this time to most profoundly impact beneficial uses are included.

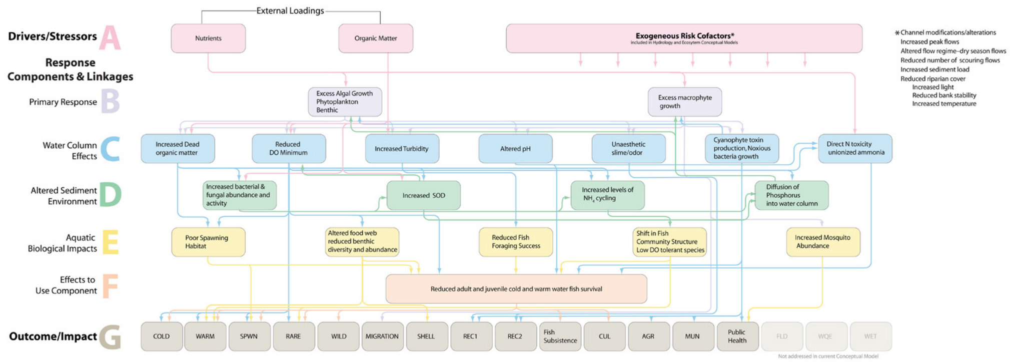

Figure 5-1 Water quality overview conceptual model
(see full-sized inset)

5.2 Data analysis

This section presents the results of the initial analysis of existing water quality data obtained from several sources. This analysis was conducted to provide information for the response to management questions and to further refine the conceptual model. This section consolidates analysis and information from several technical reports and studies.

5.2.1 Sources and loadings of nutrients and BOD

Historical accounts describe the Laguna as a productive low gradient system that included a mosaic of open channels, wetlands, and lake like features. Nutrient and BOD loadings associated with increased development within the watershed were important contributing factors to low dissolved oxygen conditions. The purpose of this section is to better characterize the relative magnitude of various source loading categories, and the timing of those loadings. The results have been incorporated into the overview water quality conceptual model and a series of other illustrations included below to begin the process of assigning priorities for managing nutrient and BOD loadings to the Laguna.

Potential pollutant sources and loadings

Various point and non-point sources exist within the Laguna watershed. They contribute excess nutrients and BOD loads that in combination with other factors contribute to water quality and ecosystem impacts (Figure 5-2). The categories that were used in this initial analysis to develop an improved understanding of the location, relative magnitude, timing, and potential impact on Laguna water quality are provided below.

- *Municipal wastewater discharge* – is a point source that contributes to loadings of nitrogen, phosphorus and BOD during winter discharge period;

- *Stormwater runoff from urban area* - carries pollutants such as sediments, nitrogen, phosphorus and BOD that build up on impervious areas and lawns and are transported to the Laguna during storm events;
- *Runoff and erosion from agricultural areas* – carries excess sediments, nutrients and BOD from agricultural lands that receive fertilization, manure application and irrigation using reclaimed water;
- *Atmospheric deposition* – (particularly nitrogen deposition as a result of automobile uses and agricultural activities) can increase the background nitrogen levels;
- *Groundwater input* –is a potential source during summer dry season and can be influenced by the application of fertilizer, manure and reclaimed water on agricultural lands and recharge from septics;
- *Septic effluents* - can contribute to nutrient and BOD loadings;
- *Internal nutrient cycling and sediment fluxes* – as a result of releases of nutrients from sediments and rapid turnover in the biological cycle can be potential sources; and
- *Dry weather storm drain flows* –capture runoff from incidental urban water uses (e.g., car washing, lawn watering, etc.) that also delivers sediment, nutrients, and BOD but perhaps more importantly extends wet season conditions within stream channels that were formerly dry during the summer season.

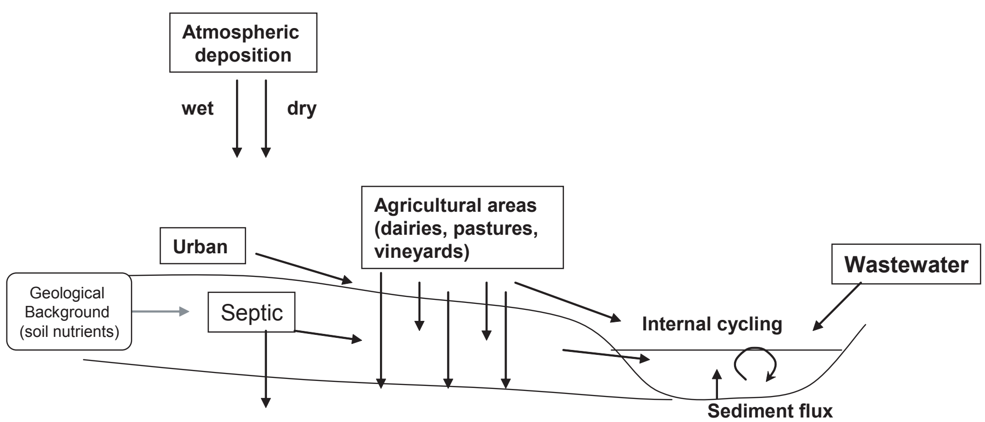

Figure 5-2 Potential point and non-point sources of nutrients/BOD in the Laguna watershed

Municipal wastewater discharges

Within the watershed, the Laguna Treatment Plant is the major source of municipal wastewater discharges. The plant is allowed to discharge in winter months only and the discharge volume in 2006 is around 2,127 million gallons to the river (http://cisanta-rosa.ca.cs). The discharge has nitrate concentrations of 8-10 mg/l, phosphorus concentrations 1.5-2.5 mg/l and BOD of 2-5 mg/l (Table 5-1).

Daily flow data and weekly concentrations are available at http://ci.santa-rosa.ca.us. Loadings from the plant were estimated by multiplying monthly total discharge volume and monthly average concentrations of the constituents. Discharge from May 15 through

September 30 is prohibited and generally occurs in January through March. The estimated average loadings for 2004-2006 are around 121,000 lbs/yr for nitrogen, 22,000 lbs/yr for phosphorus and 32,000 lbs/yr for BOD (Table 5-2). Calculated discharge volume and loadings for 2002 and 2003 (before off-watershed Geyser disposal project) are also included for comparison.

Table 5-1
Discharged effluent characteristics

Based on self monitoring report data for 2006 and 2007 available at http//ci.santa-rosa.ca.cs

Parameter	Value
Ammonia (mg N/L)	<0.2-0.5
Unionized Ammonia (mg N/L)	<0.1
Nitrate (mg N/L)	8.0-10.0
Organic Nitrogen (mg N/L)	<0.2-1.9
Phosphorus (mg P/L)	1.5-2.5
Chlorine	<0.1
BOD (mg/L)	<2.0-5.0
Dissolved Oxygen (mg/L)	8.7-13.6
pH	7.2-8.1
+Turbidity (NTU)	2.3-17.0
Conductivity (umhos/cm)	447-589
Temperature (F)	58-70
Non Filterable Residue (mg/L)	3.8-42.0

Table 5-2
Volume of treated wastewater discharged to the Laguna and the estimated pollutant loadings

Water Year	Volume (million gallon)	Ammonia (lbs N/yr*)	Nitrate (lbs N/yr)	Organic Nitrogen (lbs N/yr)	Phosphorus (lbs P/yr)	BOD (lbs/yr)
2006	2,122	6,490	141,500	18,062	24,581	48,563
2005	899	4,670	62,879	5,930	17,275	16,493
2004	1,522	5,528	109,895	8,916	23,660	31,958
Average	1,515	5,563	104,758	10,969	21,839	32,338
2003	4,091	16,647	288,930	38,743	61,305	94,672
2002	3,693	12,168	258,388	32,528	68,214	107,645

* Although the load is expressed on an annual basis, the discharge occurs only for a few months in winter.

Urban stormwater runoff

The main urban areas in the Laguna watershed include the cities of Santa Rosa, Sebastopol, Cotati, Rohnert Park, and Windsor. Storm event sampling by the City of Santa Rosa at Santa Rosa Creek indicated generally higher nutrients, fecal coliform, and total suspended sediment (TSS) concentrations downstream of the urban area compared to upstream sampling locations (Tables 5-3 and 5-4). For the sampling period of 1997-2006, two to four storm events were sampled each year, including some first flush events (Figure 5-3). A large portion of the nitrogen is in the organic form.

Table 5-3
Range of nutrients, BOD, TSS and bacteria concentrations at Site C1
(downstream of the City of Santa Rosa) for storm events sampled during 1998-2006

Parameter	Median	Average	Minimum	Maximum
Ammonia (mg N/L)	0.38	0.36	<0.20	0.68
Nitrate (mg N/L)	0.41	0.49	0.03	2.10
Nitrite (mg N/L)	0.2	0.2	<0.2	0.2
TKN, Total Kjeldahl Nitrogen (mg N/L)	1.35	1.91	0.28	5.40
Total Nitrogen (mg N/L)	2.3	2.3	0.44	5.0
Dissolved Phosphorus (mg P/L)	0.008	0.185	<0.002	1.00
Total Phosphorus (mg P/L)	0.114	0.251	<0.01	1.20
BOD (mg/L)	5.2	6.9	<5.0	15.0
TSS (mg/L)	70	84	<4	370
Fecal Coli. (mpn /100ml)	20000	555224	>1600	5000000
Fecal Strep (mpn /100ml)	25000	118680	920	1300000

Table 5-4
Range of nutrients, BOD, TSS and bacteria concentrations at Site C2
(upstream of the City of Santa Rosa) for storm events sampled during 1998-2006

Parameter	Median	Average	Minimum	Maximum
Ammonia (mg N/L)	0.20	0.23	<0.20	0.33
Nitrate (mg N/L)	0.24	0.60	<0.20	5.00
Nitrite (mg N/L)	0.2	0.2	<0.2	0.2
TKN (mg N/L)	0.77	1.19	0.21	4.60
Total Nitrogen (mg N/L)	0.59	0.69	<0.50	1.20
Dissolved Phosphorus (mg P/L)	-	-	0.2	0.2
Total Phosphorus (mg P/L)	-	-	0.11	0.25
BOD (mg/L)	6.5	7.4	<5.0	12.0
TSS (mg/L)	11	79	1.0	1500
Fecal Coli. (mpn /100ml)	17000	144416	170	2400000
Fecal Strep (mpn /100ml)	3000	99781	13	1800000

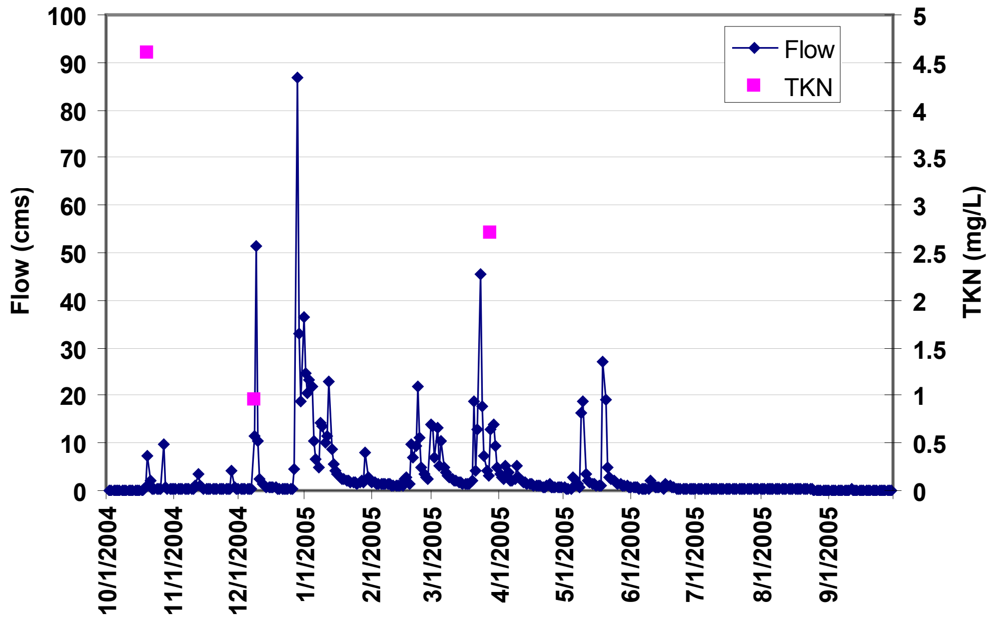

Figure 5-3 Flow at Santa Rosa Creek at Willowside Road with TKN concentrations Sampled during storm events of 2005

To calculate pollutant loadings from urban stormwater runoff, flow monitoring data at Santa Rosa Creek at Willowside Road (USGS 11466320) was used. Based on the flow record, we assumed storm event runoff to be greater than 75 cfs, which results in an average of 92 days each water year with flow greater than this criterion (C. Ferguson, personal communication). Records from the City of Santa Rosa's weather station at 69 Stony Circle average 82 days a year with rain > 0.01 inches. Therefore the assumption of 75 cfs flow should be reasonable. Pollutant loadings were estimated as runoff multiplied by the observed median storm event concentrations downstream of the City of Santa Rosa, subtracted by loadings from upstream rural area (C2 watershed and Matanzas Creek). Loadings from upstream were calculated by multiplying flow and medium concentrations observed at C2. Flow from Santa Rosa Creek above C2 was assumed to be proportional to watershed area. Based on the limited flow data from Matanzas Creek (USGS 11466170), flow at Matanzas Creek is about 24% of the flow at Santa Rosa Creek at Willowside. Concentrations from Matanzas Creek were assumed to be the same as the C2 site (both forested areas). Estimated pollutant loadings show large variations across the years due to amount of runoff (Table 5-5). Total urban areas in the watershed are 49 square miles. Loadings from all urban areas can be calculated by scaling the loadings in Table 5-5 to the total urban areas. Some of the loadings from urban areas are originally from atmospheric deposition. Loadings reported in Table 5-5 will include contribution from the atmospheric deposition. Atmospheric deposition to urban areas was estimated and included in Table 5-9 for comparison.

Table 5-5a
Estimated urban storm runoff and pollutant loadings of Santa Rosa Creek
at Willowside Road downstream of the City of Santa Rosa

Water Year	Volume (million gallons)	Ammonia (lbs N/yr)	Nitrate (lbs N/yr)	TKN (lbs N/yr)	TN (lbs N/yr)	Total Phosphorus (lbs P/yr)	BOD (lbs/yr)
2004	10,442	44,918	46,644	155,668	314,163	17,341	367,438
2005	12,466	53,624	55,685	185,842	375,059	20,702	438,660
2006	23,687	101,893	105,810	353,126	712,665	39,336	833,516
Average	15,532	66,812	69,380	231,546	467,295	25,793	546,538

Table 5-5b
Loadings normalized to area[1,2]

Water Year	Volume (million gallons)	Ammonia (lbs N/acre/ yr)	Nitrate (lbs N/acre/ yr)	TKN (lbs N/acre/ yr)	TN (lbs N/acre/ yr)	Total Phosphorus (lbs P/acre/ yr)	BOD (lbs/acre/ yr)
2004	10,442	1.72	1.79	5.98	12.06	0.67	14.11
2005	12,466	2.06	2.14	7.13	14.40	0.79	16.84
2006	23,687	3.91	4.06	13.56	27.36	1.51	32.00
Average	15,532	2.56	2.66	8.89	17.94	0.99	20.98

1. Calculated based on urban areas of 40.7 square miles.

2. http://www.epa.gov/waterscience/ftp/basins/training/b4lec15.pdf

Frink's export coefficients (lb/ac/yr)

	TN	TP
Urban	12.0±2.3	1.5±0.20

CTWM loading rates (lb/ac/yr)

	TN	TP
Urban-pervious	8.5 (5.6-15.7)	0.26 (0.20-0.41)
Urban –impervious	4.9 (3.7-6.6)	0.32 (0.18-0.36)

Agricultural storm runoff

The main agriculture land uses in Laguna include vineyards, pastures, and dairies. Dairies can be sources of nutrients and BOD to streams since dairies contain many loading units such as waste management areas where elevated nutrients and organic matter were found (Lewis et al. 2005; Meyer et al. 1997). Application of manure and slurry to pastures has the potential of increasing nutrients in runoff if excess nutrients beyond crop demand are applied (Bellows, 2001). Many of the dairies are located near streams, and therefore poor management can result in loadings to streams. As summarized in Decker (2007), vineyards and pastures that receive fertilization can be potential sources of nutrients due to over-fertilization or asynchrony with crop demands. Long-term fertilization can also result in accumulation of nutrients in the soils and therefore results in elevated nutrient concentrations in runoff.

Table 5-6
Agricultural types in the Laguna watershed

Determined from GIS layers provided by J. Honton

Agricultural type	Acres
Vineyard	5536
Pasture	3955
Dairy	2815
Beef Cattle	468
Corn	287
Orchard	278
Truck (small row crop production)	263

A typical dairy in California contains flushed freestalls in open barns (Meyer et al. 1997). Manure in freestall is flushed and liquid manure is stored in holding ponds. Solid and liquid manure is usually used to fertilize and irrigate crops or pasture lands nearby. Liquid manure is used for irrigation, spread as slurry or transported off the farm. Solid manure is spread on farm land, used for bedding, composted or transported off the farm.

Potential nitrogen loadings from 31 dairies during winter storms were estimated earlier by CH2M Hill and Merritt Smith Consulting (1994). In that study, dairy survey data were used to rank the management practices as poor, fair or good. Over half of the dairies surveyed were ranked to have poor practices. Manure and nitrogen production were calculated based on numbers of animals and typical manure and nitrogen production rates per body weight of animal. The loss of the produced manure nitrogen to streams was estimated based on management practices and excess nitrogen beyond requirements of irrigated crops. The estimated total nitrogen and organic matter (OM) loadings from dairies in winter storms was 179,000 lbs N/yr and 6,050,000 lbs/yr OM. With the waste reduction strategy, the management practices have been significantly altered and improved, although load estimates have not been updated so the beneficial effect is unquantified.

Without detailed information on current dairy operations and animal population, we estimated nutrient and BOD loadings based on a dairy runoff study conducted in Tomales Bay watershed (Lewis et al. 2005). In that study, fecal coliform and nutrient concentrations and flow were measured for different dairy loading units and upstream and downstream of dairies and were used to estimate instantaneous and storm loadings from dairies and the adjacent pastures. We attempted to extrapolate the results to Laguna watershed by taking the estimated nutrient loadings per storm (Table 5-7) and multiplied by typical numbers of storms and total areas of dairies in the Laguna watershed. Dairies in Tomales Bay watershed are just beginning to implement improved waste reduction and management practices that were established in the Laguna as a result of the waste reduction strategy. Therefore the Tomales Bay estimates are likely to have a higher per capita loading rate. It is also assumed that dairies in the Tomales Bay watershed produce more runoff due to steeper slopes and possible higher rainfall. Therefore the extrapolation developed for this analysis represents an upper bound of actual loadings to the Laguna from Laguna watershed dairies. On average, there are 21 runoff events per year with an average 1.25 inch rainfall per event (CH2M Hill and Merritt Smith Consulting, 1994). The estimated mean loadings from dairies and pastures during storms are presented in Table 5-8.

Table 5-7
Mean storm loads for nutrients
(Lewis et al. 2001)

Loading Unit	Ammonium (kg/acre/storm)	Nitrate (kg/acre/storm)	Total Nitrogen (kg/acre/storm)	Phosphate (kg/acre/storm)
Pasture	0.004 (0.001)	0.005 (0.001)	0.047 (0.031)	0.003 (0.001)
Downstream of dairies	0.286 (0.158)	0.006 (0.001)	0.513 (0.275)	0.011 (0.005)

Table 5-8
Estimated loadings of nutrients and BOD loadings from pasture and dairies

Loading Unit	Ammonium (lbs/yr)	Nitrate (lbs/yr)	Total Nitrogen (lbs/yr)	Phosphate (lbs/yr)	BOD (lbs/yr)
Pasture	732	916	8606	549	24,097
Downstream of dairies	37,273	782	66857	1434	187,201

Erosion from agricultural lands increases transport of pollutants associated with sediments, particularly for phosphorus. Here loadings of particulate phosphorus are not yet quantified. Information on vineyard fertilization or runoff quality is not available at this point and therefore we have not attempted to derive loadings for vineyards. Locations of these vineyards are mostly downstream of Santa Rosa Creek.

Atmospheric deposition

Atmospheric deposition can be a large non-point source of nitrogen. Atmospheric nitrogen deposition occurs both in inorganic (both ammonia and nitrate) and organic forms. To estimate atmospheric deposition loadings, data from the National Atmospheric Deposition Program (NADP) in station CA 45 (Hopland, Mendocino County, CA) were used. Another nearby station CA 88 (Davis, CA) also exists. Mendocino/Hopland was selected because the Davis station is more distant from the Laguna and is not as consistent with conditions found around the Laguna. For example, the Davis station has higher ammonia loadings (~ 4kg N/ha-yr) suggesting possibly larger influence from more intensive agriculture operations characteristic of the Central Valley. For CA 45 only wet deposition of ammonia and nitrate were available through the NADP network. Wet ammonia loading at CA 45 averaged 0.45 kg N/ha-yr and wet nitrate loading averaged 2 kg N/ha-yr at this station. Although total atmospheric deposition loadings can be large, the deposited loads will be retained partially by the watershed and runoff from various land uses will include contributions from atmospheric deposition. Direct deposition to water body however, was estimated to be 368lbs N /yr for ammonia and 1633 lbs N/yr for nitrate based on total area of water (371.2 ha).

Dry deposition of nitrogen occurs both in gaseous and particulate forms. Dry deposition of nitrogen can be as high as wet deposition and often higher than wet deposition. Wet deposition as well as dry deposition intercepted by forests and grasses can be washed off by precipitation and infiltrated into soils. Infiltrated nitrogen can be taken up by various types of vegetation. Nitrogen deposited to impervious areas can be directly washed off by overland flow and reaches the streams. Riparian vegetation provides a mechanism of nitrogen removal before reaching the streams. Stormwater monitoring data shown in Tables 5-3 and 5-4 indicated the range of concentrations from forested areas and urban areas. Runoff from other natural areas such as annual grass lands may also contribute to nitrogen loadings to streams. Figure 5-4 provides an overview of nitrogen transformation in the water column and sediments which illustrates that naturally occurring processes can introduce bio-available to the system should it become a limiting nutrient.

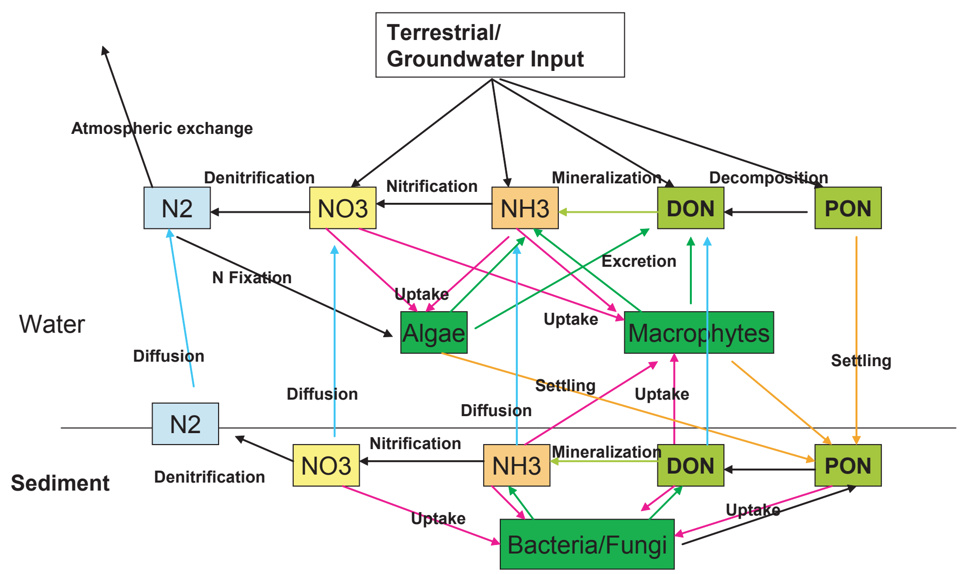

Figure 5-4 Nitrogen transformations in the water column and sediments

Groundwater

As summarized in section 4.3.4, shallow groundwater in Santa Rosa plain ranges between 0-86 feet below ground surface. During storm events, shallow ground water is likely to recharge the streams and therefore influence stream water quality, although it is not clear whether irrigation during summer seasons produces enough shallow groundwater that recharges to the streams. There is also evidence suggesting vertical connection of deep groundwater and surface near the confluence of Santa Rosa Creek and the Laguna de Santa

Rosa (as described in Section 4.3.4). Therefore the interaction between ground and surface water needs to be further evaluated. Summer base flow is generally very low for upper Laguna and the Laguna near Sebastopol when compared to Santa Rosa Creek, where incidental urban discharges occur more often during summer.

Various pollutant sources exist in the Laguna that could potentially influence ground water quality. These include dairies, irrigated pastures, and septic systems. Due to the low relief of the Santa Rosa floodplain, there is a large possibility that rainfall and septic effluents will recharge the groundwater when soil conditions permit. Current practices dictate that irrigated water be applied at rates that are less than rates of evapotranspiration. If irrigated water is applied at rates that exceed evapotranspiration it could also become a source.

Dairies can be an important nitrogen source to groundwater. Studies in the San Joaquin Valley suggested groundwater nitrogen concentrations were elevated by 40 mg/L down gradient of dairies (Harter et al. 2001). Currently there is an estimated total of 2,815 acres of dairies in the watershed (Table 5-6). Assuming 2 cows per acre and based on typical manure production rates by confined animals, these result in a total nitrogen production of 700,000 lbs/yr. Assuming half of the manure is transported off-farm, 350,000 lbs/yr is left within the watershed. Nitrate removal efficiencies in pasture were found to be around 15 lbs/acre/yr (Lowrance, 1992). In 2006, a total of 2,086 million gallons of reclaimed water was irrigated on agricultural/urban lands. Assuming an average nitrate concentration of 8 mg/L, this will result in a total surface nitrogen loading of 139,000 lbs/yr and a loading rate of 23.5 lbs/acre/yr. Phosphorus on the other hand is more easily adsorbed by soil and therefore is less susceptible to leaching to groundwater.

Septic systems

There are large numbers of septic units in the watershed. According to the 1990 census data, there are a total 19,901 septic units in the watershed. Due to the soil conditions in Laguna, septic failing rates might be high in certain areas. However, currently there is not enough information for evaluating the loadings from septics both during storms and under baseflow conditions due to septic failing. CH2M Hill and Merritt Smith consulting (1994) estimated a total nitrogen loading of 274,164 lbs/yr could be recharged into groundwater. However there is not enough information to verify this estimate.

Internal nutrient cycling in the Laguna

Wickham (2000) suggested a hypothesized mechanism of sequestering soluble reactive phosphorus from the wastewater treatment plant (SRP, mostly phosphate) in the Laguna with sediment deposition. Since phosphate is readily adsorbed to clay particles, elevated concentrations of phosphate can be adsorbed to and settle with sediments. Due to the high clay content of the Laguna soils, sediment eroded from various land uses contains phosphorus and can contribute to a phosphorus pool in the sediments. Sediment erosion and animal wastes transported from dairies have been found to accumulate in the bottom sediments of the Laguna (CRWQCB, 1992).

As a result, high concentrations of phosphorus were found in the sediments of the Laguna (as high as 2,400 mg P/kg, Otis 2006). High concentrations of organic carbon and nitrogen were also found in sediments (TN of 4,600 mg/kg). Sediment accumulation in certain sections of the Laguna is also significant (as much as 3 or 4 feet south and north of the confluence of Santa Rosa Creek; PWA 2004). These nutrient pools in the bottom sediments can serve as sources of nutrients through decomposition under aerobic and anaerobic conditions (releases of NH_3 and CH_4) and diffusion to the water column. The mixing of water, scour of sediments, and bioturbation can also immobilize nutrients from sediments to water column (Wetzel, 2001). Moreover, as the redox conditions changes to more anaerobic conditions, phosphate can be released from the sediment as the ferric ion (Fe^{3+}) that binds to phosphate is changed to ferrous form (Fe^{2+}). These processes are particularly important in summer as conditions favor the developing of anaerobic zones.

The uptake and turnover of phosphorus in an aquatic ecosystem is usually fast during summer; therefore, the cycling of phosphorus through aquatic community is also important. As shown in Figure 5-5, nutrients taken up by algae, plants and animals can be excreted or deposited to bottom sediments and can be quickly decomposed by bacteria and released back to water column.

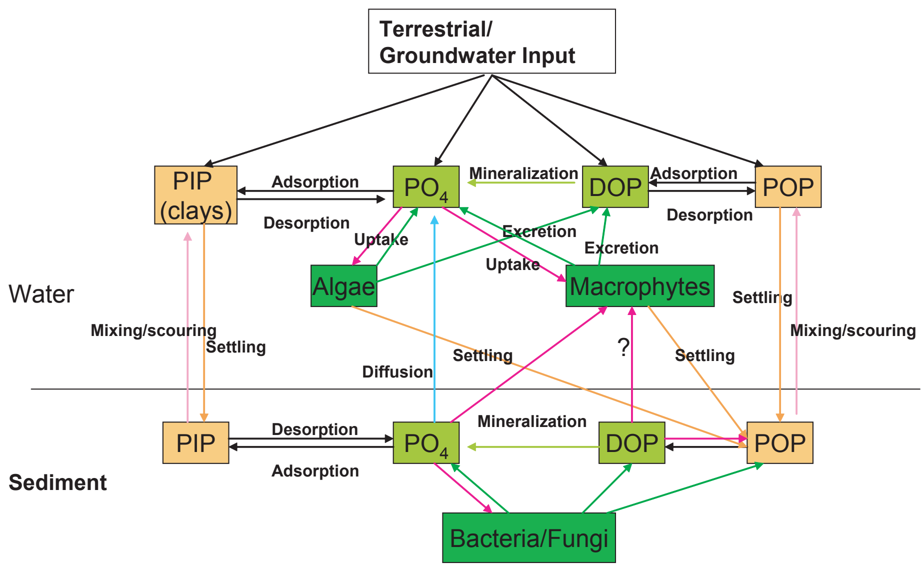

Figure 5-5 Phosphorus transformations in the water column and sediments

Quantifying sediment nutrient fluxes is very difficult without using models or real measurements. The mobility of phosphorus in particular depends on sediment redox conditions and the formation and stability of complexes with iron hydroxides. To make an attempt at an order-of-magnitude evaluation of this source, we estimated phosphorus releases from sediment due to diffusion only using simple equations derived from the WASP and QUAL2K model:

P flux = Edif/h * (Csw-Cw)

where Edif is eddy diffusion coefficient, h is active sediment depth, Csw is concentration in sediment water, and Cw is concentration in water column.

Nutrient concentrations in pore waters have not been reported for the Laguna. Therefore we estimated pore water concentrations using a partition coefficient of 1,000 as reported in literature (WASP, 2007) and the observed sediment phosphorus concentration of 2,400 mg/kg, which results in a concentration of dissolved phosphorus in sediment porewater of 2.4 mg/l. Using eddy diffusion coefficient of 2 x 10^{-4} m^3/sec reported in the literature (WASP, 2007) and an active depth of 2 cm, results in a sediment phosphorus flux of 0.02 g/m^2/day, which is near the center of the range of release rates reported by Nurnberg (1984) for lakes with anoxic sediment-water interfaces. Assuming LOR pond has a width of 250 feet and a length of 0.75 miles, results in a phosphorus loading of an order of 671 lbs/yr, which is not as significant compared to other sources during storm events, but could be significant since the majority of this flux would occur during summer low flow. However, due to the preliminary nature of this estimate, a more detailed study on sediment fluxes is needed to characterize loading from this potential source. Notably, the rate of phosphorus evolution from the sediment depends on dissolved oxygen conditions at the sediment-water interface, and may thus respond to management efforts that improve DO in the Laguna.

Nutrient loadings under flood conditions

One unique characteristic of the Laguna is that it is subjected to flood inundation due to backwater from the Russian River. When flooding occurs, lands that were originally agricultural or had other uses are submerged. Soils, sediments, nutrients and BOD originally accumulated on lands can be washed off by water. Sediments carried by flood water can also be deposited on lands when flood receded. During the flood of April 1999, aerial photos showed 3 areas of inundation in addition to wetlands including: 1) the Laguna at the Mark West confluence to 0.5 mi south (0.125 square miles); 2) 0.5 mile north of Guerneville Road (0.25 square miles); and 3) between Santa Rosa Creek and Occidental Road (0.5 square miles; PWA, 2004). These areas are scattered with agricultural areas of vineyards and dairies. The deposition of sediment and its associated water quality effecting constituents (N, P, and OM) is deposited on the floodplain above the low flow channel. This process would sequester at least some portion of the transported load away from the low flow sediment interface. More information is needed on frequency and duration of floods and the inundation areas.

Decker (2007) specifically describes a conceptual model of nitrogen and phosphorus immobilization and mobilization on the Laguna de Santa Rosa floodplain, particularly due to flood inundation. The Laguna de Santa Rosa floodplain contains agricultural land uses such as pasture and vineyards, which receive heavy fertilization. When manure or fertilizers are applied to these lands, excess application or asynchrony with crop demands can result in nutrient leaching, particularly for the more mobilized form NO_3^-. Phosphorus on the other hand can be adsorbed and accumulated in soils. When these soils with high nutrient levels are inundated with floodwater for a prolonged time, it potentially presents a way of immobilizing these nutrients to water. Decker (2007) estimated, for a flood event of winter 2006, the inundation area contains 42% pasture, 24% vineyards, and 26% natural woodlands. Nonetheless, the inundation of floodplains particularly on the agricultural lands can be an important and not yet quantified pathway of mobilizing nutrients to the Laguna.

Ranking of watershed loadings

Within the Laguna watershed urban stormwater is the largest source for ammonia, total nitrogen, total phosphorus and BOD (Table 5-9). Although concentrations in urban stormwater runoff are much lower than municipal wastewater, stormwater runoff is of much larger volume and therefore contributes to larger loadings of TN, TP and BOD. Note that nitrogen in municipal wastewater discharges to the Laguna is mostly in the nitrate form. As a result, municipal wastewater discharge is the largest source of nitrate loading. Nitrogen from dairies is mostly in ammonia form and therefore dairies are the second largest source of ammonia following urban stormwater runoff. For nitrate and phosphate, municipal wastewater discharge and urban stormwater runoff are generally equivalent sources. Here urban stormwater runoff includes loadings from the cities of Santa Rosa, Rohnert Park and Cotati (total area of 49 square miles).

The estimated loads for ammonia and total nitrogen from municipal wastewater and dairies are less than the previous estimates by CH2M Hill and Merritt Smith (1994; Table 5-10). Calculated ammonia loads from urban water are greater than the previous estimates. The estimated loads for nitrate and total nitrogen from urban areas were also greater, compared to other previous estimates reported (Table 5-10). The estimated phosphorus loading from urban areas compared favorably to the previous estimate (Table 5-11). Figures 5-6 through Figure 5-8 illustrate the relative magnitude of loadings by category for nitrogen, phosphorus, and BOD for the Laguna watershed.

Table 5-9
Summary of estimated pollutant loadings during winter by land uses

	Ammonia (lbs/yr)	Nitrate (lbs/yr)	Total Nitrogen (lbs/yr)	Phosphate (lbs/yr)	Total Phosphorus (lbs/yr)	BOD (lbs/yr)
Municipal wastewater	5,563	104,758	121,290	21,839	21,839	32,338
Dairies	37,273	782	66,857	1,434	--	187,201
Pasture on dairies	732	916	8,606	549	--	24,097
Urban stormwater*	80,437	69,380	562,591	12,915	31,053	657,994
Atmospheric deposition to urban areas	12,564	55,836	68,400			

* *calculated based on total urban area of 49 square miles (including the cities of Santa Rosa, Rohnert Park and Cotati).*

Table 5-10
Loads to the Laguna during winter storm and non-storm periods

Estimated by CH2M Hill and Merritt Smith (1994)

	Ammonia (lbs/yr)	Total Nitrogen (lbs/yr)
Municipal wastewater	56,610	424,400
Dairies	179,000	179,000
Urban	21,400	246,000

Table 5-11
Loads from urban stormwater

(NPDES permit, 1996)

	Nitrate (lbs/yr)	Total Nitrogen (lbs/yr)	Phosphorus (lbs/yr)
Urban	72,000	242,000	62,000

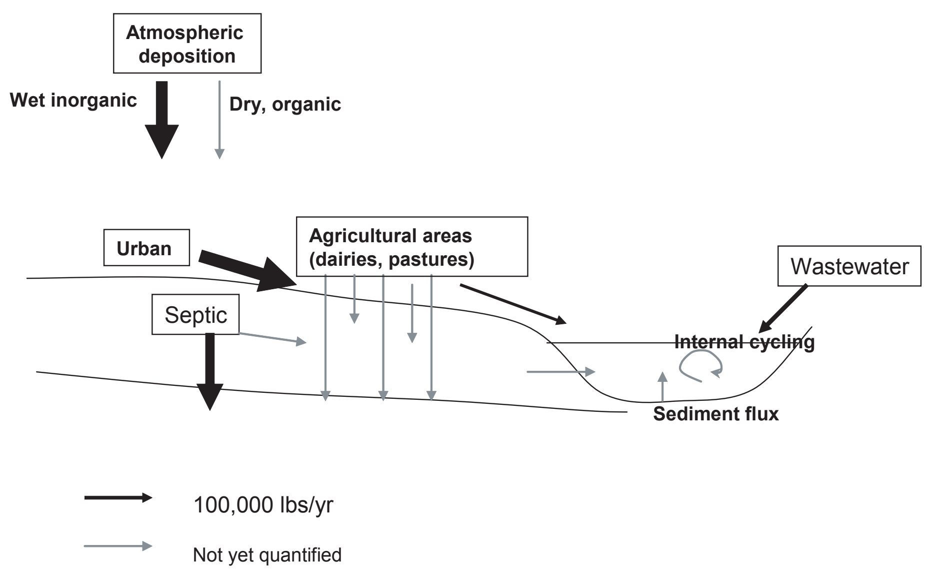

Figure 5-6 Preliminary TN loading conceptual model

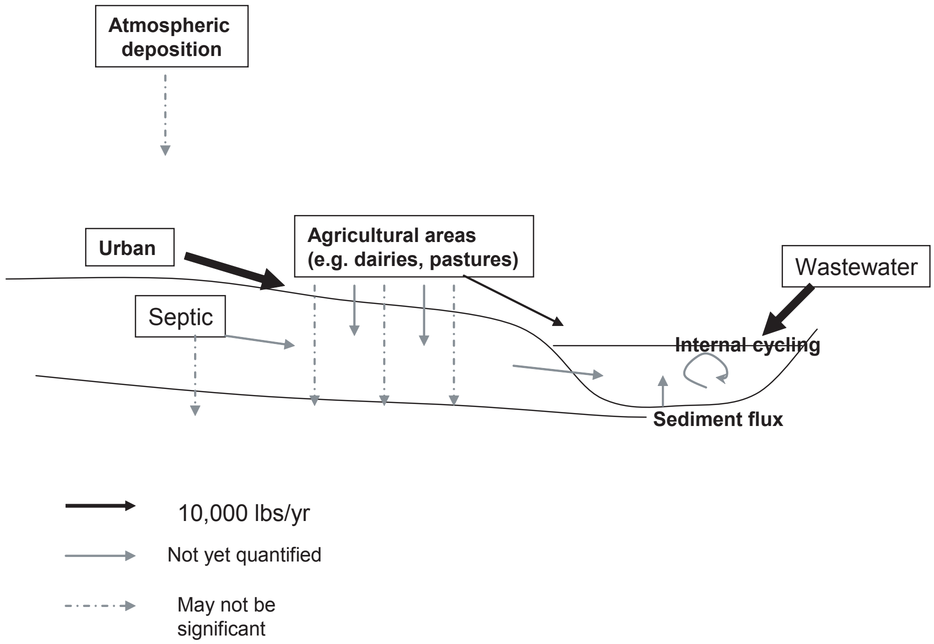

Figure 5-7 Preliminary dissolved phosphate loading conceptual model

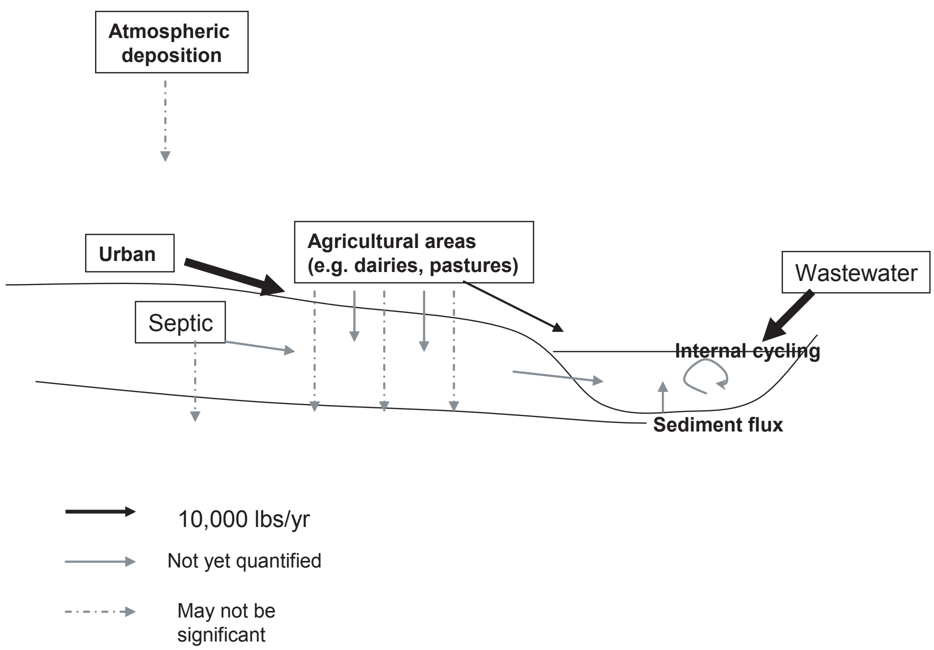

Figure 5-8 Preliminary BOD loading conceptual model

Loadings by tributaries

Loadings by tributaries were calculated based on available USGS flow data and monthly average nutrient concentrations observed in the same reach for the years 2004 through 2006. Figures 5-9 through 5-11 show the relative magnitude of loadings by tributaries. BOD concentrations are not available therefore loadings by tributaries could not be calculated. Spatially there are increases in loadings of ammonia, nitrate, and total phosphorus from upstream (LSP) to downstream (LOR). Loadings from Santa Rosa Creek are generally less than LOR (upstream of Santa Rosa creek confluence). USGS flow data suggested the flow at Santa Rosa Creek is generally equivalent to the flow at Laguna Sebastopol. However, higher loadings at the Laguna near Sebastopol suggested various other potential sources or reasons (*e.g.*, point source, dairies, or clay based soils) exist in the upper Laguna and other tributaries that contribute to higher loadings and that these sources are absent or less evident in the Santa Rosa Creek sub-watershed.

For ammonia, loading at LSP is greater than loading from Meadow Lane Ponds, suggesting the contribution of non point sources (*e.g.*, urban runoff, pasture, and dairies). Nitrate loading at LSP is roughly equivalent to Meadow Lane Ponds, suggesting both point and non-point source loadings of nitrate to the Laguna main channel. For total phosphorus, loading from the wastewater discharge is generally equivalent to the loading from Colgan Creek and less than LSP, again suggesting the contribution of both non-point and point sources to TP loading.

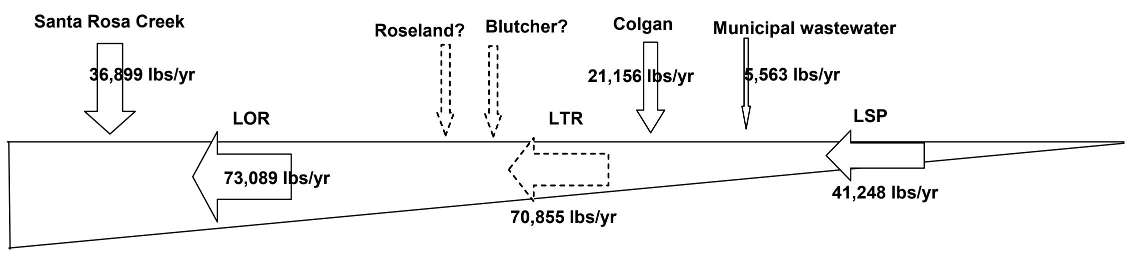

Figure 5-9 Total ammonia loadings by reaches
(note location of municipal wastewater discharge varies with year,
with most recent discharge point located below LOR)

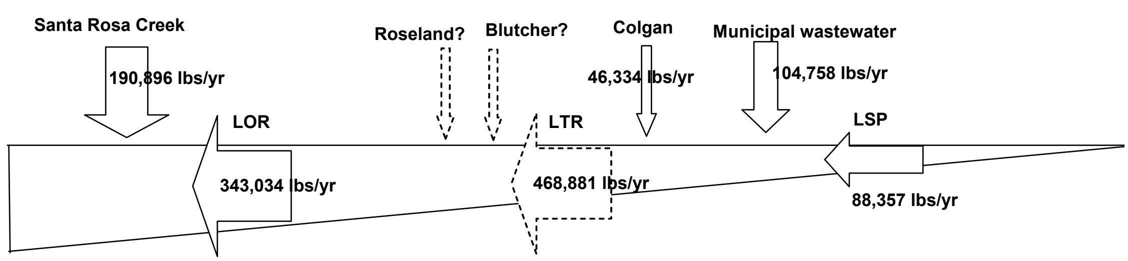

Figure 5-10 Nitrate loadings by reaches
(note location of municipal wastewater discharge varies with year,
with most recent discharge point located below LOR)

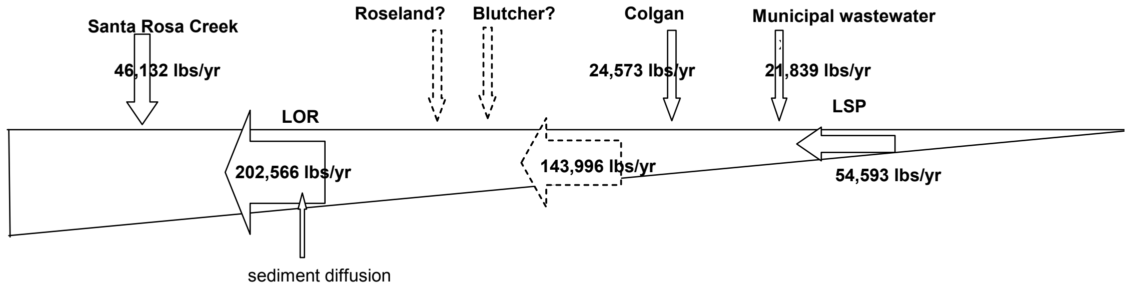

Figure 5-11 Total phosphorus loadings by reaches
(note location of municipal wastewater discharge varies with year, with most recent discharge point located below LOR)

5.2.2 Historical and current status of nutrient concentrations

A summary of the current nutrient concentrations that reflects the current status in the Laguna (2000-2005), compared to historical levels (1989-1994, 2000-2005) is provided below. Spatial and temporal patterns of nutrient concentrations were also explored. Some key observations from the analysis are:

- Historically very high total NH_3 and TKN concentrations (e.g., average of 6.8 mg/l at certain locations) were observed for the period of 1989 to 1994.
- Nutrient concentrations have shown large decreases since 1989. The largest decreases are in total NH_3 and TKN concentrations.
- Current median nutrient concentrations for the Laguna main channel are mainly 0.3-0.5 mg N/l for total NH_3, 1-3 mg N/l for NO_3 and 1-2 mg N/l for organic nitrogen. Median TP concentrations are generally between 0.5- 1 mg P/l with a few locations above 1 mg P/l.
- For the main channel of the Laguna, nutrient concentrations generally increase from upstream station (LSP) to LTR and LOR, and then decrease downstream of LOR. The section between LOR and upstream of the Santa Rosa Creek confluence can potentially function as a nutrient sink. 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.

Available data for analysis

The available data for analysis includes: 1) City of Santa Rosa Self Monitoring Program (SMP) nutrient data for 2000 to 2005; 2) TMDL monitoring data collected by NCRWQCB during 1995 to 2000; and 3) collated data from the City of Santa Rosa and NCRWQCB for the period of 1989 to 1994. Using these data requires knowledge recycled water discharge (ie where, when and amount). Discharge location, timing and amount in the future may not be the same as that in the past.

- *City of Santa Rosa SMP data for 2000 to 2005.* These are weekly grab samples collected upstream and downstream of the city's wastewater discharging locations during discharging periods. Constituents monitored include total NH_3-N, NO_3, organic nitrogen, and TP. This set of data provides us the current status of nutrient concentrations in the watershed.
- *TMDL monitoring data collected by NCRWQCB during 1995 to 2000.* These are TMDL monitoring data collected by NCRWQCB at five stations (LSP - Laguna at Stony Point, LOR - Laguna at Occidental Road, LGR - Laguna at Guerneville Road, LTH - Laguna at Trenton-Healdsburg Road, and SRCWS - Santa Rosa Creek at Willowside Road) for the period of 1995 to 2000. The data are bi-weekly grab samples. During this period, the Waste Reduction Strategy (WRS) was implemented, and therefore this set of data provides us with the effect of WRS.
- *Combined data from the City of Santa Rosa and the NCRWQCB for the period of 1989 to 1994.* These are weekly or biweekly samples collected at a few key locations of the Laguna during 1989 to 1994 by both the City of Santa Rosa and NCRWQCB. Data in this period generally reflect status before the implementation of WRS.

Data for 2000 to 2005 were collected for the discharging months only. For consistency, for 1989 to 1994 and 1995 to 2000 only data for the discharging months were used in the analysis. Locations and total number of data points for different periods are shown in Figure 5-12.

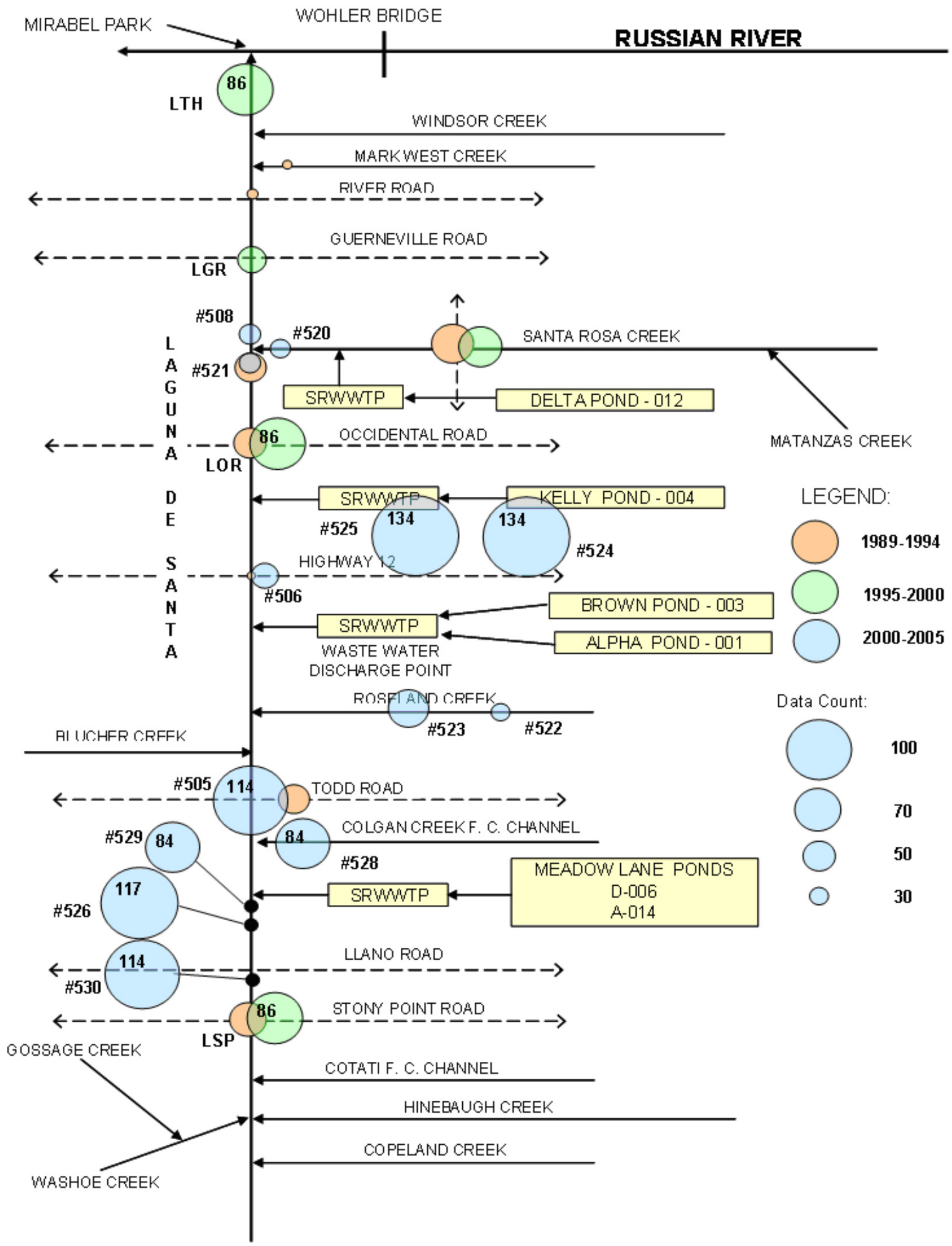

Figure 5-12 Total number of data points for the samples during 1989-1994, 1995-2000, and 2000-2005.

Spatial and temporal trends in nutrient concentrations

Spatial pattern and temporal changes in NO_3 concentrations

For 1989-1994, mean NO_3 concentrations increase from upstream (LSP) to LTR (3.8 mg N/l) and LOR (4.0 mg N/l; Figure 5-13). NO_3 concentrations decreased between the section of LOR and upstream of the confluence of Santa Rosa Creek, suggesting possible nutrient sinks in this section. Mean NO_3 concentrations continued to decrease downstream below the confluence of Santa Rosa Creek due to dilution of Santa Rosa Creek. For the period of 1995 - 2000, observed mean NO_3 concentrations are much lower (Figure 5-14). The highest mean NO_3 concentrations were again observed at LOR (1.8 mg N/l), below wastewater discharge points. The rest of the Laguna main channel and Santa Rosa Creek all showed mean NO_3 below 1 mg N/l.

For the period of 2000 - 2005, observed mean NO_3 concentrations range from 0.9 – 3.5 mg/l at the main channel (Figure 5-15). NO_3 concentrations again increase downstream below A pond discharge (Station #526; 2.3 mg N/l), and further downstream at LTR (3.5 mg N/l). Monitoring stations at several tributaries upstream and downstream of discharge points indicate relatively high NO_3 concentrations below discharge point.

Overall for the three sampling periods, 1995 - 2000 has a large decrease in NO_3 compared to concentrations from 1989- 1994. For 2000 -2005, the Laguna above the confluence of Santa Rosa Creek also has a decrease in NO_3 from 1989 - 1994. However, NO_3 concentrations at LTR, the Laguna at Highway 12, and the Laguna below Llano Road continue to have high concentrations. Monitoring data for 2000 -2005 also show some relatively large NO_3 concentrations in the tributaries.

For NO_3, generally higher concentrations are observed for winter and spring months in December to April for LSP, LOR and LTH. Summer generally has lower NO_3 concentrations. Lower total NH_3/NO_3 concentrations during summer months indicated nitrogen is rapidly taken up by algae or plants.

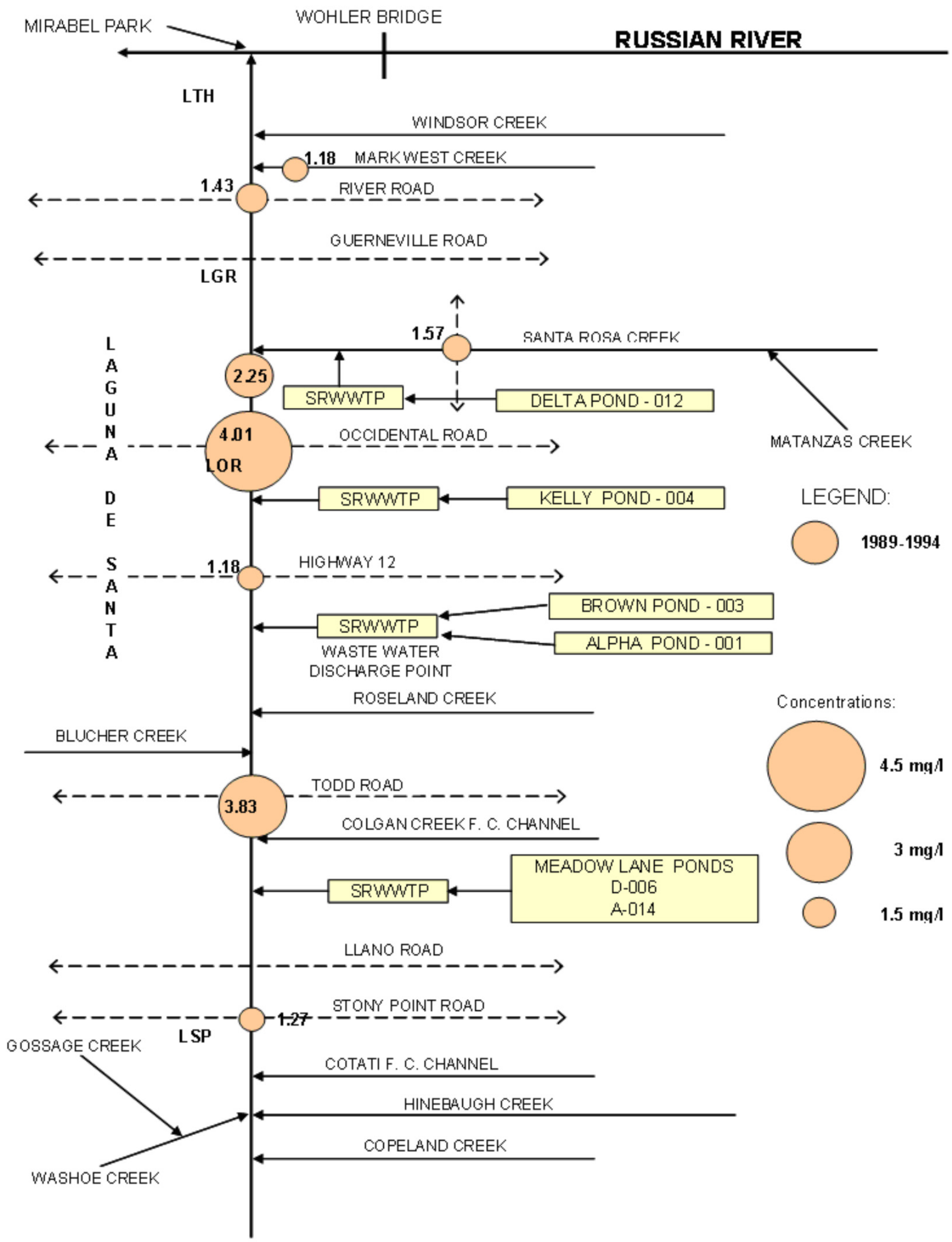

Figure 5-13 Mean NO_3 concentrations for 1989-1994

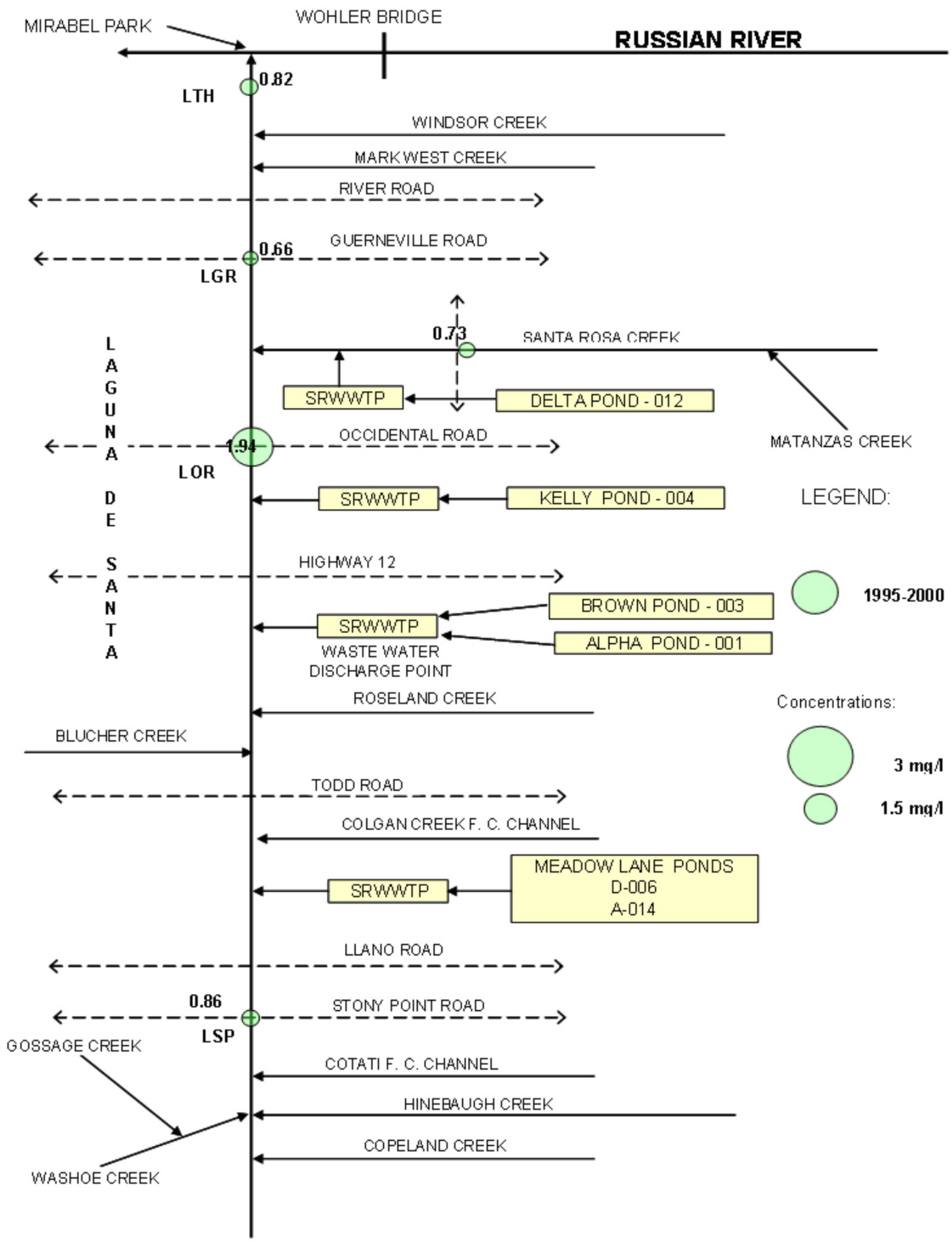

Figure 5-14 Mean NO_3 concentrations for 1995-2000

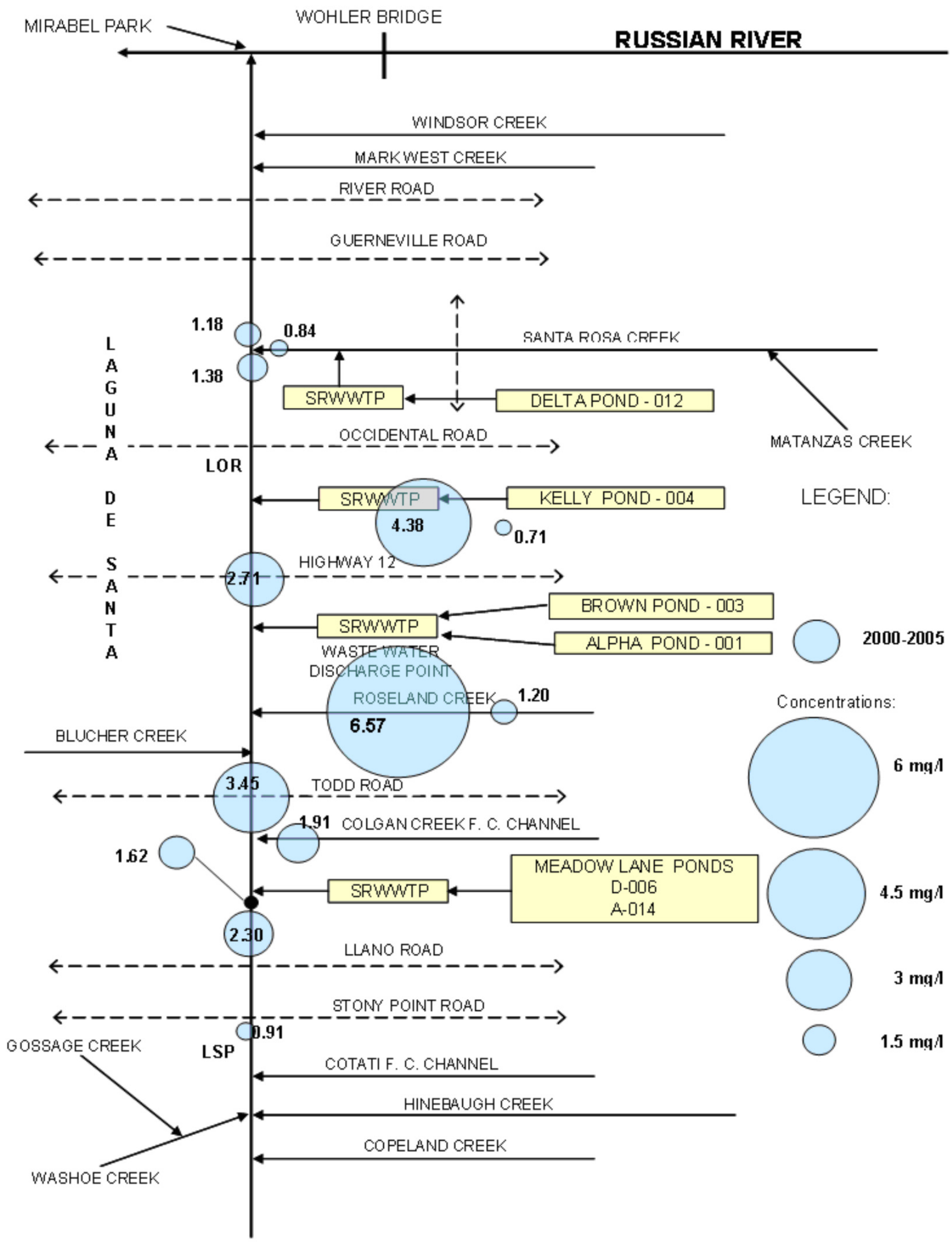

Figure 5-15 Mean NO_3 concentrations for 2000-2005

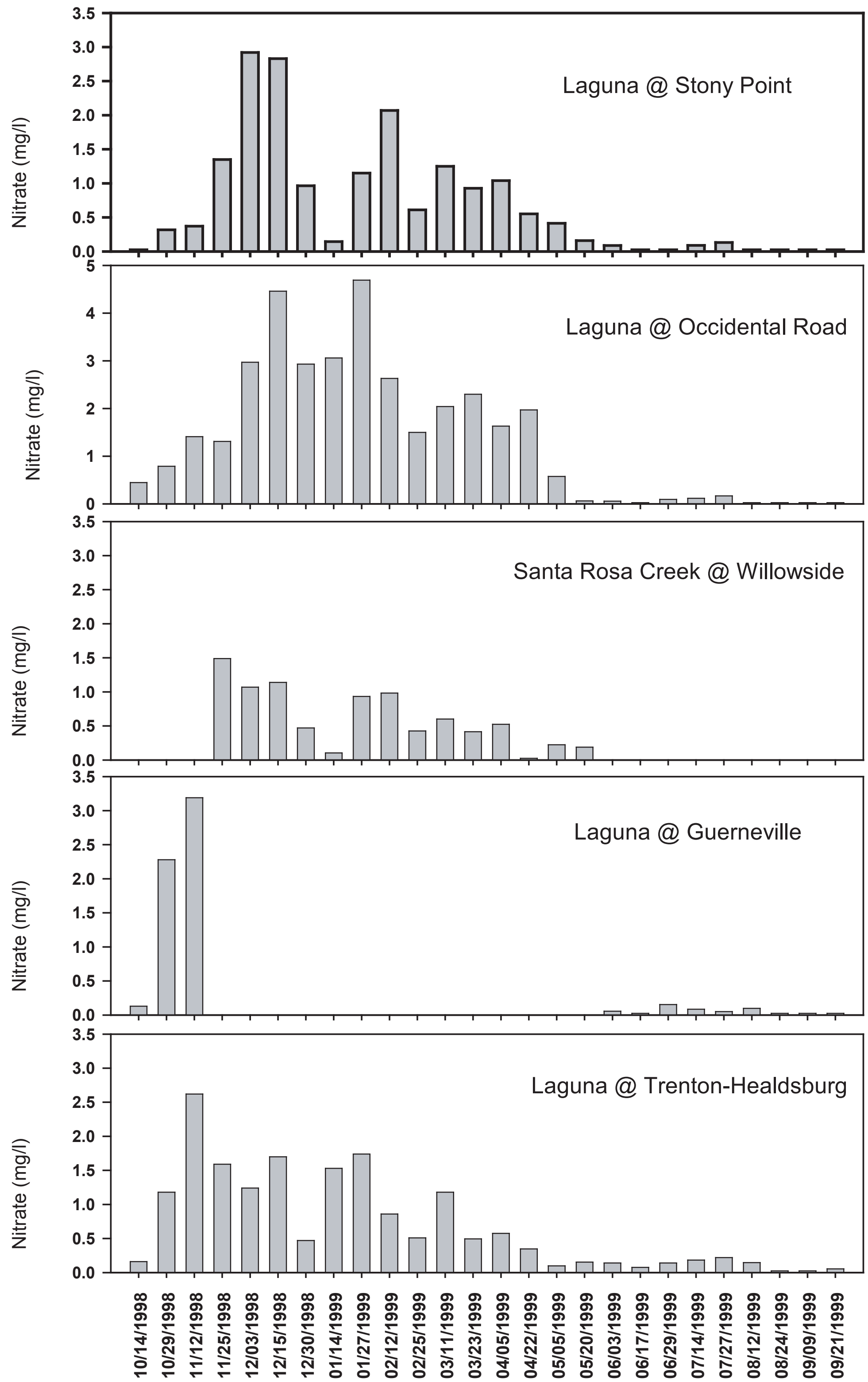

Figure 5-16 Seasonal pattern of NO_3 concentrations

Spatial pattern and temporal changes in TKN concentrations

For the period of 1989-1994, very high TKN concentrations have been observed at LTR (mean of 6.8 mg N/l) and the Laguna at Highway 12 (mean of 7.6 mg N/l; Figure 5-17). TKN measures the sum of ammonia and organic nitrogen forms. High TKN, if predominantly due to elevated NH_3, is usually an indicator of recent contamination of animal wastes, possibly from dairies. The most upstream station LSP showed lower TKN of 1.1 mg/l. Average TKN values increased downstream from the Laguna at Highway 12 to 3.0 mg/l at LOR and 2.4 mg/l upstream of Santa Rosa Creek (Figure 5-18). Observed TKN values during 1995 to 2000 were lower and were relatively uniform across the main channel of the Laguna ranging from 0.9-1.2 mg/l. Observed TKN values for the period of 2000 to 2005 are also relatively uniform across the Laguna ranging from 1.1-1.5 mg/l (Figure 5-19). Slight increases in TKN have been observed upstream and downstream of the discharge point at Roseland Creek.

Overall, large decreases in TKN have been observed in the main channel of the Laguna during 1995 to 2005, compared to the high concentrations in 1989 to 1994. This may possibly be due to the effect of the waste reduction strategy.

Generally higher total NH_3 concentrations are observed for winter months particularly in November/December for LSP, LOR, and LTH. Summer and fall generally show lower total NH_3 concentrations. Due to the lack of data, the seasonal pattern at LGR and Santa Rosa Creek is unclear. TKN concentrations show a less clear seasonal pattern as total NH_3 or NO_3. Relatively uniform TKN concentrations were observed throughout the year.

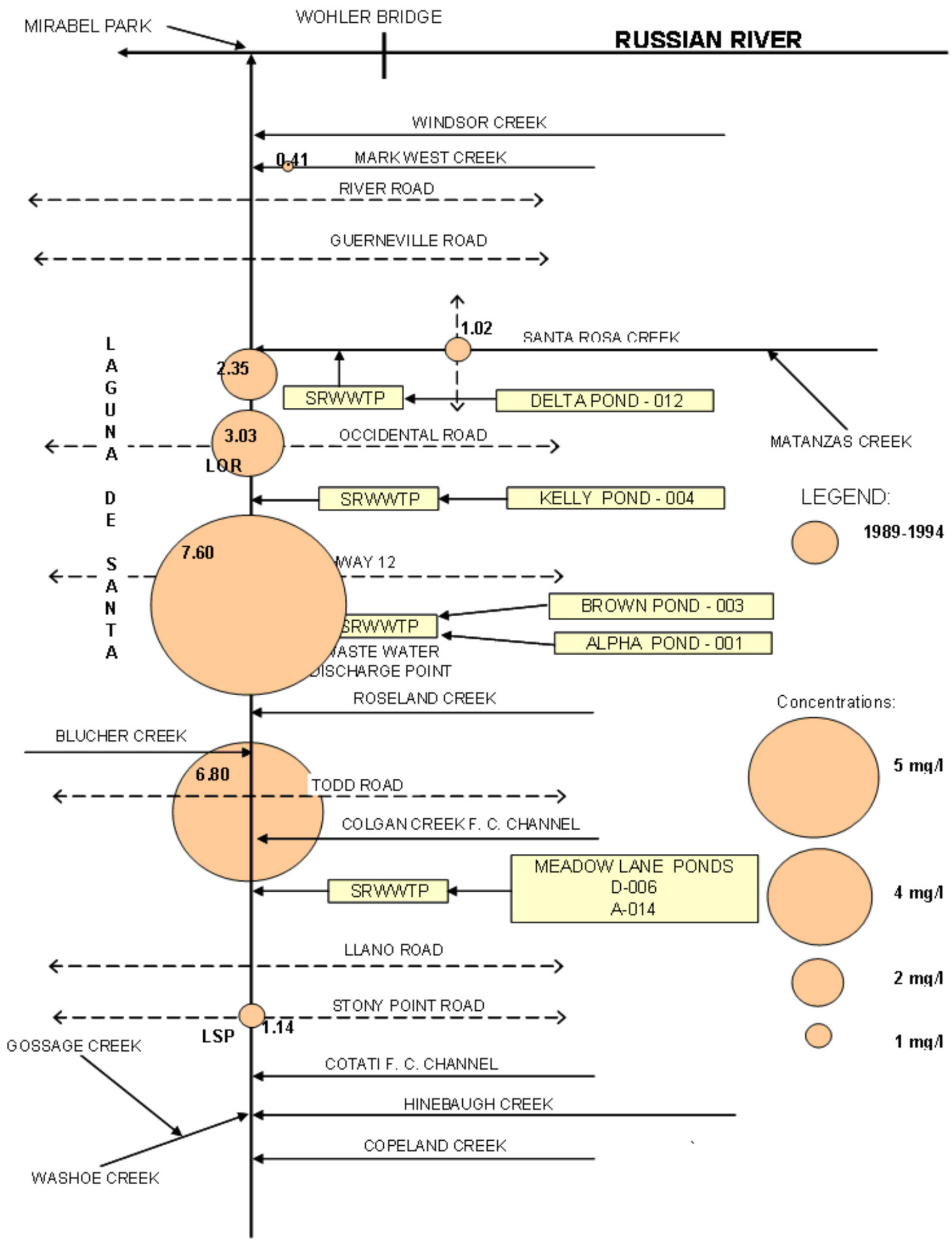

Figure 5-17 Mean TKN concentrations for 1989-1994

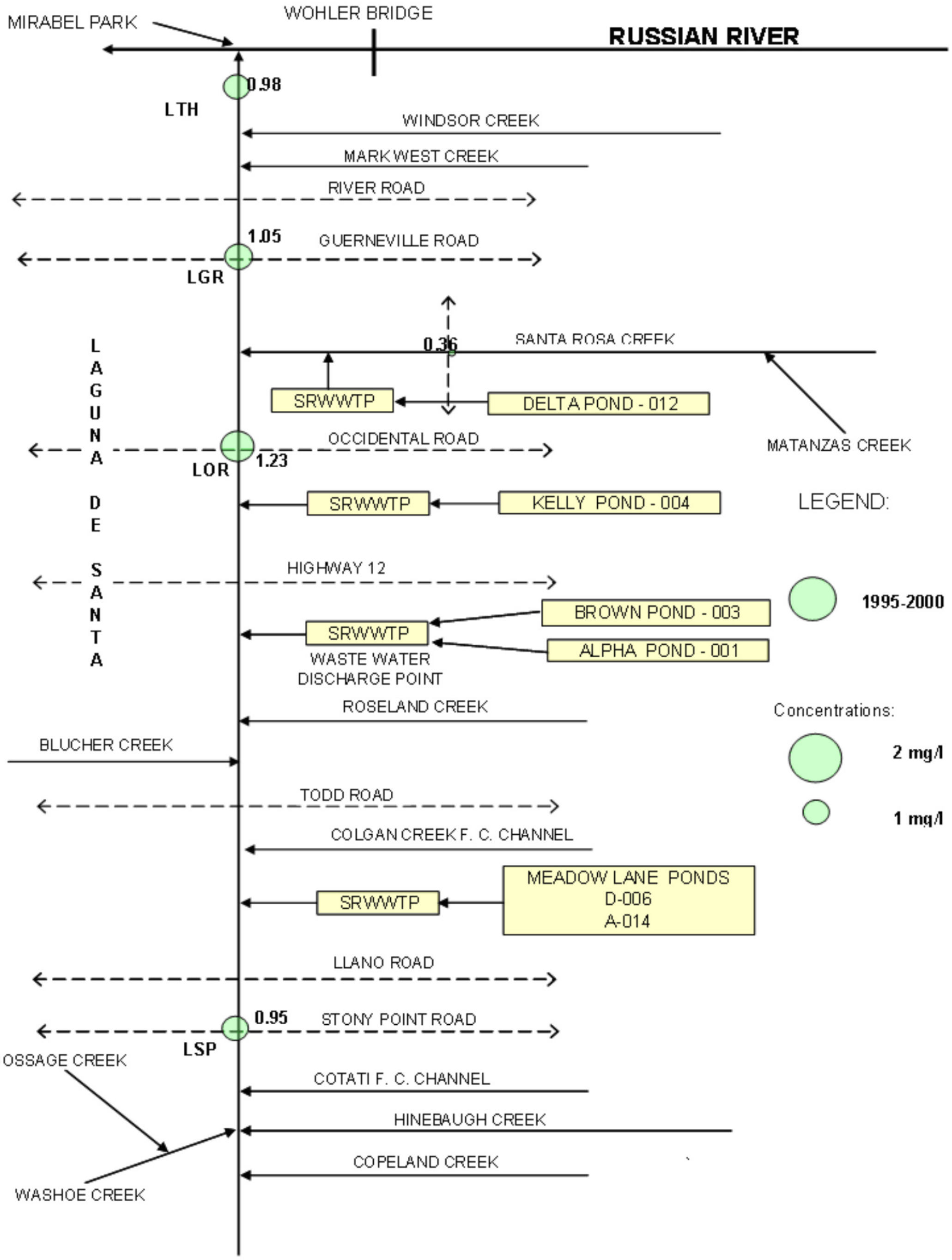

Figure 5-18 Mean TKN concentrations 1995-2000

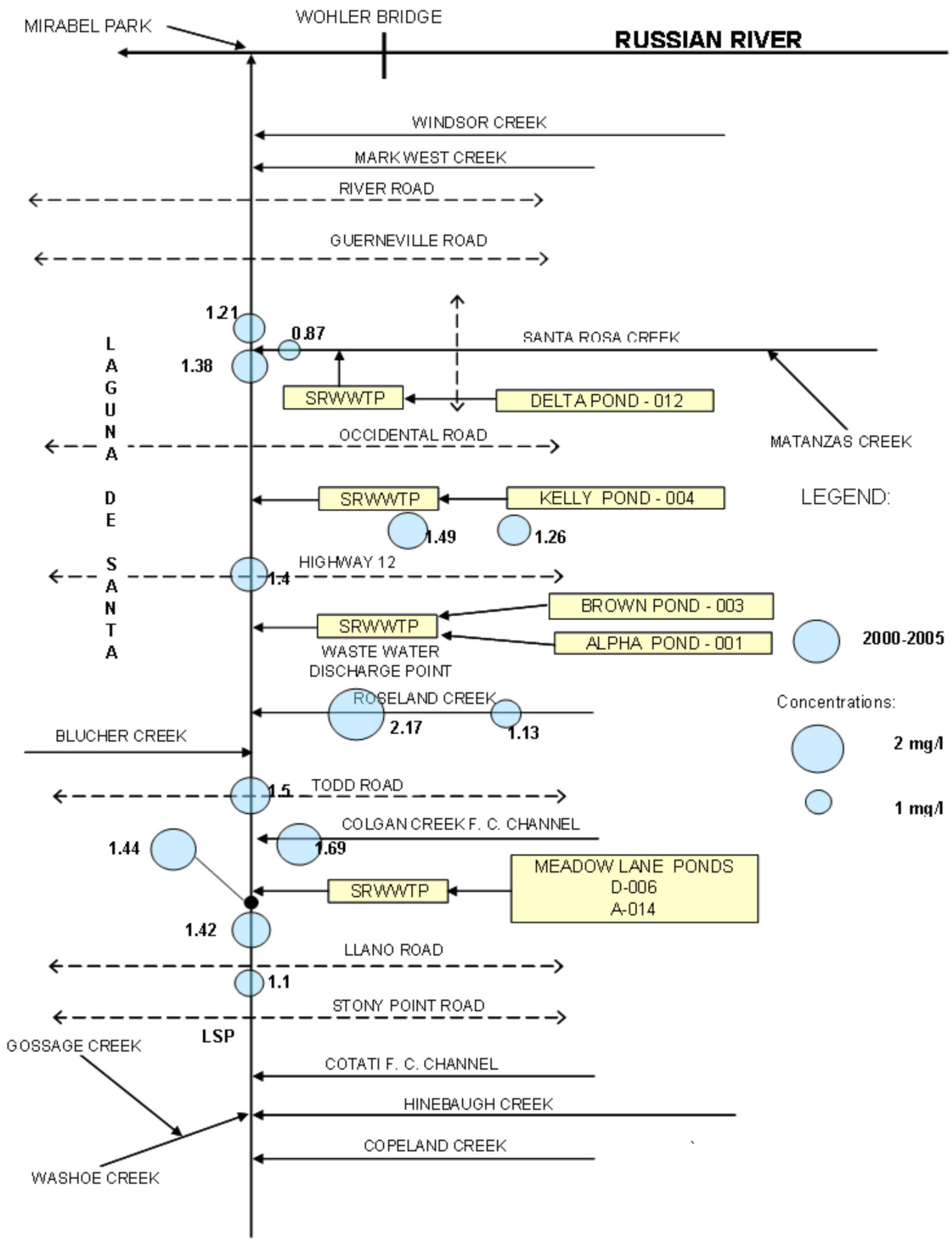

Figure 5-19 Mean TKN concentrations for 2000-2005

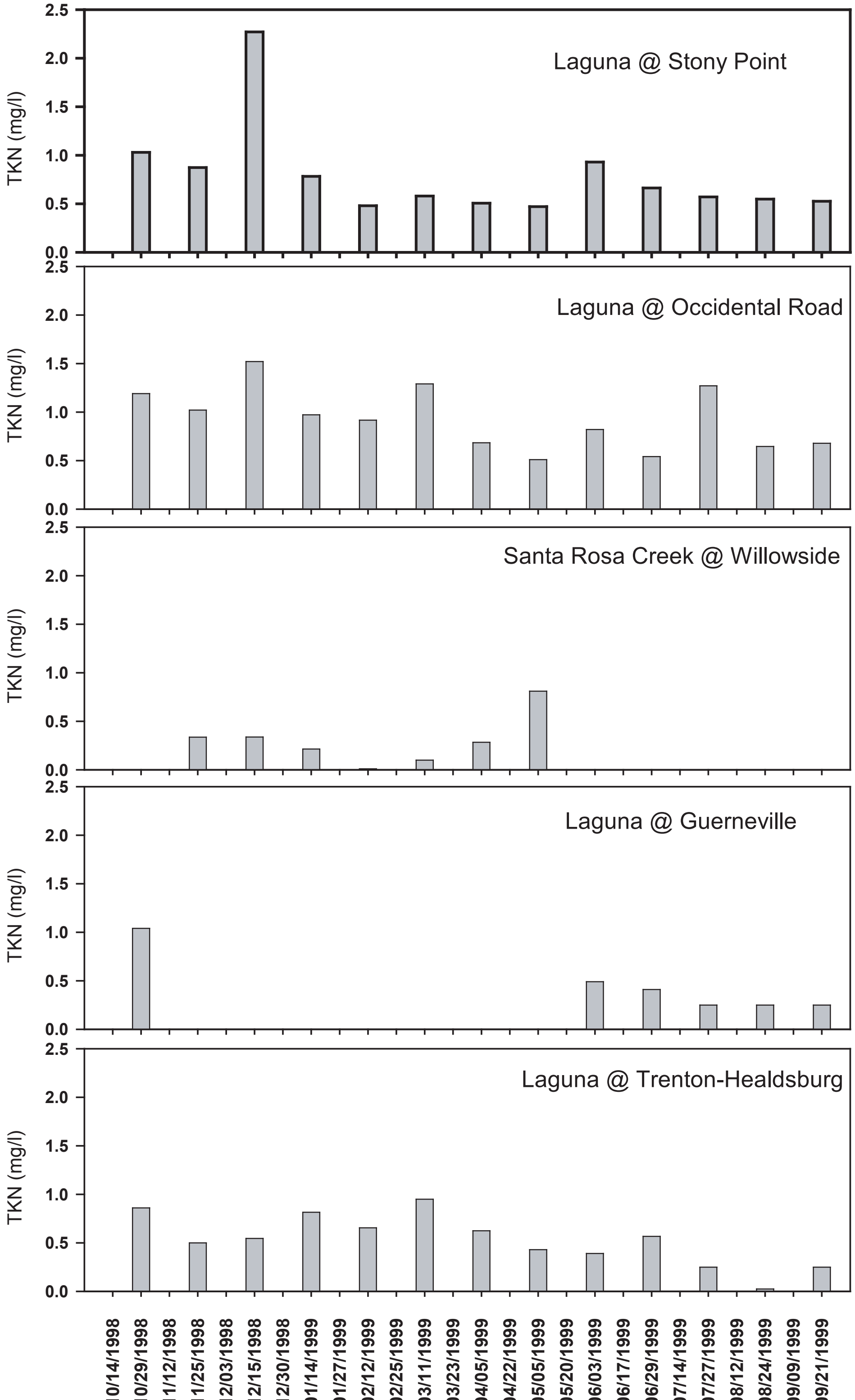

Figure 5-20 Seasonal Pattern of TKN

Spatial pattern and changes in TP concentrations

For the period of 1989 to 1994, observed mean TP concentrations ranged from 0.6 -1.8 mg P/l at the Laguna main channel (Figure 5-21). TP concentrations also show a trend of increasing from upstream (LSP) to mid-section stations (LTR and LOR) and decrease downstream. Mean TP concentrations decreased between the section of LOR and upstream of the Santa Rosa Creek confluence are likely due to a combination of factors such as precipitation due to binding to sediments (Wickham, 2000) and dilution from surrounding watershed. TP concentrations continued to decrease downstream of the Santa Rosa Creek confluence due to dilution from Santa Rosa Creek. The observed TP concentrations at Santa Rosa Creek were relatively low at 0.24 mg P/l. Large decreases in TP concentrations were observed for the period of 1995 -2000 relative to 1989 to 1994 (Figure 5-22). The monitoring period of 2000 - 2005 also shows lower TP concentrations compared to 1989 - 2004 (Figure 5-23).

TP also has relatively higher concentrations during late fall and winter months, particularly at LOR and LTH. However, relatively high TP concentrations are also observed in summer months across the Laguna including LSP (over 0.5 mg/l), LOR (around 0.4 mg/l), LGR (0.3 mg/l) and LTH (around 0.3 mg/l). The observed TP concentrations during summer indicate sources other than wastewater discharge are contributing to TP loading, possibly from internal cycling of phosphorus in the Laguna. The pattern is also affected by P uptake by algae and plants. Inorganic nitrogen is depleted in summer, but P remains at relatively high levels.

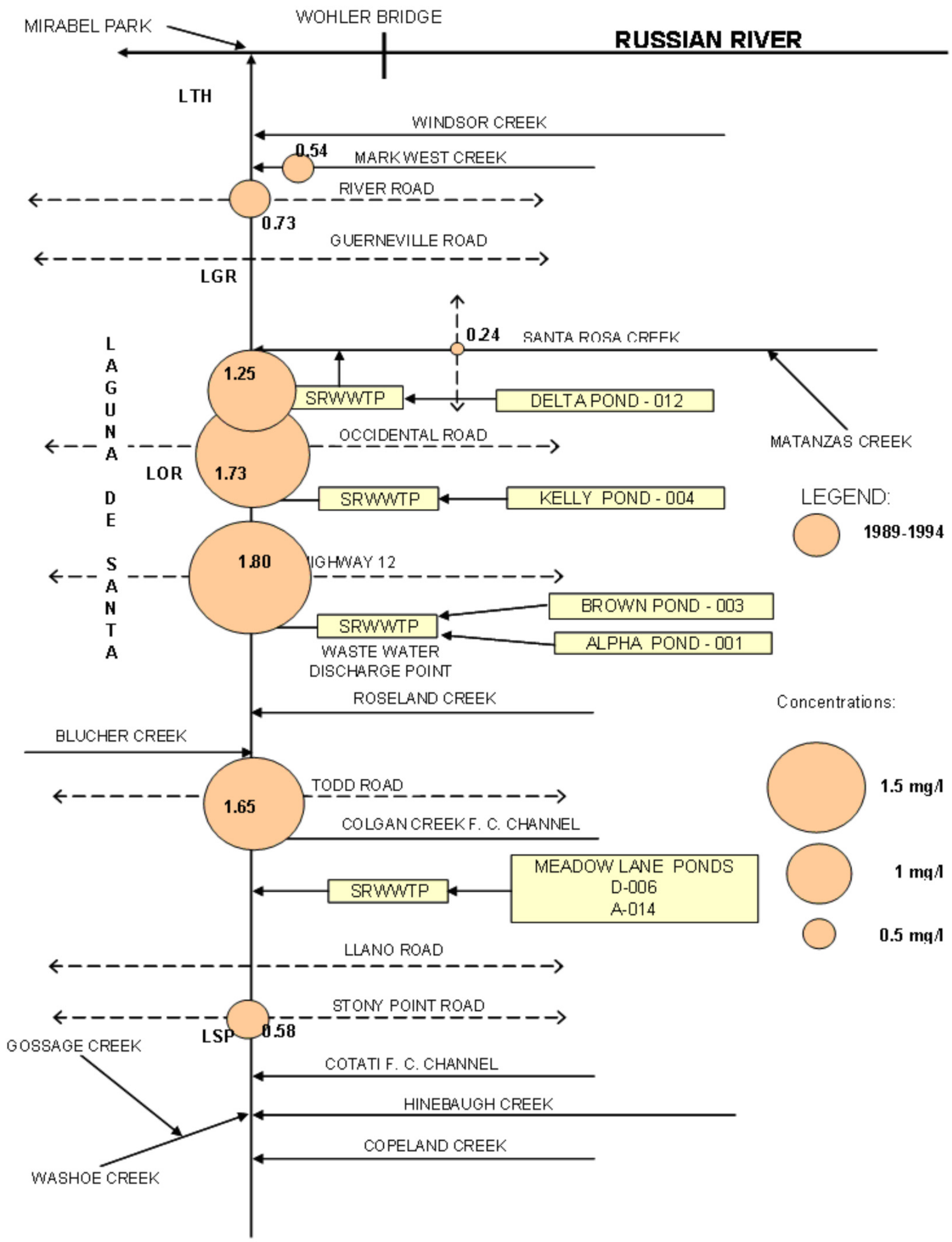

Figure 5-21 Mean TP concentrations for 1989-1994

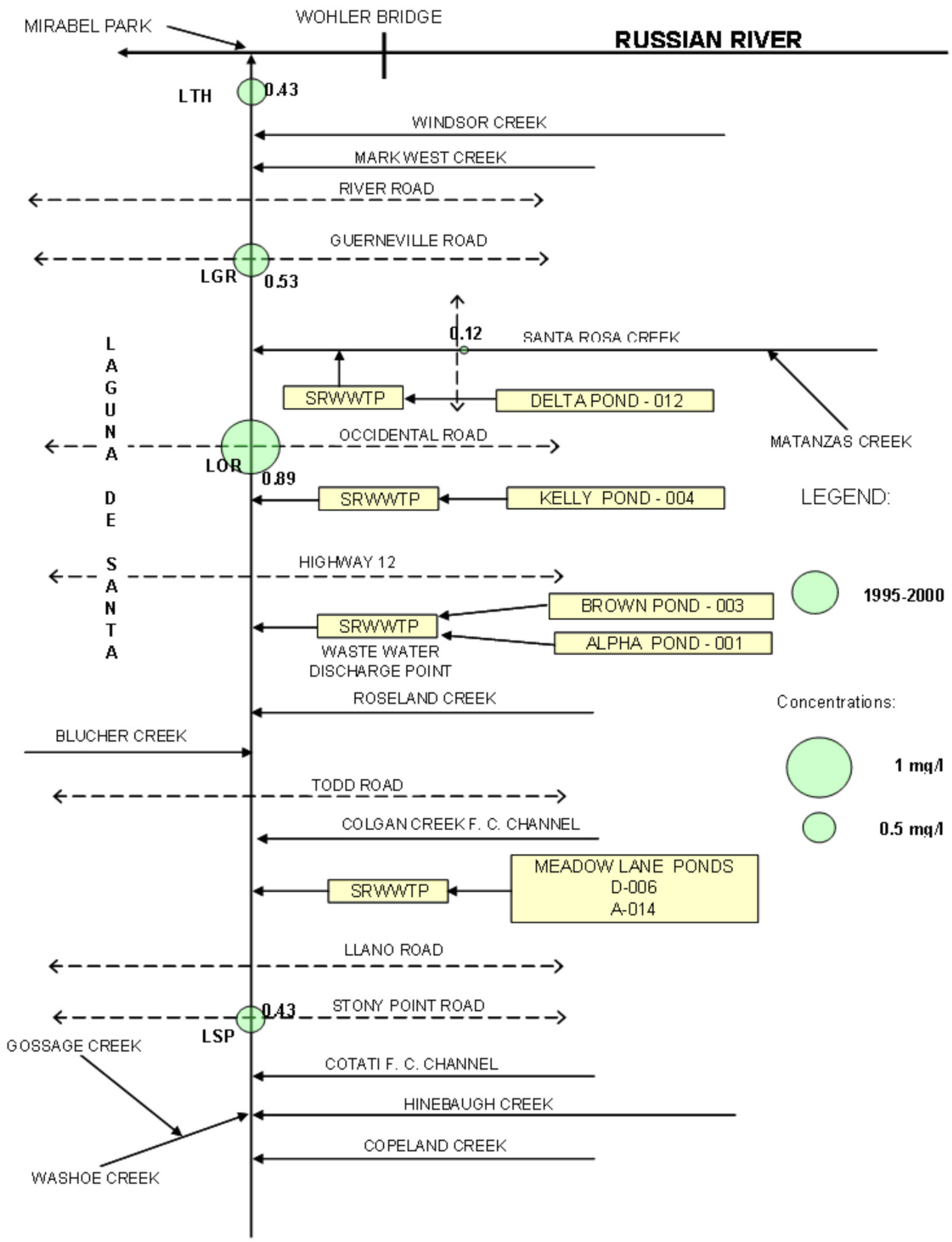

Figure 5-22 Mean TP concentrations for 1995-2000

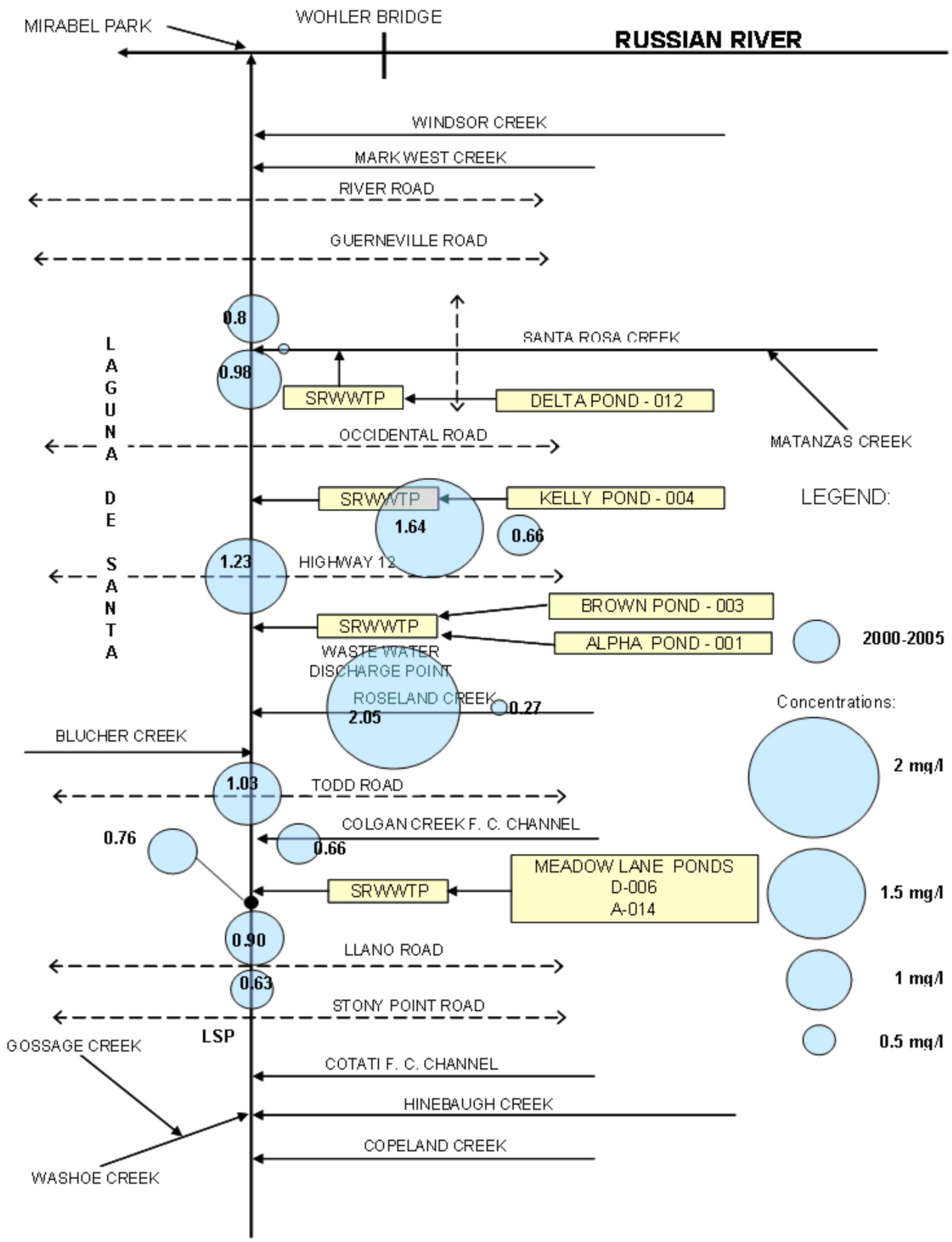

Figure 5-23 Mean TP concentrations for 2000-2005

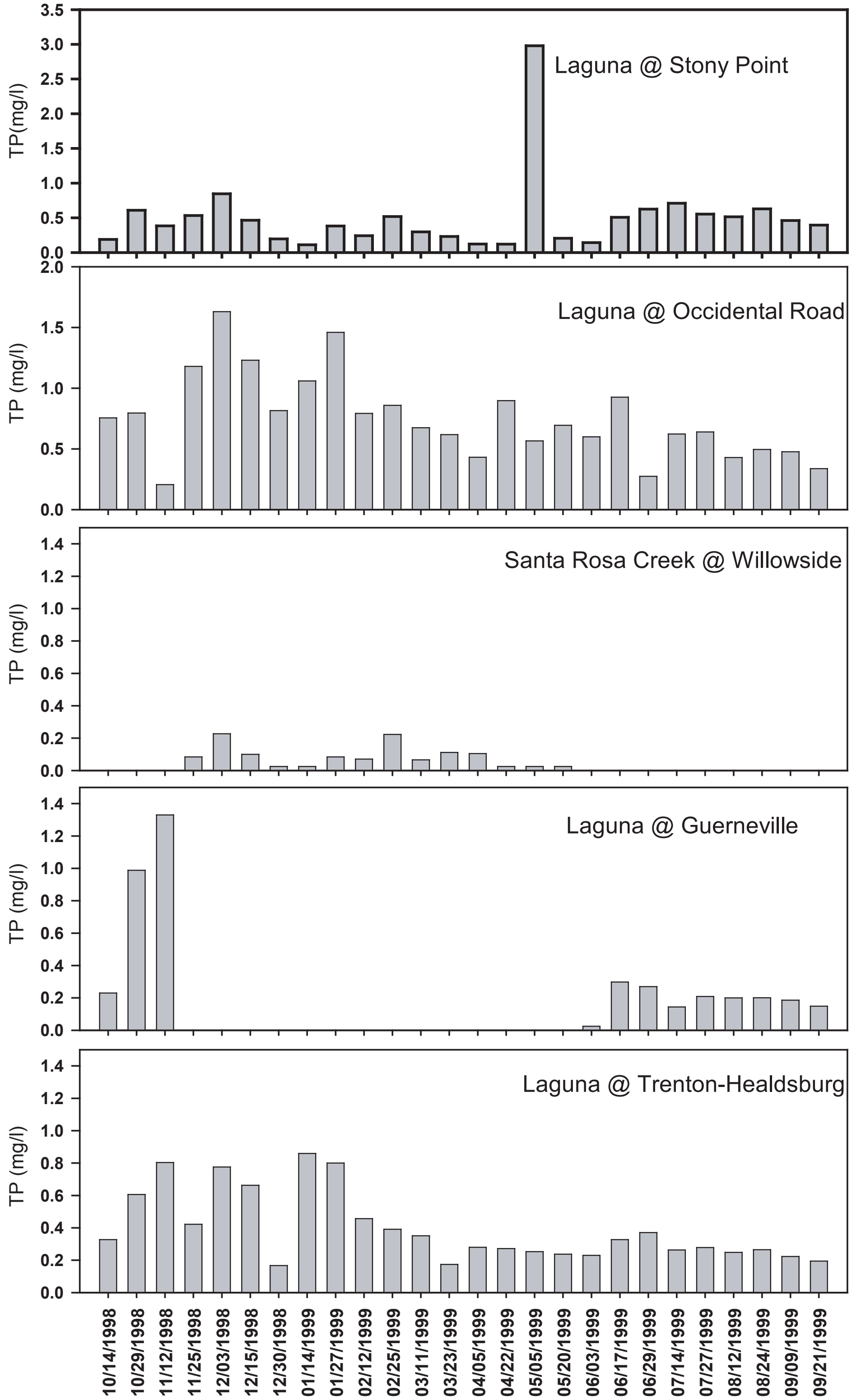

Figure 5-24 Seasonal pattern of TP

Figure 5-25 through Figure 5-36 present the range of concentrations of total NH_3, NO_3, organic N, and TP by sampling station for 1989–1994, 1995–2000, and 2000–2005.

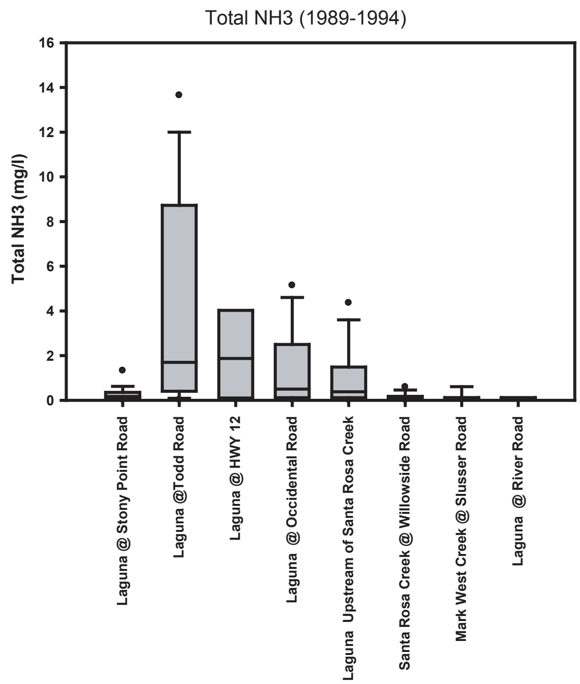

Figure 5-25 Total NH_3 concentrations for 1989-1994 by sampling locations

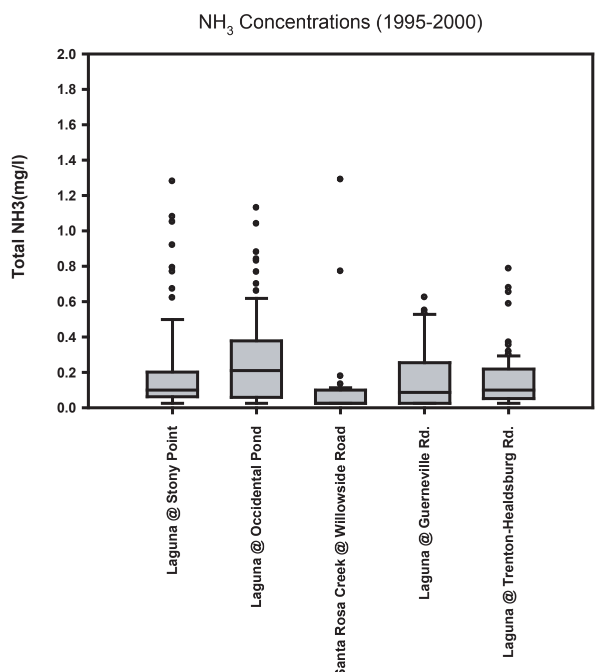

Figure 5-26 Total NH_3 concentrations for 1995-2000 by sampling locations

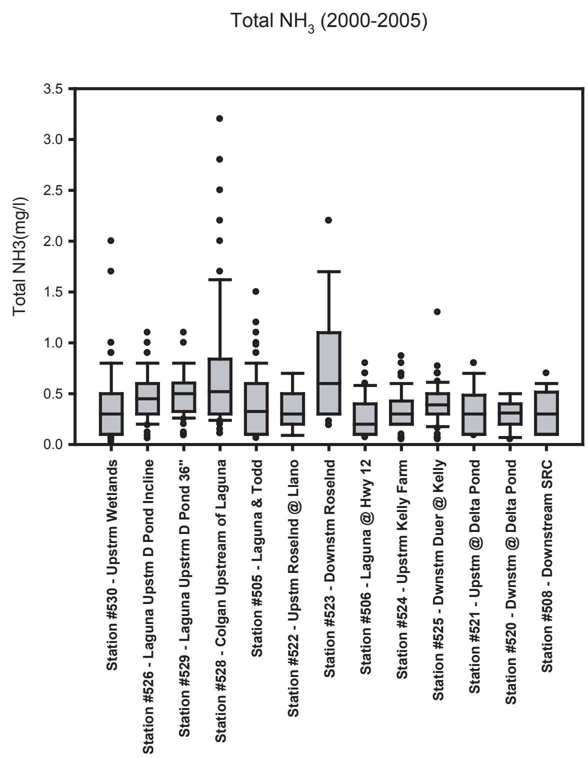

Figure 5-27 Total NH_3 concentrations for 2000-2005 by sampling locations

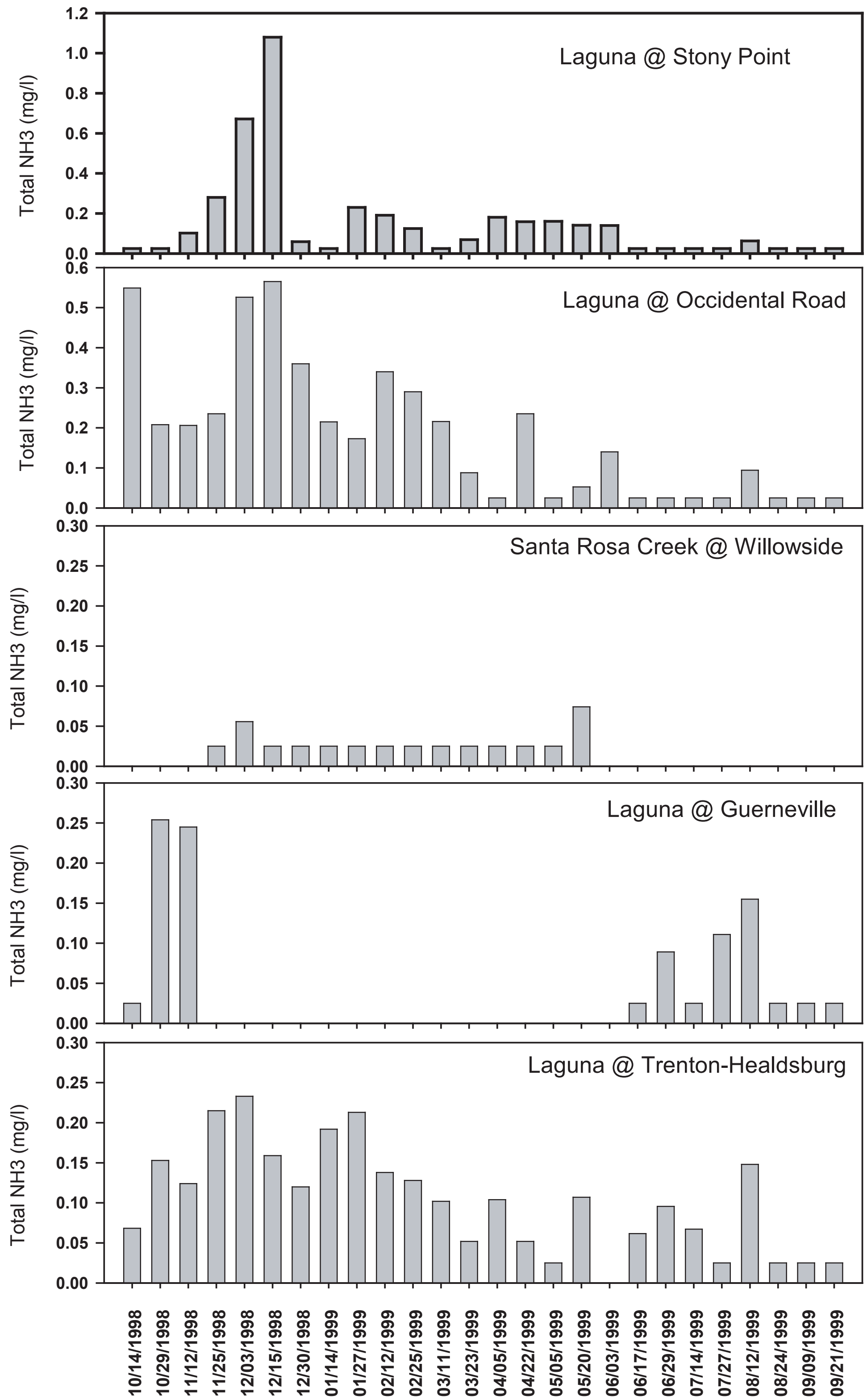

Figure 5-28 Seasonal pattern of total NH_3 concentrations

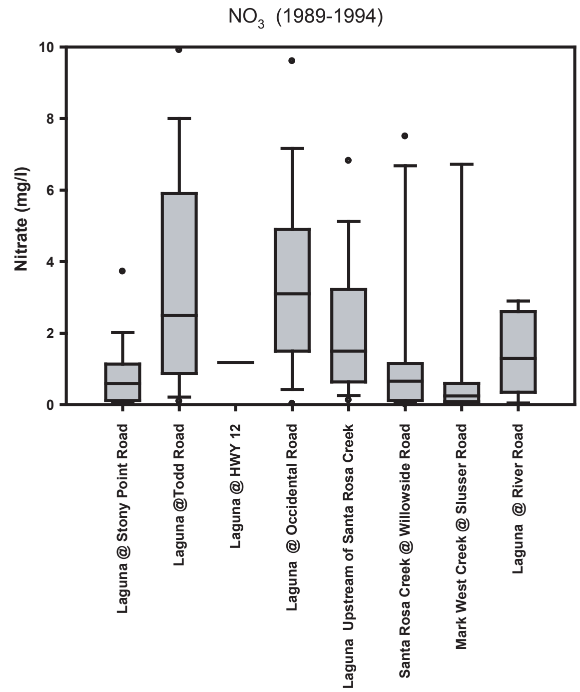

Figure 5-29 Total NO_3 concentrations for 1989-1994 by sampling locations

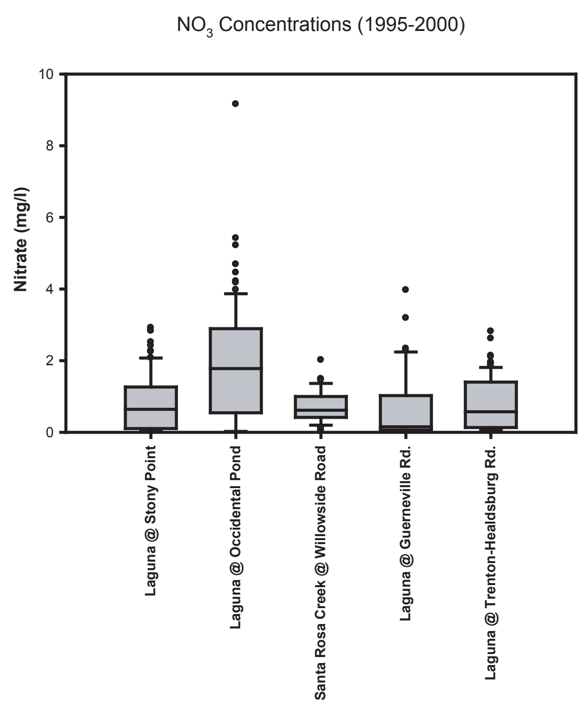

Figure 5-30 Total NO_3 concentrations for 1995-2000 by sampling locations

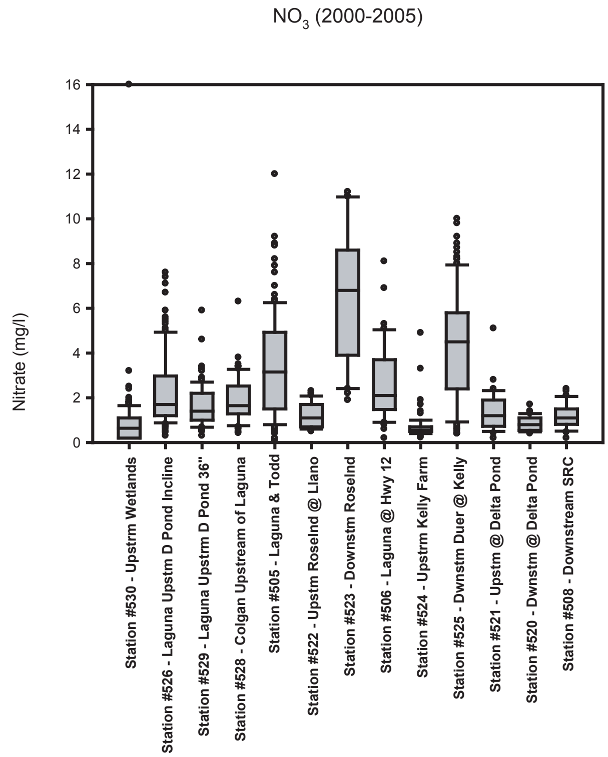

Figure 5-31 Total NO_3 concentrations for 2000-2005 by sampling locations

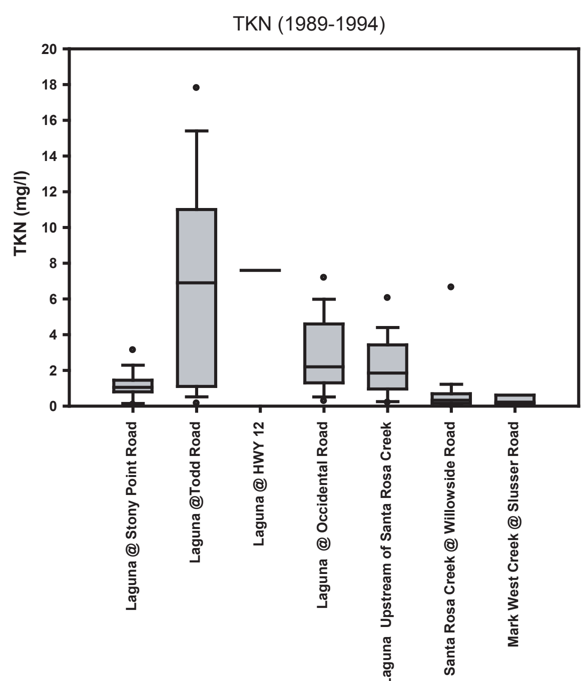

Figure 5-32 TKN concentrations for 1989-1994 by sampling locations

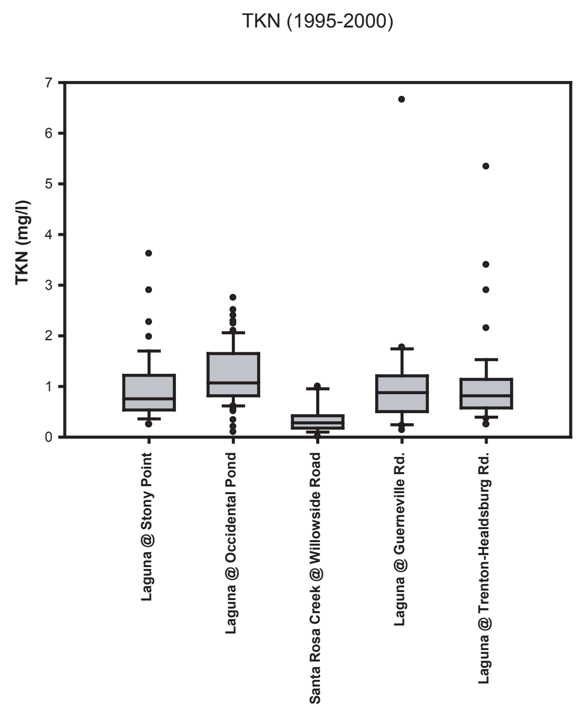

Figure 5-33 TKN concentrations for 1995-2000 by sampling locations

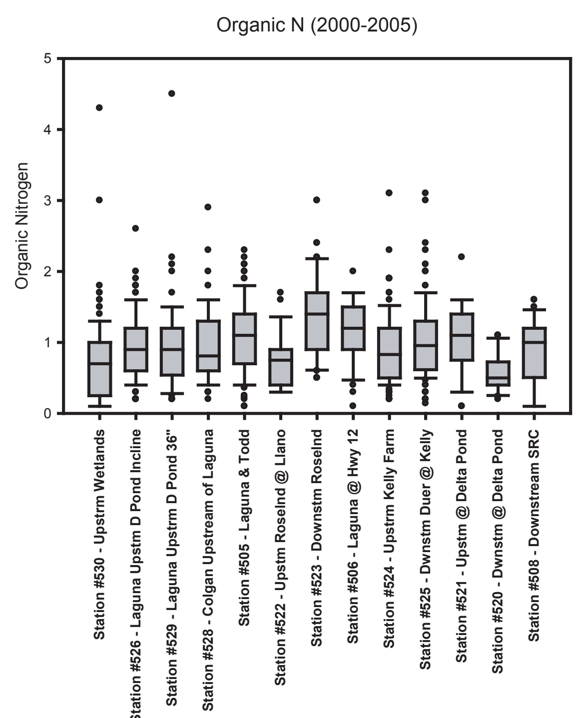

Figure 5-34 Organic nitrogen concentrations for 2000-2005 by sampling locations

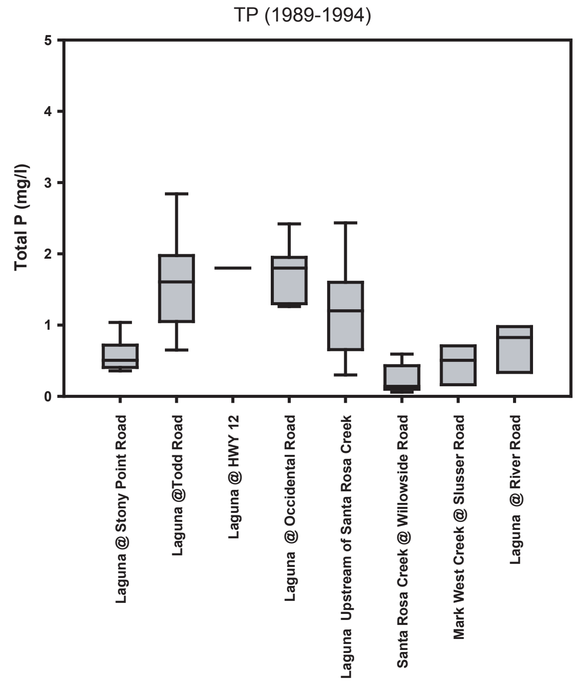

Figure 5-35 TP concentrations for 1989-1994 by sampling locations

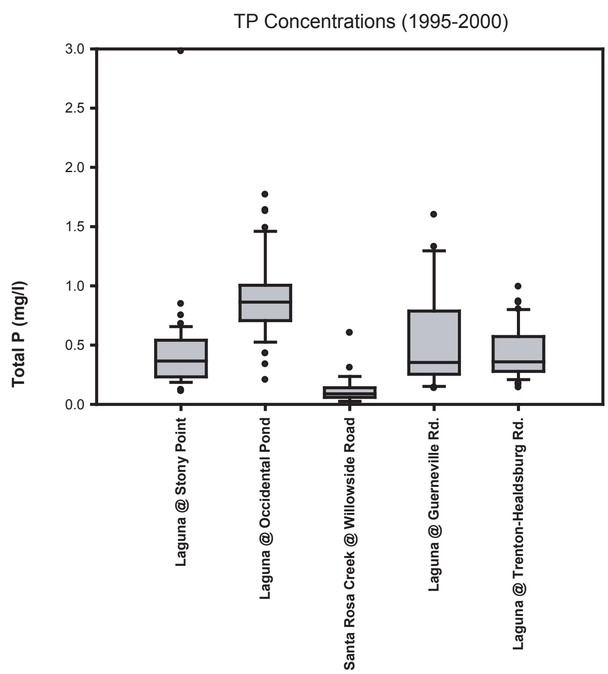

Figure 5-36 TP concentrations for 1995-2000 by sampling locations

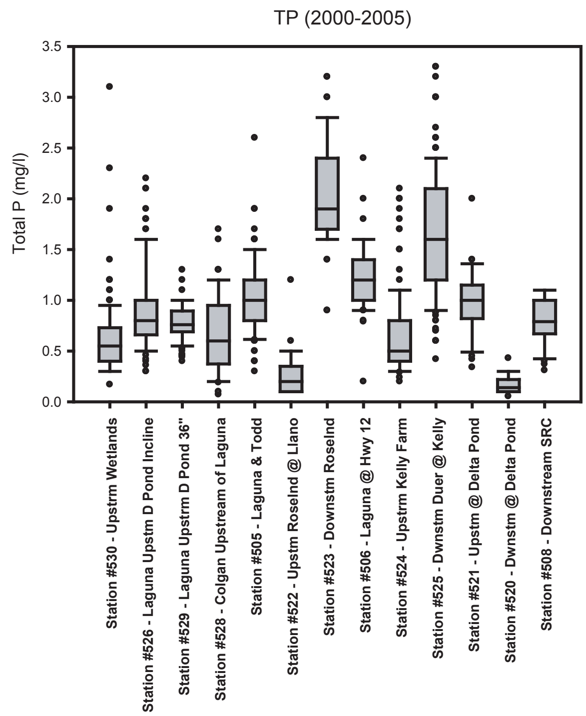

Figure 5-37 TP concentrations for 2000-2005 by sampling locations

Ranges of current nutrient concentrations

The following tables (Table 5-12 to Table 5-15) list the range of concentrations observed at different locations of the Laguna from 2004 to 2006 (after the Geyser Disposal Project).

Table 5-12 Range of concentrations for total ammonia (mg/l)

Total ammonia	Median	Mean	Min	Max	Count
Station #530 Laguna Upstream Wetlands	0.6	0.55	0.1	1	11
Station #504 Laguna & Llano	0.75	0.75	0.7	0.8	2
Station #529 Laguna Upstream D Pond	0.59	0.53	0.26	0.8	23
Station #526 Laguna Upstream D Pond	0.6	0.60	0.25	1	15
Station #527 Laguna Downstream D Pond	0.55	0.55	0.5	0.6	3
Station #528 Colgan Upstream	0.48	0.59	0.22	2.8	23
Station #505 Laguna & Todd	0.5	0.49	0.1	1.5	24

Station #506 Laguna @ Hwy 12	0.38	0.38	0.38	0.38	1
Station #524 Upstream Kelly	0.37	0.37	0.2	0.6	26
Station #525 Downstream Duer	0.4	0.42	0.3	0.6	26
Station #521 Laguna Upstream @ Delta	0.25	0.28	0.1	0.5	13
Station #508 Laguna Downstream SR Ck.	0.3	0.28	0.1	0.6	13
Station #520 SR Ck. Downstream @Delta	0.32	0.31	0.2	0.4	12
Station #515 SR CK. Upstream	0	0.00	0	0	1

Table 5-13 Range of concentrations for nitrate (mg/l)

Nitrate	Median	Mean	Min	Max	Count
Station #530 Laguna Upstream Wetlands	1.10	1.13	0.41	1.80	11
Station #504 Laguna & Llano	1.65	1.65	1.60	1.70	2
Station #529 Laguna Upstream D Pond	1.30	1.55	0.50	4.60	23
Station #526 Laguna Upstream D Pond	1.50	1.66	0.45	3.80	15
Station #527 Laguna Downstream D Pond	3.20	2.67	1.50	3.30	3
Station #528 Colgan Upstream	2.20	2.10	0.42	3.40	23
Station #505 Laguna & Todd	2.85	2.96	0.40	5.70	24
Station #506 Laguna @ Hwy 12	0.89	0.89	0.89	0.89	1
Station #524 Upstream Kelly	0.50	0.52	0.22	0.90	26
Station #525 Downstream Duer	2.50	3.38	0.59	6.70	26
Station #521 Laguna Upstream @ Delta	0.69	0.87	0.20	2.80	13
Station #508 Laguna Downstream SR Ck.	0.71	0.75	0.20	1.20	13
Station #520 SR Ck. Downstream @Delta	0.58	0.64	0.46	1.10	12
Station #515 SR CK. Upstream	1.00	1.00	1.00	1.00	1

Table 5-14
Range of concentrations for organic nitrogen (mg/l)

Organic N	Median	Mean	Min	Max	Count
Station #530 Laguna Upstream Wetlands	0.70	0.69	0.10	1.80	11
Station #504 Laguna & Llano	2.00	2.00	0.10	3.90	2
Station #529 Laguna Upstream D Pond	0.69	0.81	0.20	2.20	23
Station #526 Laguna Upstream D Pond	1.00	1.04	0.20	1.80	15
Station #527 Laguna Downstream D Pond	0.60	0.60	0.40	0.80	3
Station #528 Colgan Upstream	0.80	0.90	0.40	1.60	23
Station #505 Laguna & Todd	1.00	0.96	0.10	2.10	24
Station #506 Laguna @ Hwy 12	1.00	1.00	1.00	1.00	1
Station #524 Upstream Kelly	0.53	0.73	0.30	1.90	26
Station #525 Downstream Duer	0.84	0.86	0.20	1.70	26
Station #521 Laguna Upstream @ Delta	0.90	0.84	0.10	1.60	13
Station #508 Laguna Downstream SR Ck.	0.51	0.65	0.10	1.50	13
Station #520 SR Ck. Downstream @Delta	0.50	0.55	0.24	1.10	12
Station #515 SR CK. Upstream	0.60	0.60	0.60	0.60	1

Table 5-15 Range of concentrations for total phosphorus (mg/l)

Total P	Median	Mean	Min	Max	Count
Station #530 Laguna Upstream Wetlands	0.60	0.59	0.39	0.80	11
Station #504 Laguna & Llano	0.69	0.69	0.62	0.75	2
Station #529 Laguna Upstream D Pond	0.60	0.63	0.44	0.90	23
Station #526 Laguna Upstream D Pond	0.65	0.65	0.36	0.85	15
Station #527 Laguna Downstream D Pond	0.70	0.70	0.54	0.85	3
Station #528 Colgan Upstream	0.57	0.60	0.20	1.10	23
Station #505 Laguna & Todd	0.98	0.96	0.61	1.40	24

Station #506 Laguna @ Hwy 12	0.79	0.79	0.79	0.79	1
Station #524 Upstream Kelly	0.55	0.61	0.36	1.30	26
Station #525 Downstream Duer	1.15	1.22	0.42	1.90	26
Station #521 Laguna Upstream @ Delta	0.81	0.80	0.34	2.00	13
Station #508 Laguna Downstream SR Ck.	0.68	0.65	0.31	0.94	13
Station #520 SR Ck. Downstream @Delta	0.12	0.17	0.05	0.43	12
Station #515 SR CK. Upstream	0.11	0.11	0.11	0.11	1

5.2.3 Current status and factors influencing the DO dynamics

The following section describes the data analysis of existing DO data for the Laguna de Santa Rosa. The analysis explores the spatial and temporal patterns of DO impairment at different scales (inter-annual, seasonal and diurnal, temporally, and by reach and water column scale, spatially). One of the main objectives of the analysis is to better understand when and where DO impairment occurs and to form the basis for inferring and identifying processes and factors that contribute to the DO impairment. The analysis also provides an update of current status with respect to DO in the Laguna. In the analysis we review previous studies of nutrient and dissolved oxygen dynamics in the Laguna by Otis (2006) to provide a synthesis of the current understanding of the DO dynamics in the Laguna.

Available data for analysis

The available data for analysis includes: 1) short-interval DO data collected by the City of Santa Rosa for the period of 1998 to 2006; 2) short-interval DO data collected by *Ludwigia* Abatement Project team during the summers of 2005 and 2006; 3) grab samples collected by NCRWQCB for the period of 1995 to 2000; and 4) DO profile collected by NCRWQCB during the summers of 1997, 1998 and 1999.

- *Short-interval DO data collected by the City of Santa Rosa:* These are continuous DO data collected by the City of Santa Rosa using data sondes at 15 minute intervals, upstream and downstream of the city's wastewater discharging locations for the period of 1998 to the present. Generally there are two weeks of data each month during the discharging period (October 1 to May 14). Main sampling locations are upstream and downstream of the discharging points of 06A (Meadow Lane Pond D incline pump), 06B (Meadow Lane Pond D 36" discharge), 12A (Delta Pond 24" pipeline) and 12B (Delta Pond 48" pipeline). Figure 5-38 schematically illustrates the approximate sampling locations with the number of data points for the years 2005 and 2006.
- *Short-interval DO data collected by Ludwigia Abatement Project team:* In the summer of 2005 and 2006, continuous DO data at 30 and 15 minute intervals were collected

using data sondes at three locations (SCWA WQ4/5, CDFG WQ1, CDFG WQ3) within two *Ludwigia* control areas of the Laguna (Sonoma County Water Agency Site and Department of Fish and Game Site) by *Ludwigia* Abatement Project team. The measurements were taken generally five to tweleve inches below water surface. It was noted during sampling that DO probes are subject to hydrogen sulfide fouls and resulted in some erratic readings, particularly at CDFG WQ3. CDFG WQ3 is located in an area with 80 percent *Ludwigia* cover and a shallow water depth of 2.5 feet, where sediment probably poses a big effect on water quality in the water column (Sonoma County Water Agency and Laguna de Santa Rosa Foundation, 2006). The anaerobic sediment frequently fouled the probes. The false readings due to DO probe fouling were therefore excluded from the analysis. Approximate sampling locations are shown in Figure 5-38 with total number of valid samples collected for the summers of 2005 and 2006.

- *Grab samples collected by NCRWQCB:* These are TMDL monitoring data collected by NCRWQCB at five stations (LSP-Laguna at Stony Point, LOR-Laguna at Occidental Road, LGR-Laguna at Guerneville Road, LTH-Laguna at Trenton-Healdsburg Road, and SRCWS-Santa Rosa Creek at Willowside Road) for the period of 1995 to 2000. The data are bi-weekly grab samples, with most of the samples taken before noon. The Waste Reduction Strategy (WRS) was implemented during this period to reduce nitrogen loads in the watershed and to meet EPA's criterion for unionized ammonia by phases (60% by July 1996, 70% by July 1998, and 80% by July 2000). Therefore the data from the most recent years will be closer to current conditions. For this reason we used the data from the most recent years of 1998 to 2000.
- *DO profile collected by NCRWQCB:* These are data from the water column study at several locations in the Laguna (LOR1, LOR2, LOR3, SEB1, SEB2, SEB3 (SEB-Laguna @ Sebastopol), including profiles of DO, temperature, specific conductivity and pH, conducted by Peter Otis of RWQCB for the summers of 1997, 1998, and 1999.

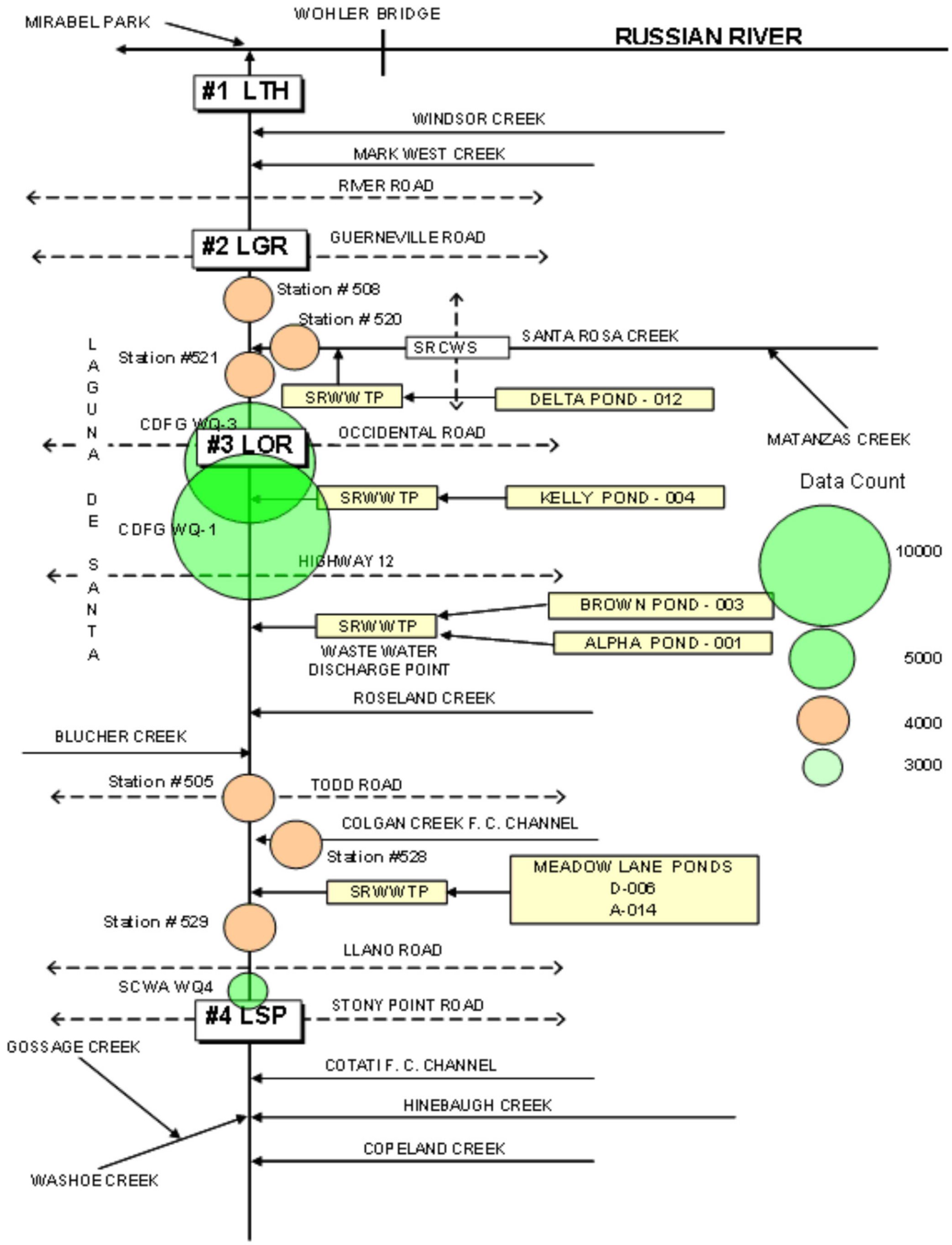

Figure 5-38 Locations and total number of data collected for dissolved oxygen.
Short-interval (15 or 30 minutes) DO monitoring
Orange: City of Santa Rosa (spring/winter 2005 and 2006)
Green: *Ludwigia* Control Project team (summer 2005 and 2006)

Spatial and temporal patterns of dissolved oxygen

Temporal pattern–inter-annual

Figure 5-39 through Figure 5-44 show the range of DO concentrations at different monitoring locations collected by City of Santa Rosa during discharging months (winter/spring) for 1998-2006, compared to the Basin Plan objective (minimum 7 mg/l at all times). The general observations for these data are for the monitoring period, there is no clear trend of increase in DO concentrations, even the nutrient concentrations have shown large decreases. Some stations (e.g., Station #529 upstream of discharge point and Station #505 Laguna Todd Road) even show a trend of decreasing DO below basin plan objectives. It is not clear what is causing this downward trend. A likely cause may be due to the infestation of *Ludwigia* which can consume oxygen when decaying. Further analysis is needed to identify factors that are driving the observed trend. The collected data also indicated large month-to-month variation.

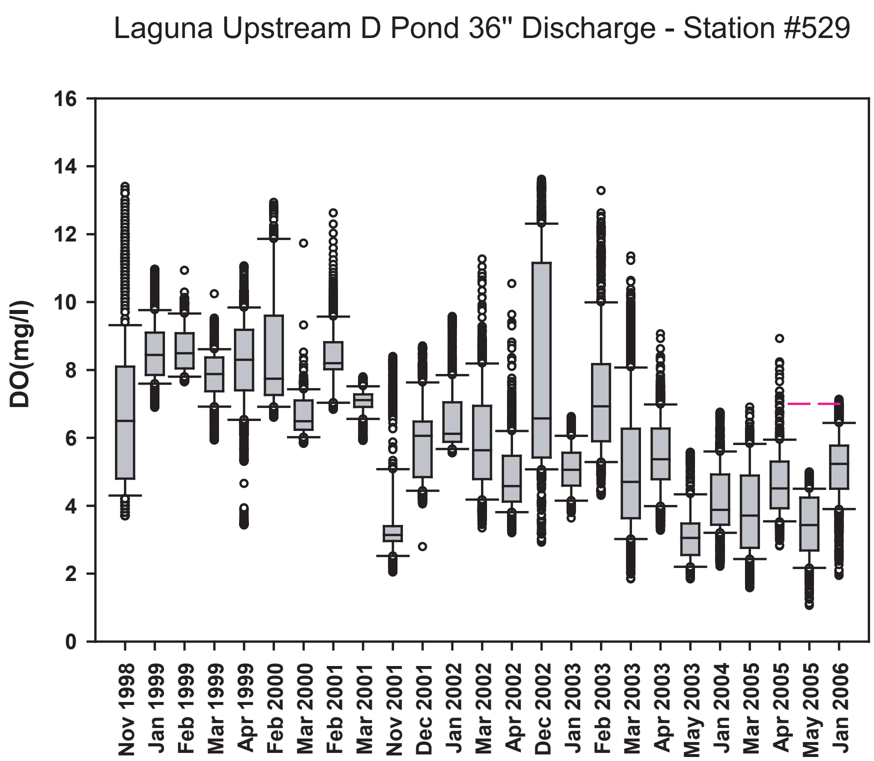

Figure 5-39 Range of DO concentrations by sampling months at Laguna upstream of D Pond 36” discharge

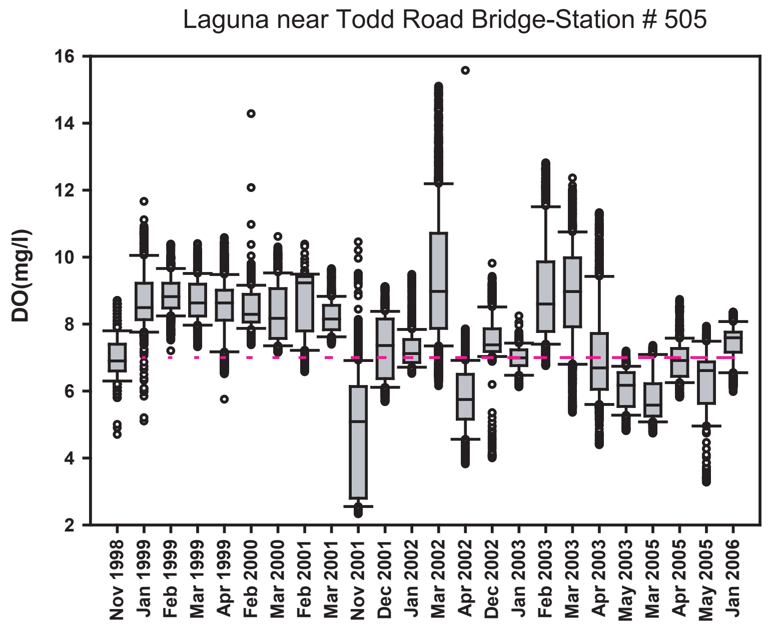

Figure 5-40 Range of DO concentrations at Laguna near Todd Road bridge

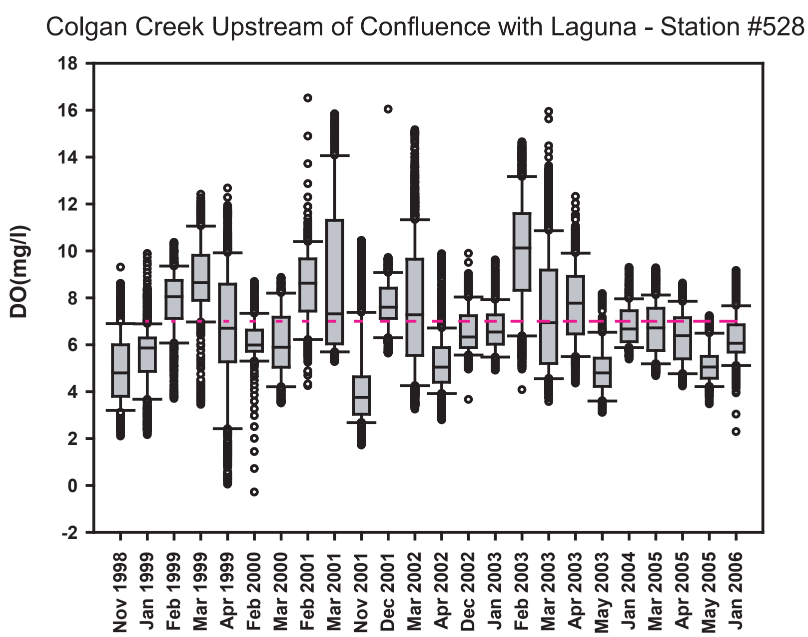

Figure 5-41 DO at Colgan Creek upstream of confluence with Laguna

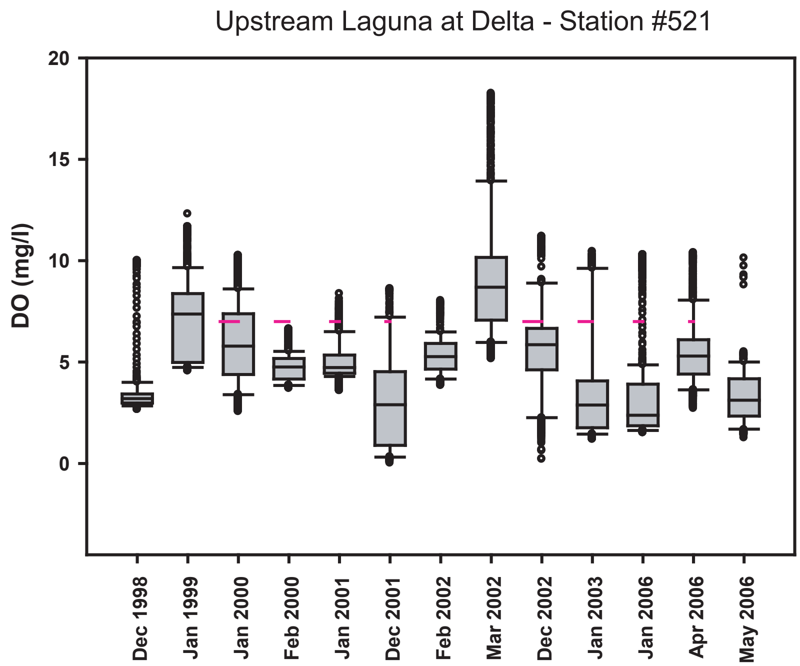

Figure 5-42 DO at Laguna upstream of Delta Pond

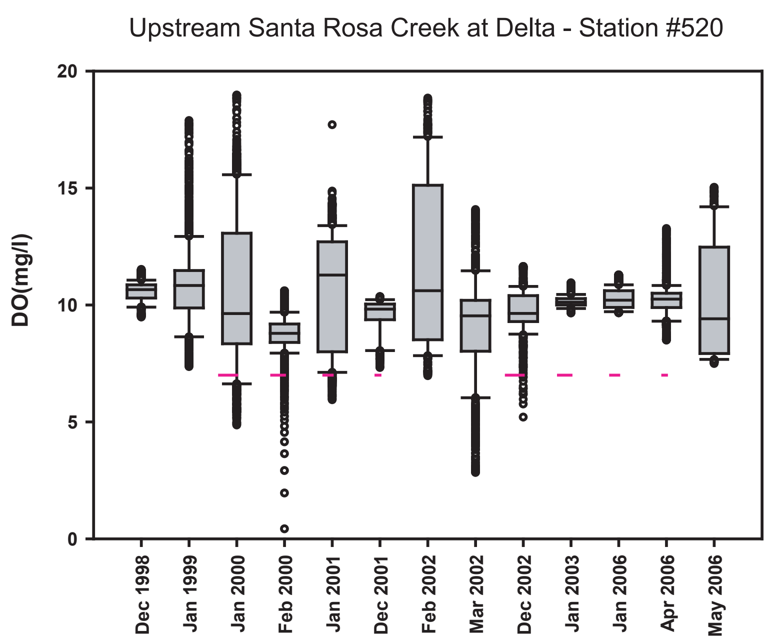

Figure 5-43 DO at Laguna near Santa Rosa Creek

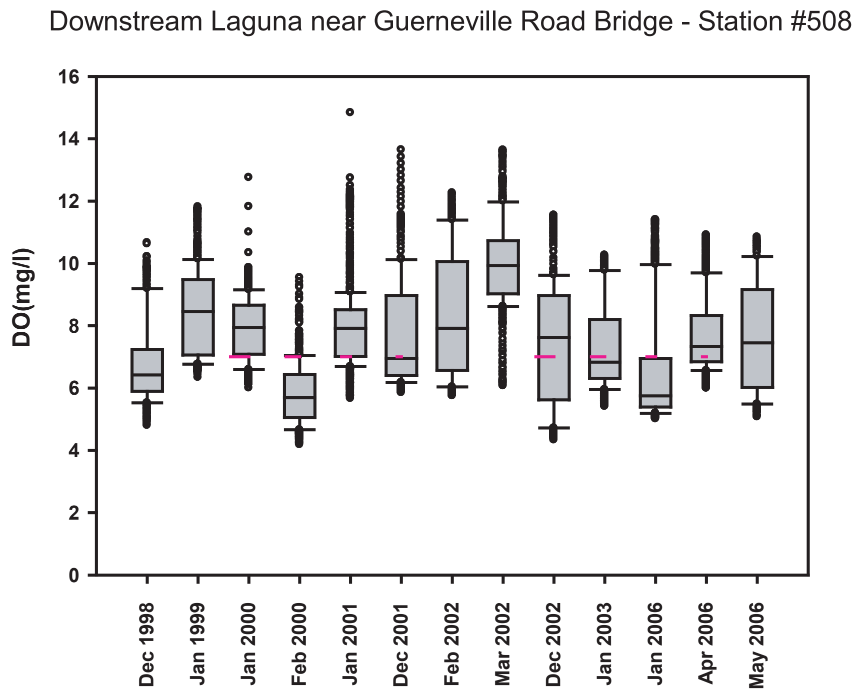

Figure 5-44 DO at Laguna near Guerneville Road

While the data presented above were based on monitoring during winter/spring months, Figure 5-45 through 5-47 show the range of DO concentrations at the three sampling locations in the *Ludwigia* control areas for the summers of 2005 and 2006. CDFG WQ-1, which is upstream of the *Ludwigia* control area, generally has moderate DO. For summer 2005, 75th percentiles of DO in both July and August were below 7 mg/l. Median DO concentrations appear to be higher in 2006. The minimum DO in summer 2006 also seem slightly higher than 2005, although two years of data are probably not sufficient for inferring any inter-annual temporal trend.

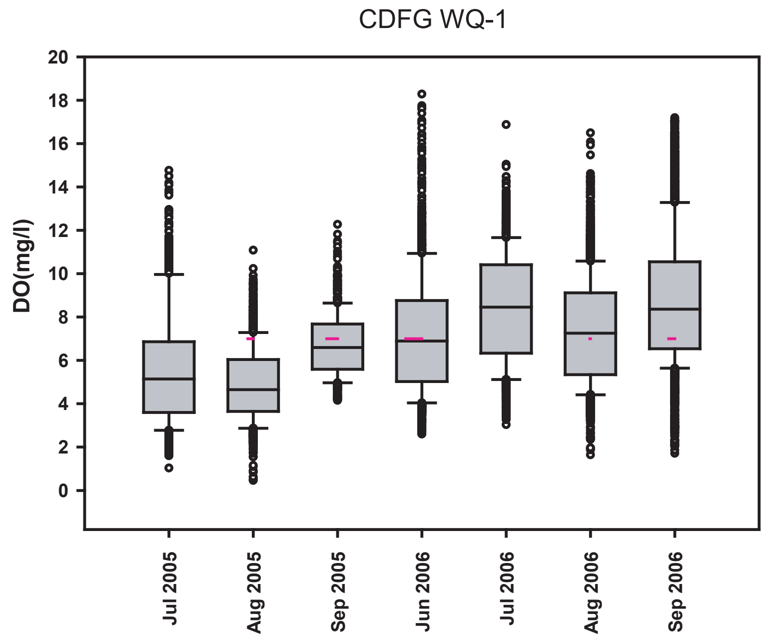

Figure 5-45 DO at CDFG WQ-1 during summer 2005 and 2006

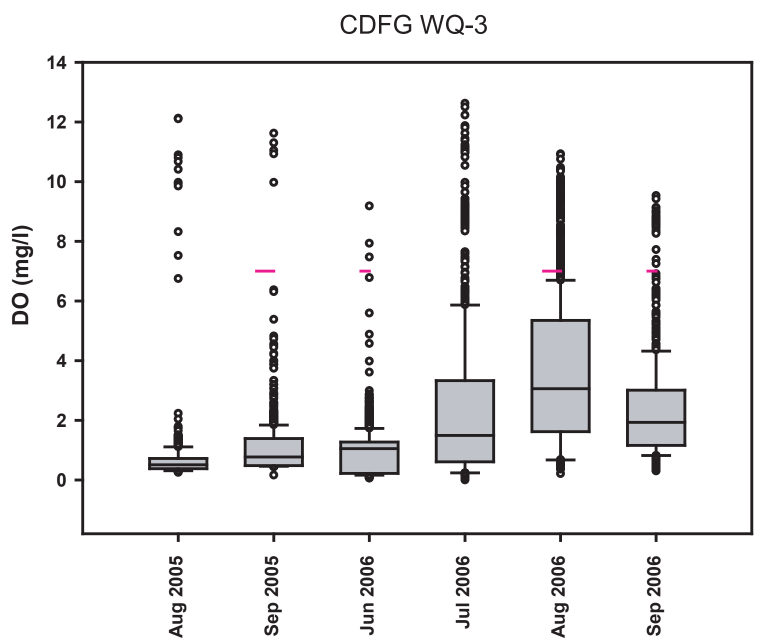

Figure 5-46 DO at CDFG WQ-3 during summer 2005 and 2006

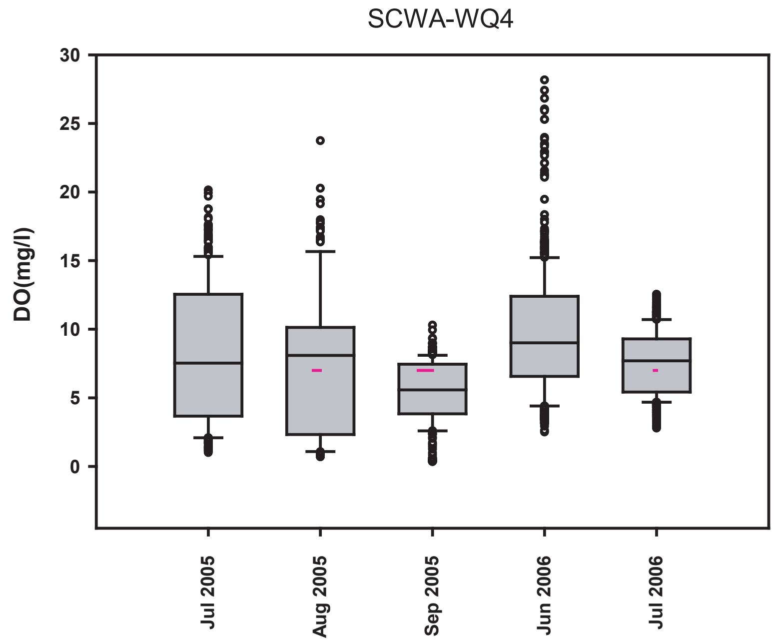

Figure 5-47 DO at SCWA-WQ4 during summer 2005 and 2006

DO concentrations at CDFG WQ-3 were severely depressed due to shallow water susceptible to a large influence from the sediment. DO concentrations at CDFG WQ-3 in summer 2005 were below 2 mg/l for over 90 percent of the time (Figure 5-46). DO concentrations during the summer of 2006 appear to be higher, but still remain at very low levels. Data for summer 2006 also indicated an increase in the diurnal fluctuations in DO. CDFG WQ-3 is located within the *Ludwigia* control area. It is possible that *Ludwigia* removal has opened up the water column promoting algal growth that contributes to the more evident diurnal pattern and higher median DO concentrations. However, minimum DO at CDFG WQ-3 during summer months remains near zero.

DO concentrations at SCWA-WQ4, downstream of *Ludwigia* control area in the Sonoma County Water Agency site, did not show marked difference between the two years; however, it seems that the minimum DO for 2006 are slightly higher than 2005.

Temporal pattern – seasonal

Because continuous DO measurements were not available at the same locations for different seasons, biweekly grab sample DO measurements taken by the NCRWQCB for the period of 1999 to 2000, which cover 12 months of the year at five locations were used to explore the seasonal pattern. During the period of October 1999 to August 2000, LSP has 13 samples out of 23 samples below the Basin Plan objective (56%). Seasonally there appear to be low DO in both winter and summer months. Low DO was observed in the months of November through early February, April to early June, and August (Figure 5-48). Low DO in winter months indicates that processes other than algal activity (e.g. BOD/SOD due to organic carbon or TKN) are contributing to the oxygen consumption, as algae activity would be low during this time of the year. During the high flow period of late February and March, DO concentrations are generally higher.

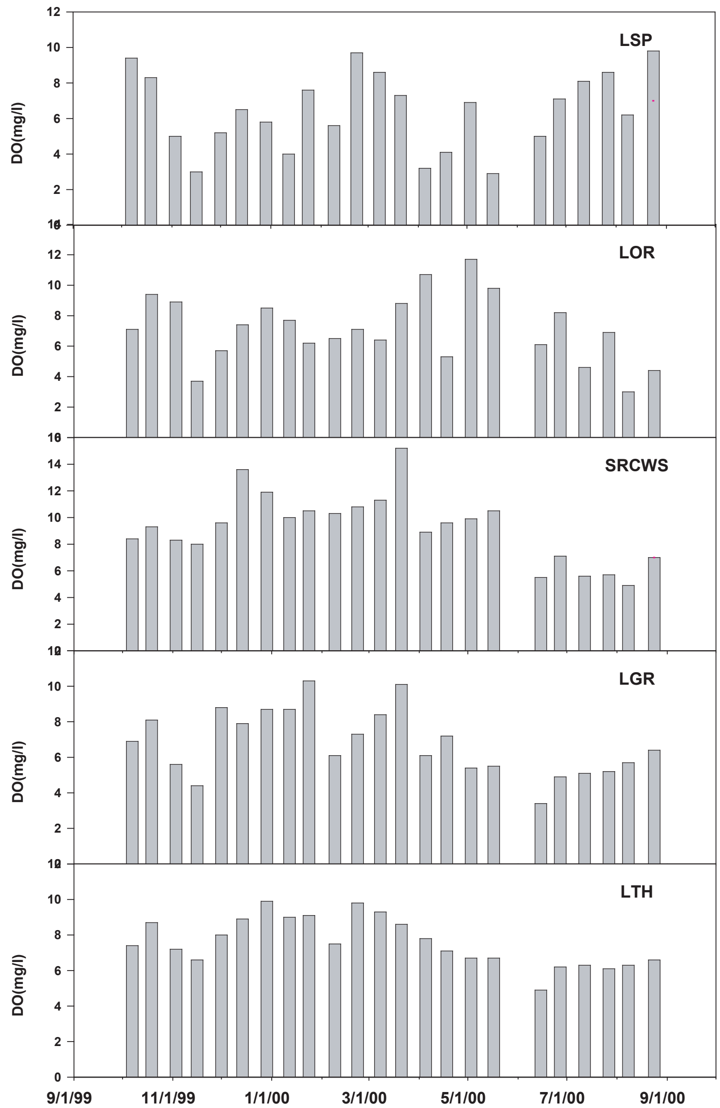

Figure 5-48 Seasonal Pattern of DO

Low DO was also observed at LOR in November 1999, April 2000 and June 2000. For SRCWS, DO concentrations are generally above the Basin Plan objective for most months of the year, with low DO occurring during the summer. LGR has low DO for the months of April to August, as well as in November. DO concentrations at the last attainment point (LTH) are generally above Basin Plan objective for most months of the year, except summer months.

Therefore, overall low DO was observed both in the winter months of November to January and the late spring/summer months of April to August at different locations in the Laguna. High flow months of February and March generally show higher DO. The observed seasonal pattern is consistent with the pattern shown in the continuous monitoring data (Figure 5-40 through Figure 5-47). As noted previously, very low DO was observed in the winter months of November to January as well as the spring/summer months.

Temporal pattern – diurnal

Continuous monitoring by the city at different locations during the WWTP winter/spring discharging period indicated that large DO swings (probably due to algal growth) are most common in March, April, and May and occasionally in January and February. In months without large DO variation (*e.g.*, January), DO is generally continuously depressed at multiple locations with less variation, and in some cases the variation may be related to flow.

Continuous monitoring data in the summer months indicated a large DO swing at SCWA WQ4/5 and CDFG WQ-1, indicating a large influence of photosynthesis activity and respiration. The magnitude of DO swing can be as high as 8 mg/L. There are large increases in DO during a certain time of the day, the respiration phase of the cycle results in lower DO that would be harmful to fish and other aquatic life. As important to the magnitude of the DO swing, baseline DO can also affect minimum DO observed. In summer 2005, CDFG WQ-3 shows continuously depressed DO below 2 mg/l without any variation. In summer 2006, some DO swing was observed as well as higher baseline DO. Figure 5-49 presents a snapshot of the diurnal pattern observed in January 2006 and summer 2006 in the Laguna. Chl-a concentrations observed in previous monitoring conducted by the Water Board from 1989 to 1994 (Table 5-16) confirmed that algal growth is evident at several locations within the Laguna. The California Nutrient Numeric Endpoint framework (Tetra Tech 2006) suggests a concentration boundary condition of 25 µg/L for impairment to WARM Beneficial Use.

Table 5-16
Average Chl-a concentrations for 1989-1994

	Chl-a (µg/l)	Count
Laguna @ Stony Point Road	25.2	25
Laguna @ Todd Road	57.0	25
Laguna @ HWY 12	43.0	19
Laguna @ Occidental Road	78.7	23
Laguna Upstream of Santa Rosa Creek	53.0	25
Santa Rosa Creek @ Willowside Road	5.7	24
Laguna @ River Road	28.8	25
Mark West Creek @ Slusser Road	24.5	10
Laguna @ Trenton-Healdsburg Road	14.0	15

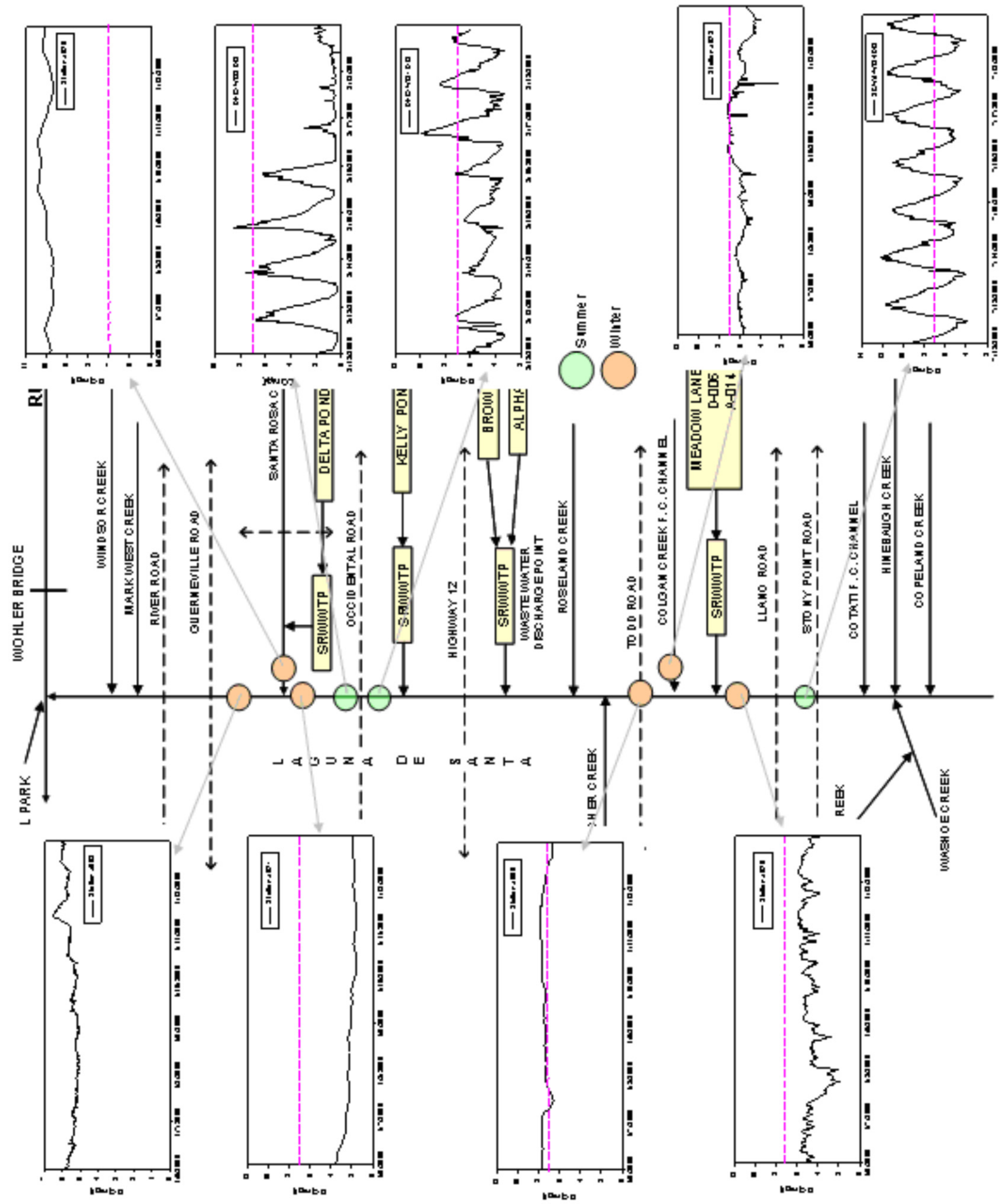

Figure 5-49 Examples of DO diurnal cycle at various locations of Laguna during winter and summer season respectively.

Spatial pattern – reach scale

For all the sampling periods in the winter/spring of 2005 and 2006, various stations (*e.g.*, Station #529, Station #521, Colgan Creek, Station #505 and Station #508) have shown over 50 percent of samples below objective (Figure 5-50). For all the summer monitoring periods of 2005 and 2006, station CDFG WQ-3 show near 100 percent of the time below the objective. The Laguna between Occidental Road and upstream of the Santa Rosa Creek confluence seems to be a critical section with prolonged DO depression, both in the winter and summer. The reach above D Pond discharge also shows depressed DO in winter months. Colgan Creek is also a critical reach with low DO. During the sampling period of winter 2005 and 2006, Santa Rosa Creek is the only stream that has DO above 7 mg/l at all times. However, as indicated in the previous analysis based on data of 1999 to 2000, low DO has also been observed in Santa Rosa Creek during the summer months.

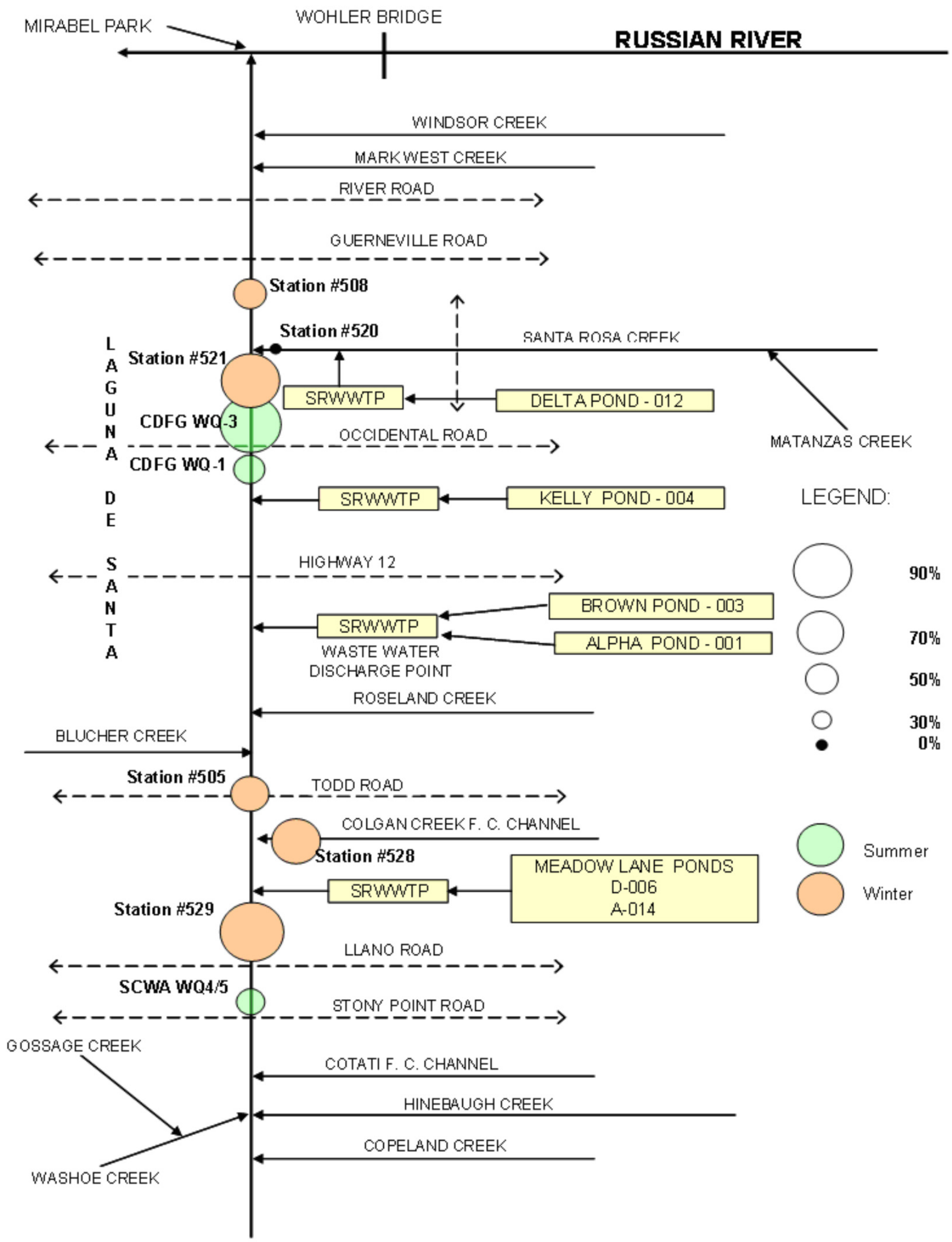

Figure 5-50 Percent of time below Basin Plan Objective (7 mg/l)
for all the samples collected in 2005 and 2006

Figure 5-51 shows the 50th percentile of the DO concentrations observed for the entire sampling period of 2005 and 2006. The 50th percentile concentrations indicated for the sampling period, for 50 percent of the time DO concentrations are at or below the concentrations shown. Similarly the reach between Occidental Road and Santa Rosa Creek has the lowest 50th percentile. The Laguna above D Pond shows very low 50th percentile of around 4.3 mg/l. Santa Rosa Creek has the highest 50th percentile. As shown in the box plot (Figure 5-53), the Laguna below Stony Point (SCWA-WQ4), the Laguna at Todd Road (Station #505), the Laguna above Occidental Road (CDFG WQ-1), and the Laguna downstream of Santa Rosa Creek (Station #508) generally show moderate DO concentrations.

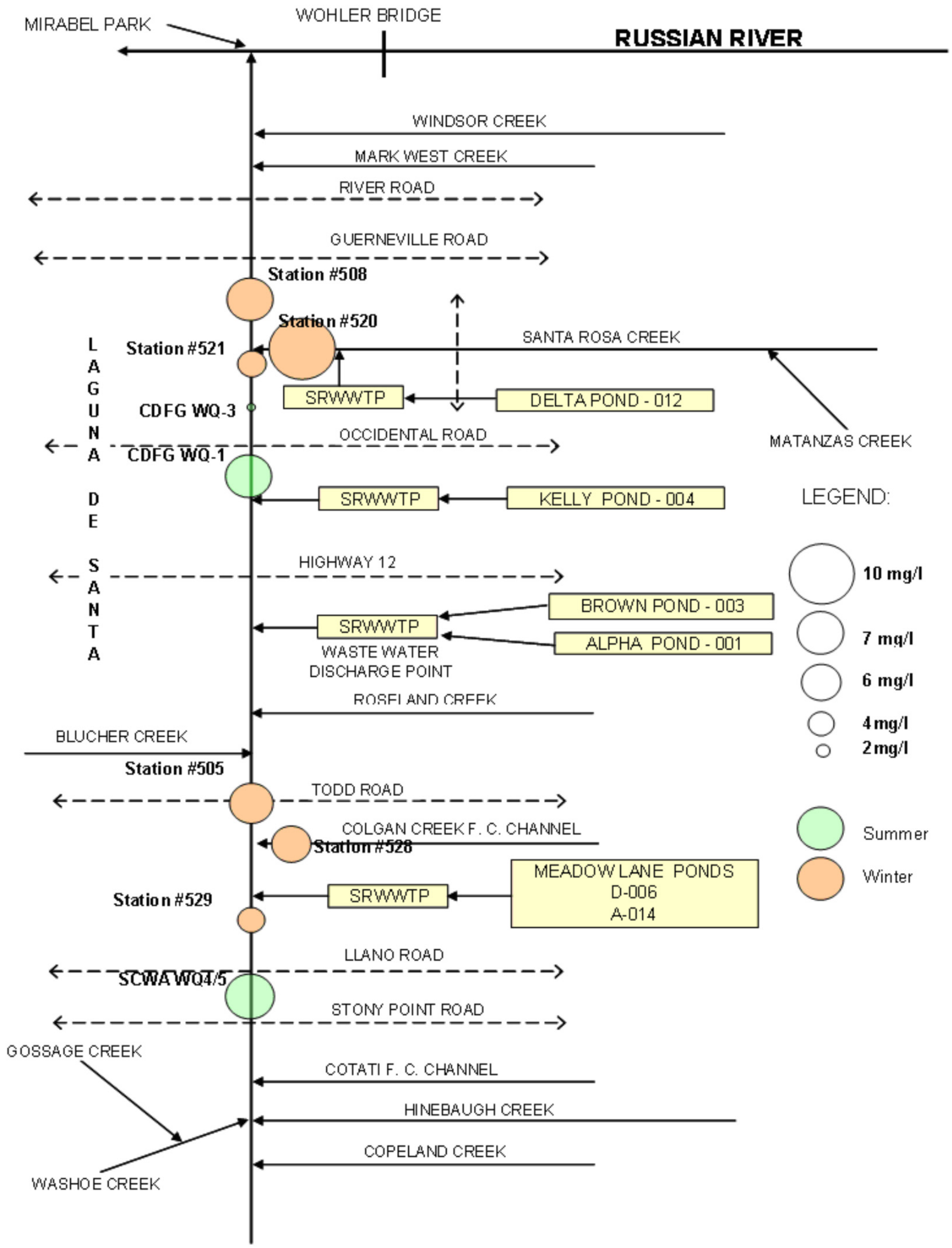

Figure 5-51 Median (50th percentile) DO concentrations
for all the short-interval samples collected in 2005 and 2006.

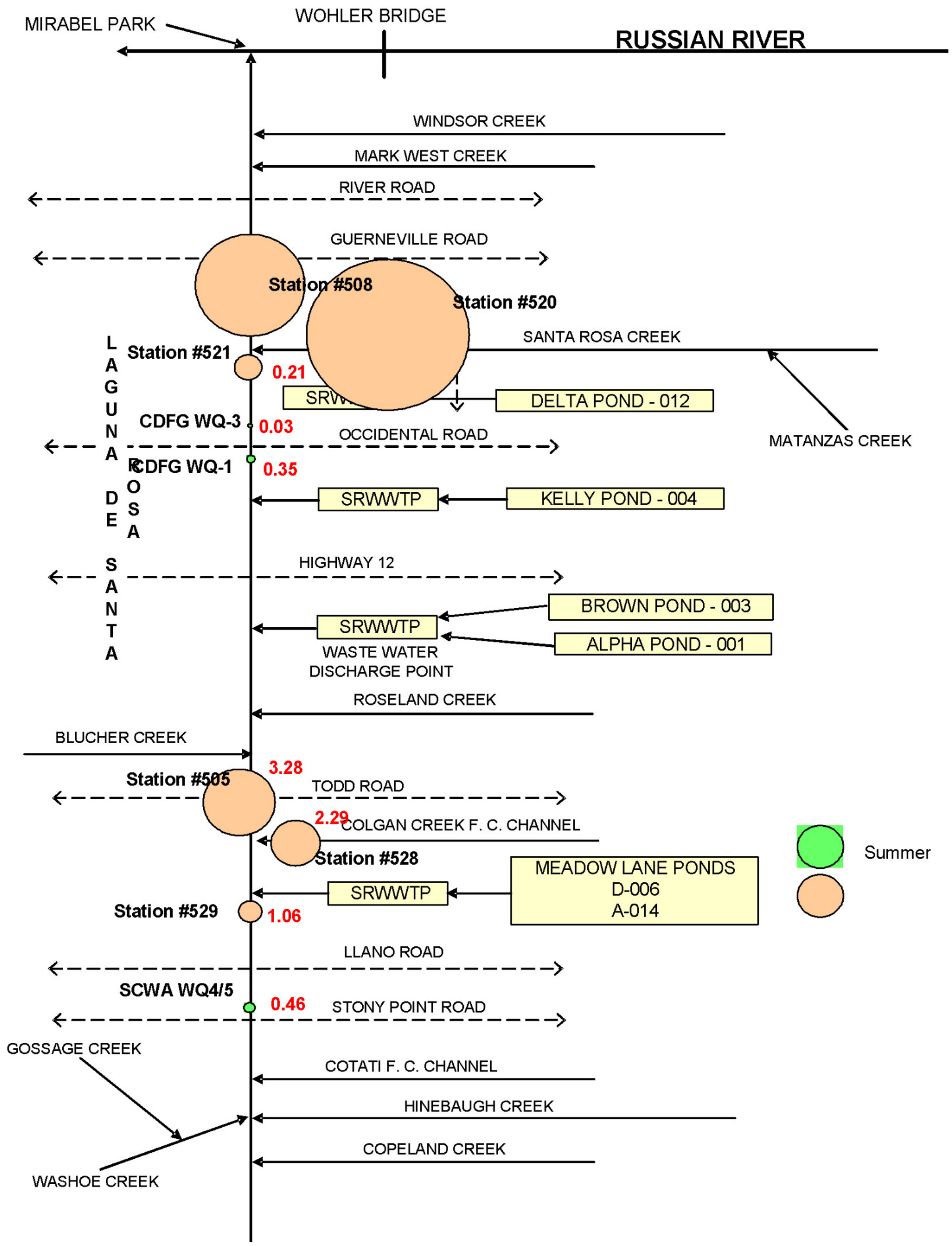

Figure 5-52 Minimum DO observed in 2005 and 2006

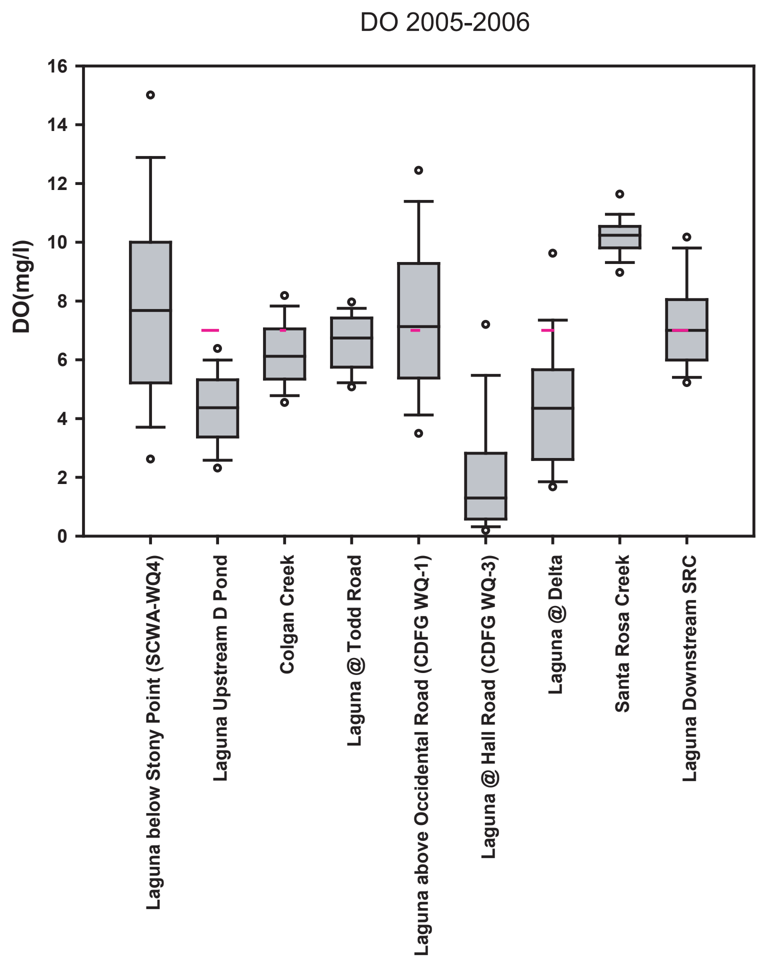

Figure 5-53 Ranges of DO observed in 2005 and 2006 at the continuously monitored locations (number of samples were shown in Figure 5-38)

Spatial pattern – water column scale

The data and results presented below are directly obtained from a nutrient/DO study conducted by RWQCB. In the summers of 1997, 1998, and 1999, profile data of DO, pH, specific conductivity and temperature were sampled at the Laguna at Occidental Road (site LOR1, LOR2, LOR3) and Sebastopol pond (SEB1, SEB2 and SEB3) in a nutrient and dissolved oxygen dynamic study conducted by RWQCB (Otis, 2006).

Figure 5-54 through Figure 5-61 illustrate the profiles for DO, pH, and specific conductivity at two sampling locations of LOR1 and SEB2 obtained through the study. The profiles shown here are typical for the sites studied. As expected, DO and temperature usually decrease with depth. Generally very low DO was observed near the bottom of the water column (as low as 1.75 mg/L at LOR1, 9/23/1998 and near zero in frequent measurements at SEB2). Low DO in the lower water column was partly attributed to stratification, which prevents transfer of oxygen to the lower water column (Otis, 2006). As shown in the temperature profile, well-established stratification is evident at LOR1 and SEB2 (Figure 5-54).. In the case when water is well mixed (10/22/1997), DO is uniformly low across the water column with slight decrease with depth. Low DO in the water column (4-5mg/l) during well- mixed conditions indicates high oxygen demand in both the water and from sediments. Specific conductivity slightly increases with depth, indicating possible releasing of constituents from the sediment. The pH profile resembles the DO profile, with higher pH in the surface of water, suggesting photosynthesis activity.

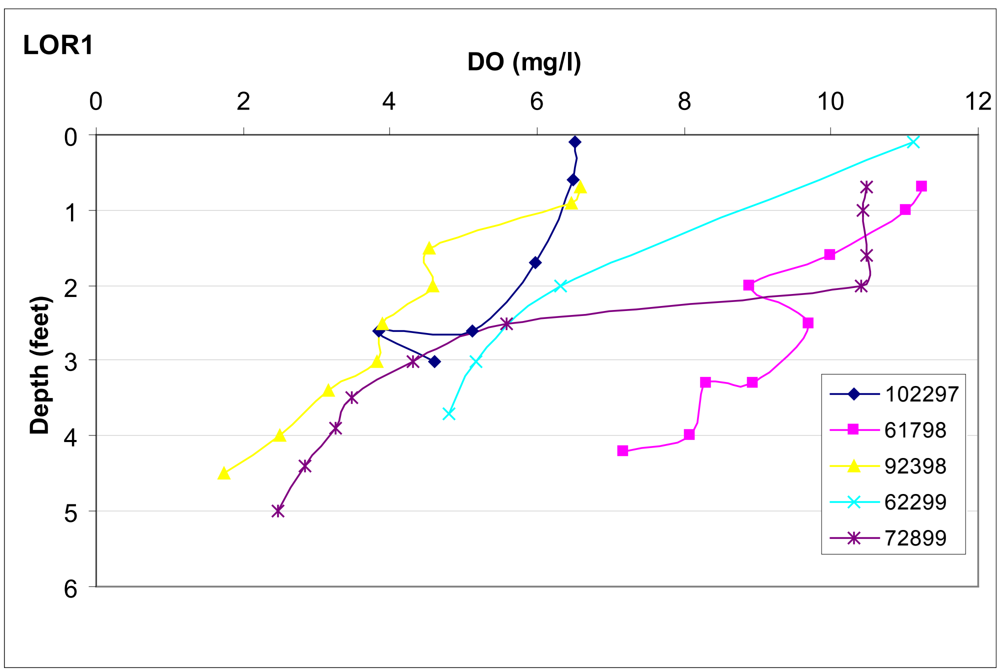

Figure 5-54 DO profile at LOR1 for summer 97, 98 and 99 (Otis, 2006)

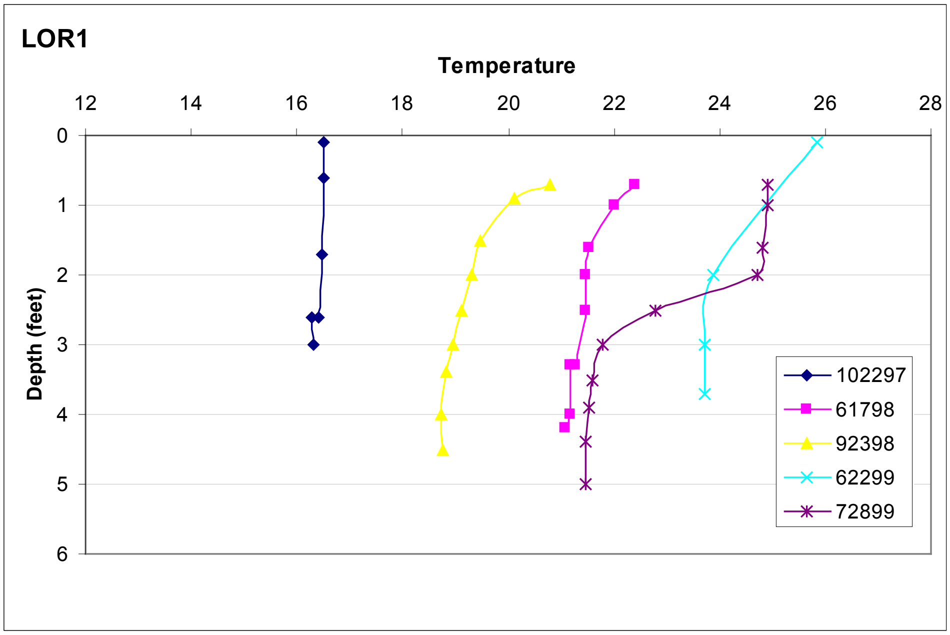

Figure 5-55 Temperature profile at LOR1 for summer 97, 98 and 99 (Otis, 2006)

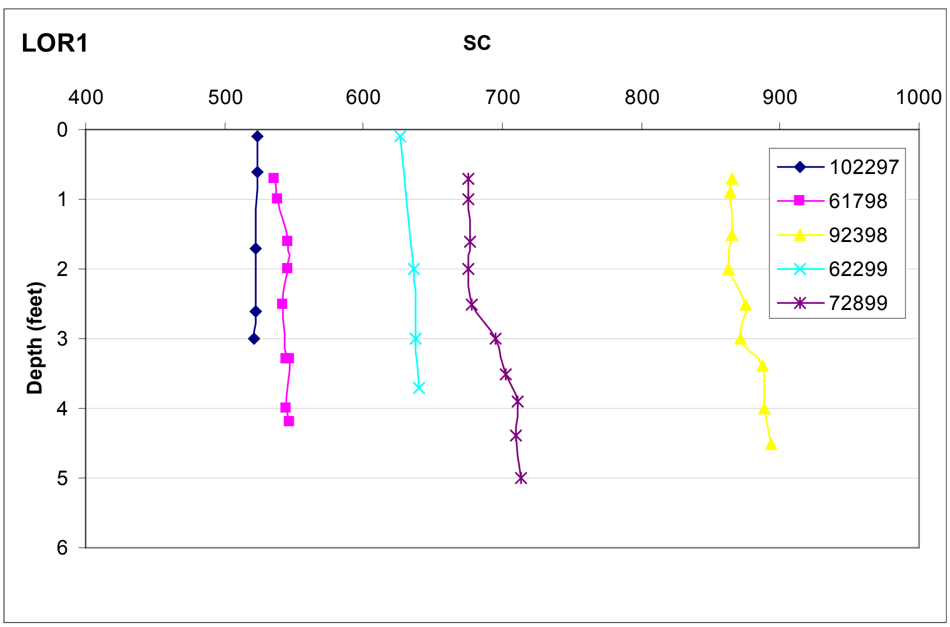

Figure 5-56 Specific conductivity profile at LOR1 for summer 97, 98 and 99 (Otis, 2006)

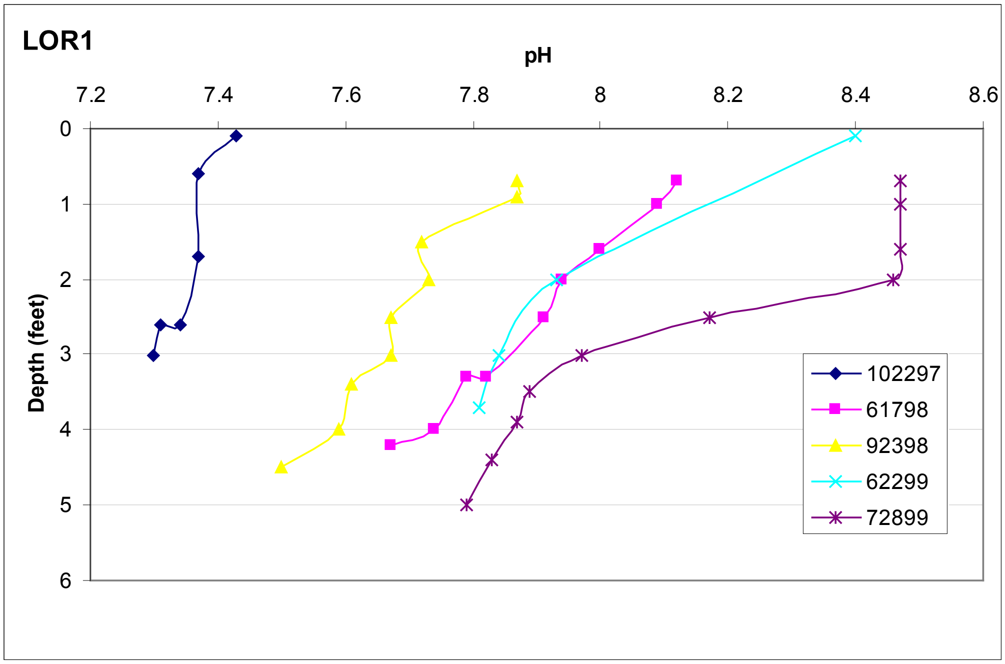

Figure 5-57 pH profile at LOR1 for summer 97, 98 and 99
(Otis, 2006)

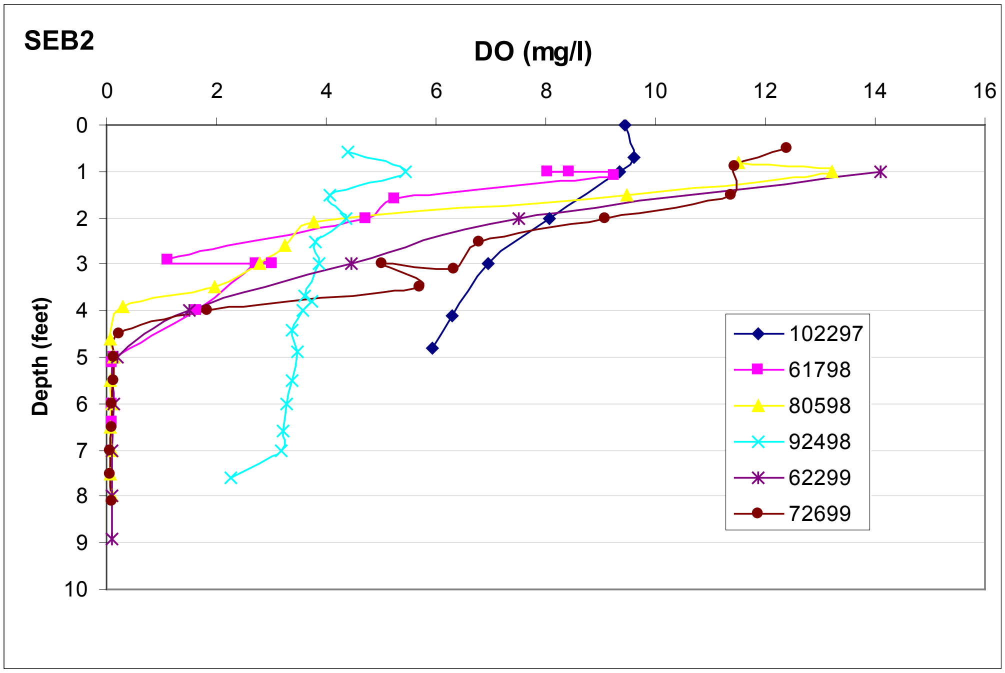

Figure 5-58 DO profile at SEB2 for summer 97, 98 and 99
(Otis, 2006)

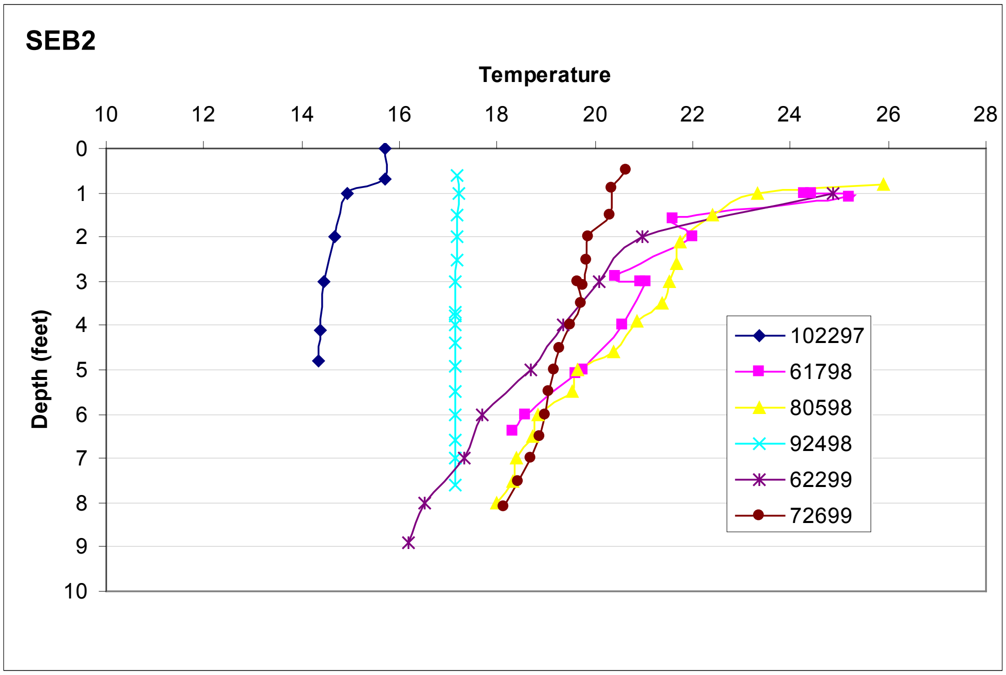

Figure 5-59 Temperature profile at SEB2 for summer 97, 98 and 99
(Otis, 2006)

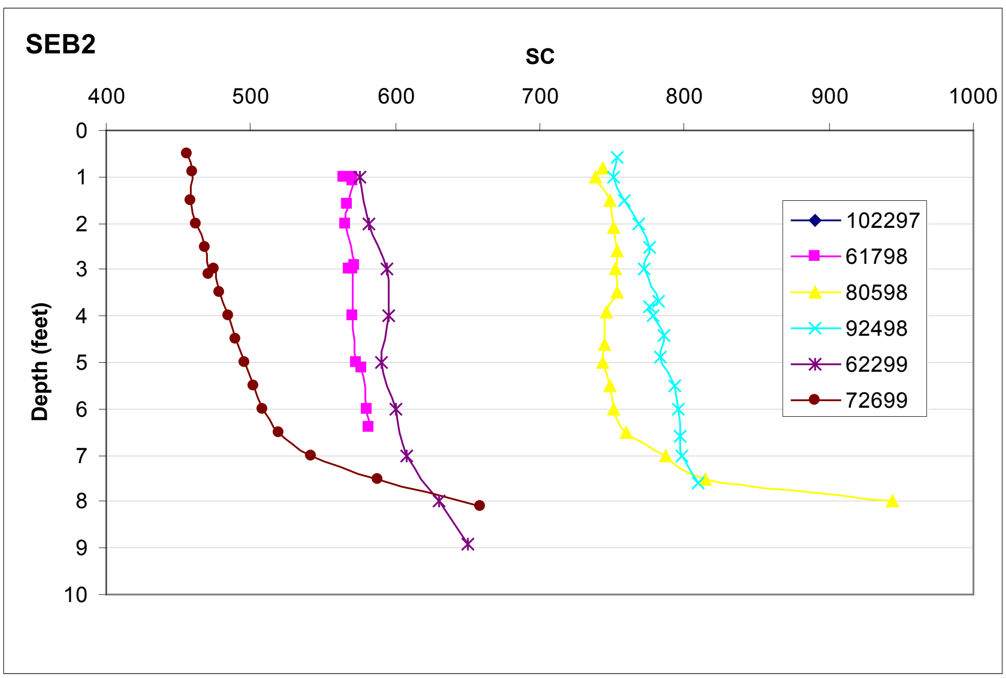

Figure 5-60 Specific conductivity profile at SEB2 for summer 97, 98 and 99
(Otis, 2006)

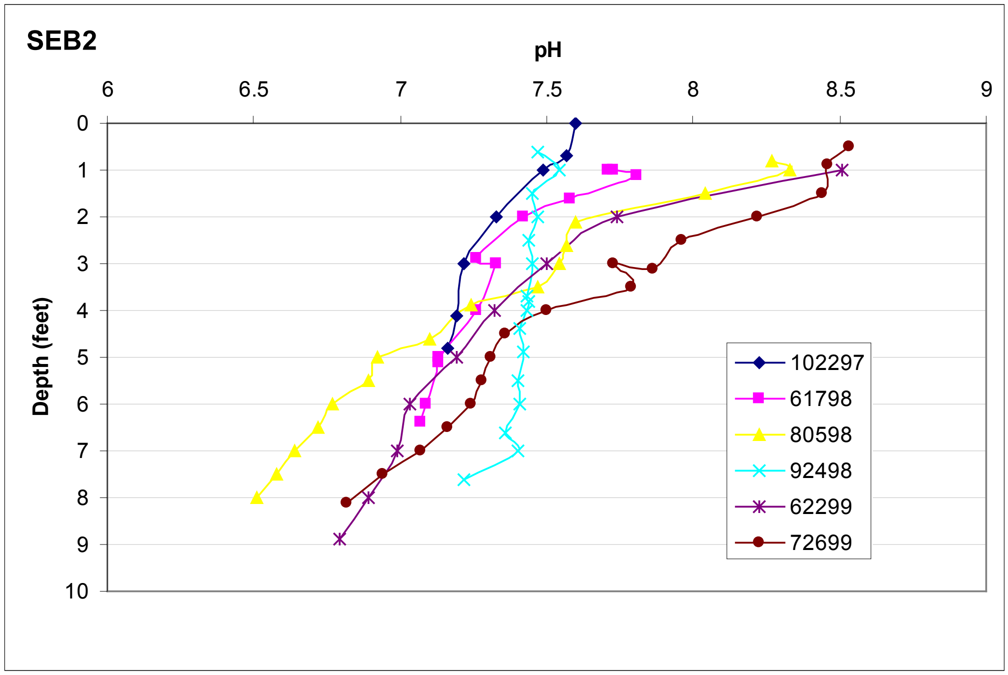

Figure 5-61 pH profile at SEB2 for summer 97, 98 and 99
(Otis, 2006)

Similar to LOR1, the DO profile at SEB2 suggested significant anoxia has developed in the lower water column. As documented in Otis (2006), the anoxic zone at SEB2 can reach 4 feet above the sediment. DO concentrations at the surface show large variations and can be as high as 14 mg/l suggesting supersaturation due to high photosynthetic activity. Stratification is also evident at SEB2. In the case when water is well mixed (9/24/1998), DO concentrations are uniformly low across the water column; however, DO remains above 0 without the development of an anoxic zone, showing that thermal stratification is an important causal factor for low DO. In the well mixed case, DO in the lower water column was above 2 mg/l. Specific conductivity at SEB2 showed very significant increases near the bottom of the water, indicating possible sources of nutrients/constituents from the sediment.

As concluded from the study, lowest DO is generally observed in deeper water with occasional anoxia near the sediment/water interface. Low DO in the lower water column is due to a combination of multiple factors including algal activity, thermal stratification, and high sediment oxygen demand.

5.2.4 Factors contributing to DO impairment

Various physical, chemical, and biological factors contribute to the DO dynamics in the Laguna. For example, physical factors such as wind and temperature that influence the mixing of water can influence the reaeration of dissolved oxygen. Chemical factors such as high TKN in the water column can consume oxygen. And noticeably, biological activity of algae and macrophytes has been attributed to causing large variation of DO in the water column. Other factors such as low flow, and high organic carbon loadings can also contribute to sustained low DO in the Laguna. The following synthesized diagram (Figure 5-62) was based on current general understanding of DO dynamics and factors identified as particularly important in the Laguna in previous studies of Otis (2006) and the data analysis presented above.

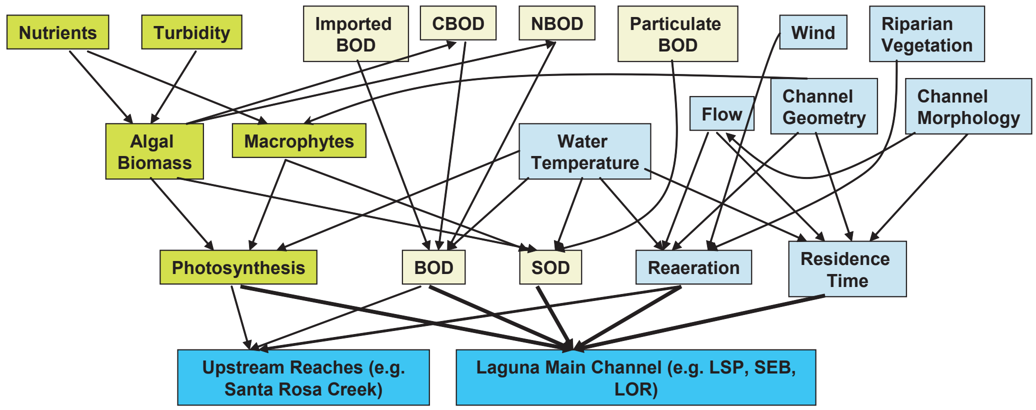

Figure 5-62 Physical, biological and chemical factors impacting DO dynamics

Physical

Flow: Flow is an important factor influencing the residence time of water and the reaeration rate, particularly in streams. Low flow and low velocity can contribute to low DO, as it will limit reaeration and promote the development of thermal stratification. Low flow also promotes settling of organic sediments, which may increase sediment oxygen demand. As indicated in the previous analysis, the high flow months of February and March generally have higher DO. There are sections in the Laguna such as LSP where low DO was observed during low flow months.

Temperature: Low flows, poor riparian cover, and degraded channel conditions can contribute to warmer column temperatures. Warmer temperatures decrease oxygen solubility while increasing rates of biological respiration, both of which increase the risk of unacceptably low DO in the water. A more detailed analysis of temperature monitoring data is not available at this time.

Channel Geometry: Channel geometry (channel width and depth) plays an important role in DO dynamics in some sections of the Laguna. There are sections in the Laguna where the channel widens, slowing down flows and leading to the formation of a ponding area. In ponding areas, flow conditions often become stagnant and wind mixing becomes an important way to reaerate the water column. As observed at LOR, in sections where the ponding area is shallow with long fetch, wind mixing is easier to result in complete mixing of water. In sections where water depth is deep, thermal stratification may establish and prevent mixing of oxygen in the lower layer. The Laguna at Sebastopol pond is a section where thermal stratification is common in summer time (SEB2, Otis, 2006). Increased depth and width and thermal stratification increases residence time of water, therefore allowing more time for biological and chemical reactions that consume oxygen to occur.

In sections with shallow water depth, DO in the water column can be more rapidly depleted by oxygen demand from bottom sediments if reaeration is limited. Shallow water depth also allows sunlight to penetrate to the bottom of the water and promotes benthic algal growth, which adds oxygen during the day from photosynthesis but depletes oxygen at night from respiration. The shallow water depth also allows rooted macrophytes to grow, and dense coverage by macrophytes can further reduce reaeration rates. LSP is a section with shallow water depth. In this section, growth of *Ludwigia* is abundant and low DO was observed. Also as observed in CDFG WQ-3 shown in previous analysis, shallow water depth and abundance of *Ludwigia* resulted in prolonged depression of DO during the summer time.

Channel Morphology: Channel morphology such as gradient, bottom roughness, and sediment can influence flow and residence time of water. Sediments have been deposited in the Laguna. It was hypothesized that the deposited sediments in some cases can form sediment plugs serving as in-stream dams that prevent water from flowing downstream. The water behind these "sediment plugs" can become stagnant without mixing, promoting algae and macrophytes growth, resulting in low DO. The infestation of *Ludwigia* also increases channel bottom roughness and decreases flow velocity, which can influence DO reaeration.

Riparian Vegetation and Wind: The lack of riparian vegetation can result in an increase in water temperature, which can contribute to low DO conditions. In some areas, lack of riparian vegetation cover may result in higher surface temperature and promote thermal stratification as observed in SEB2. In some cases, dense riparian vegetation, however, can reduce the effect of wind mixing.

Chemical

Decomposition of organic carbon in water column and particulate organic matter in sediments consumes oxygen. Organic carbon can be from aquatic sources, fom benthic and planktonic algae and plants, as well as from terrestrial sources of urban/agricultural/forest runoff and point source. The oxygen demand can also be originated from nitrification of nitrite and ammonia to nitrate. Organic nitrogen can be decomposed into ammonia, which also contributes to oxygen demand in nitrification.

Therefore the chemical factors of high nutrient (ammonia and organic nitrogen, TKN) and organic carbon loadings can directly contribute to the oxygen demand in water. High nutrient loadings (phosphate, nitrate, ammonia) can also promote primary production of algae and macrophytes in the water column, which when settled to sediment result in sediment oxygen demand. High concentrations of various forms of nutrients (phosphate, nitrate, ammonia, organic nitrogen) and BOD loadings have been observed in various sections of the Laguna. As indicated in the previous sections, sediment oxygen demand contributes significantly to low DO.

Biological

The biological factors of algae and *Ludwigia* growth undoubtly can contribute to DO dynamics. The photosynthesis and respiration activity of algae and macrophytes can result in large DO swings, as demonstrated in previous sections. Limited algal concentration monitoring results presented in Section 5.2.3 suggests that high algae concentrations are occurring within the Laguna. The aerobic bacterial decomposition of detrital material derived from algae and plants consumes oxygen and is the primary contributor to measured BOD and SOD.

Based on the description in Otis (2006), the following discussion presents several scenarios of the combination of different factors that contribute to low DO (Figure 5-63 through Figure 5-65).

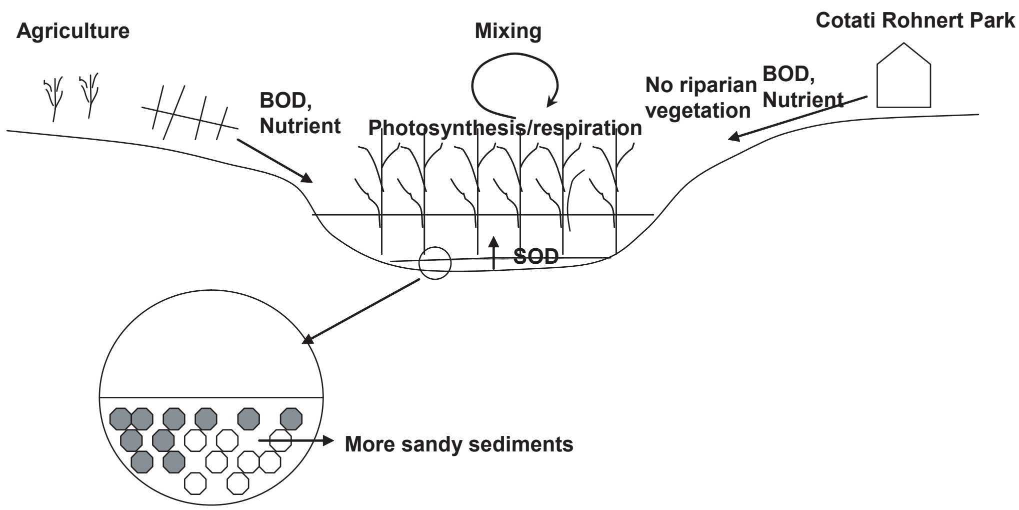

Figure 5-63 Preliminary DO conceptual model at the Laguna at Stony Point (LSP)

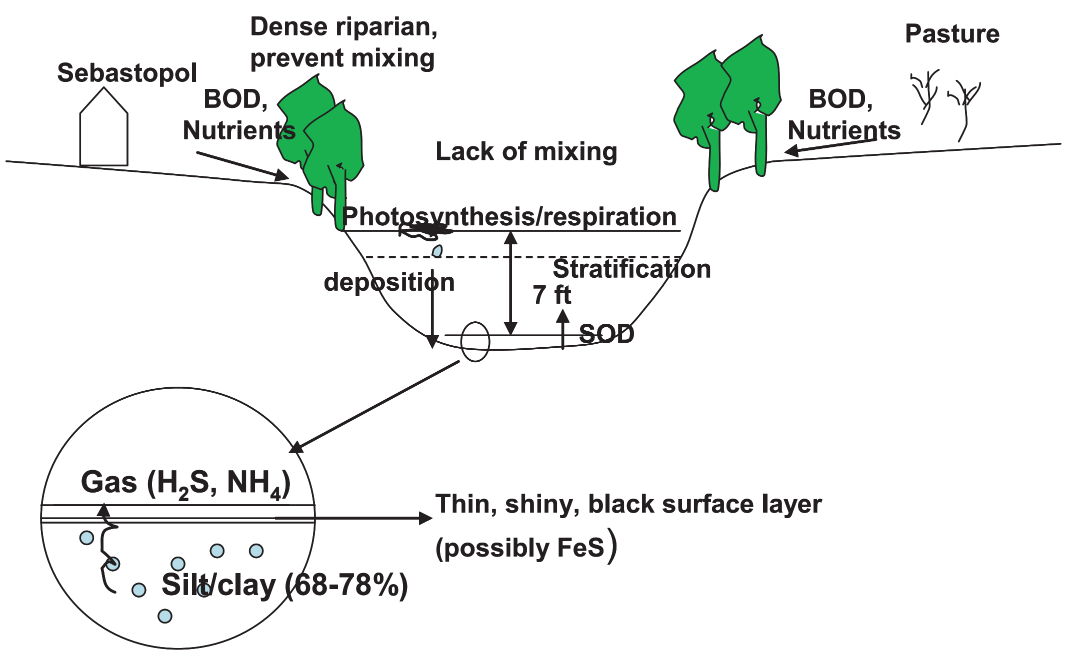

Figure 5-64 Preliminary DO conceptual model for the Laguna at Sebastopol Pond (SEB)

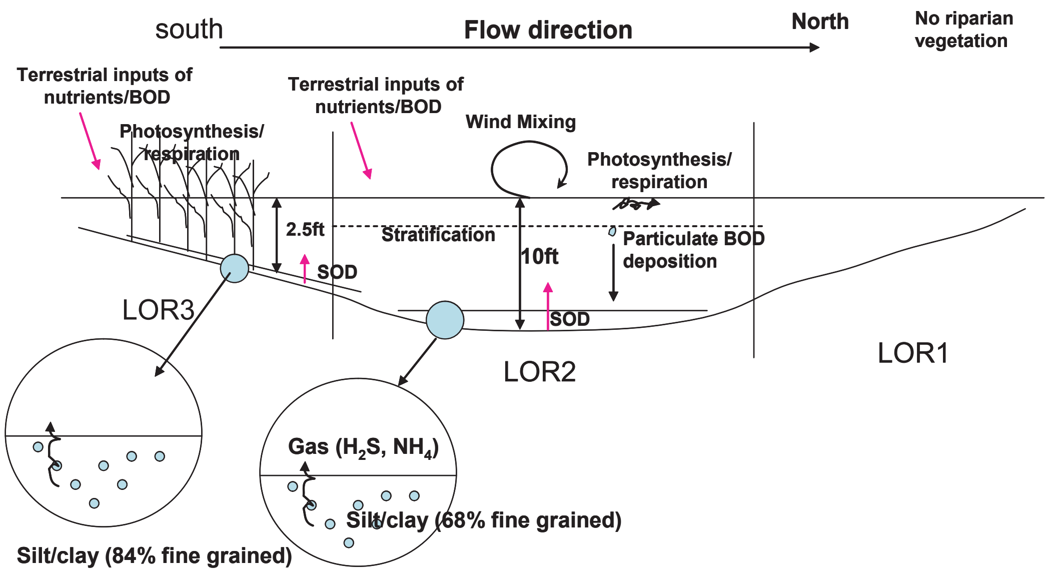

Figure 5-65 Preliminary conceptual model for the Laguna at Occidental Road (LOR)

Laguna at Stony Point (LSP) is a shallow stream section that receives nutrients and BOD inputs from agriculture and urban runoff (Figure 5-63). This section is infested with *Ludwigia*. Shallow water depth and low flow may result in large influence of SOD from bottom sediments on the water column.

The Laguna at Sebastopol Pond (Figure 5-64) is a section with a narrower and deeper channel. This section also receives nutrients and BOD inputs from a mix of urban and agricultural runoff. The bottom sediments accumulate a high level of organic matter and nutrients, which can pose high SOD. In this section dense vegetation prevents wind mixing and deeper water promotes thermal stratification. Stratification prevents water mixing and replenishing of oxygen and results in anoxia in hypolimnion. High residence time allows more time for biological and chemical reactions to occur that consume oxygen. In open water, algal photosynthesis and respiration influence DO dynamics, lowering DO in certain time of the day. Settling of algae also contributes to particulate BOD.

The Laguna at Occidental Road (Figure 5-65) is also a ponding area that receives terrestrial inputs of nutrients and BOD. The sediments also accumulate high levels of organic matter and nutrients, which may pose a high SOD. High nutrients in the water column and sediments can promote the growth of algae and macrophytes. The south section (LOR1) is shallower and is infested with *Ludwigia*. In open deeper water (LOR2) algal photosynthesis/respiration is present. Deeper water also allows thermal stratification to develop and results in low DO in the hypolimnion.