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

FROM: Steve Butkus

DATE: December 8, 2011

SUBJECT: Development of the Land Cover Loading Model for the Laguna de Santa Rosa Watershed

The development of the Total Maximum Daily Load (TMDL) for nutrients and dissolved oxygen in the Laguna de Santa Rosa (Laguna) requires a pollution source analysis. The goal of the Source Analysis is to provide a complete inventory and description of all sources of the pollutant of concern, including point, nonpoint, and background sources in the watershed. An estimate of the relative pollutant loading from the major sources informs the TMDL allocation process. The Laguna TMDL Nutrient Source Analysis uses the Land Cover Loading Model to estimate loads from differ land covers.

A TMDL addressing the reduction of nitrogen and ammonia loading was completed for the Laguna in 1995 (Morris, 1995). The load estimates for specific individual sources were based on an inventory approach with assumptions on many variables (CH2M Hill, 1994). For example, dairy related sources were based on the number of animals in the watershed, manure production per animal, access to perennial streams, etc. Similarly, load estimates from septic systems were also based on an inventory approach with assumptions including number of on-site systems, groundwater attenuation, and number of failing systems.

Regional Water Board staff developed a watershed model that estimates loads based on land cover for the Laguna TMDL Nutrient Source Analysis, called the Land Cover Loading Model (LCLM). Although estimates of pollutant loading from watersheds can be done using a variety of modeling approaches, Regional Water Board staff developed and applied the LCLM following U.S. Environmental Protection Agency guidance (USEPA, 2009). This memorandum describes the development and application of the LCLM, following these development steps and taken from EPA's guidance:

1. Design the Conceptual Model
2. Construct the Model Framework
3. Parameterize the Model Assumptions
4. Corroborate the Model Results
5. Apply the Model in Simulations

1. Conceptual Model

Regional Water Board staff developed the LCLM using a straightforward conceptual model based on simple pollutant transport from various land covers to compare current nutrient loads to pre-European settlement historical loads. The LCLM allows estimates of pollutant loading from catchments based on land cover areas and representative loading rates (i.e., load per area of land). This allows a comparison of pollutant loading among different land covers. The LCLM also estimates reductions in nutrient loads due to nutrient uptake by riverine and perennial wetland areas before a total load discharges to receiving waters. The conceptual model for estimating watershed loading to receiving waters is shown in Figures 1 and 2.

Application of the LCLM watershed model allows for improvement over the inventory approach to pollutant source analysis by including all the nonpoint sources in the watershed. Use of the inventory approach restricts the ability to estimate all nonpoint sources. One possible limitation to the LCLM is the aggregate nature of the loading estimate. The method does not directly estimate loading from individual sources, only the loads that are delivered to the Laguna as categorized by land cover. In addition, the high variability of the load estimates among land covers results in similar mean load estimates from the different land covers.

The simple representation of the LCLM allows a comparison of current pollutant loading to an estimated historical loading based on land cover that existed prior to European settlement. The LCLM can be applied to Laguna watershed pre-European settlement land cover to estimate these historical loading rates. Pollutant loading was estimated based on representative loading rates (i.e., load per area of land) from pre-settlement land cover areas. The LCLM also allows estimates of the relative distribution of loads between wet and dry periods.

2. Model Framework

The model framework for the Laguna nutrient LCLM is a formal specification of the concepts and procedures relevant to estimating pollutants loads from different land uses usually translated into computer software.

The level of model complexity needed should be considered to determine the suitability of the model framework. A model should be no more complicated than necessary to inform management questions and decisions. A common misconception is that model accuracy increases with model complexity. Models that are more complex to treat more physical processes show degradation in predictive performance because they require more input variables with greater levels of uncertainty. Complex models have problems with error accumulation and predictive performance. The lack of available input data for complex models requires estimation of many model parameters through calibration. As such, model uncertainty increases with model complexity. Simpler watershed models have shown similar predictive performance as more complex models (Loague and Freeze, 1985; Jakeman and Hornberger, 1993).

Errors may also come from the use of unrealistic assumptions. For example, a model based on one-dimensional equations of flow should not be used to represent conditions of a stratified lake. The accuracy of the results is suspect if a model is based on unrealistic assumptions. Available watershed pollutant transport models differ in complexity, modeled processes, and basic assumptions.

3. Model Parameterization

Regional Water Board staff parameterized the LCLM by (1) mapping the geographic scope of each land cover category for both current and pre-settlement time periods, and (2) selecting representative nutrient load rates for each land cover category. The rates are based on sampling data of pollutant concentrations in runoff from selected land covers.

Current Land Cover Parameterization

The most recent National Land Cover Data set (USGS, 2006; Homer et al., 2007) was used to determine current land cover distributions within the Laguna watershed. The spatial dataset is based on Landsat satellite imagery and has a high level of accuracy (Wickham et al., 2004). Imagery from 2006 was assessed spectrally to update 1992 and 2001 imagery data using methodology developed by NOAA (1995). Land cover categories are typically defined by “Anderson” Levels (Anderson et al., 1976). Level I category land uses are major land uses including Urban, Agriculture, Rangeland, Forest Lands, or Barren. Level II defines land cover subtypes such as residential and commercial. The Level I and Level II land cover areas and percentages were extracted from GIS layers for the entire Laguna watershed.

Based on the land cover type acreage within the watershed, seven land cover source categories were selected for estimating land cover loading (Table 1; Figure 3). All three rangeland types were combined into one land cover source category. Residential areas were divided between sewered and non-sewered land parcels into two land cover source categories. All commercial and services land cover types were combined with the other miscellaneous urban land cover types into an “Urban” land cover source category. The “Other Land Uses” that include transitional areas, quarries, reservoirs and other agriculture represent less than one-percent of the Laguna watershed area.

The National Land Cover Data set categorizes “Rangeland” separately from agricultural “Pasture” lands. Rangeland was defined as land where the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs. Pasture lands are those used for livestock grazing which include land used for grazing in rotation with crops.

Table 1. Current Land Cover Categories Selected for Assessment

Land Cover Category	Acres	Percent
Forest	48,315	29.7%
Cropland & Pasture	44,458	27.3%
Rangeland	21,767	13.4%
Residential - Sewered	15,348	9.4%
Orchards & Vineyards	12,825	7.9%
Residential – Non Sewered	9,857	6.1%
Commercial Urban	8,577	5.3%
Other Land Uses	1,642	1.0%
Total	162,789	100.0%

<u>Pre- European Settlement Land Cover Parameterization</u>

The spatial representation of the Laguna watershed showing pre-settlement hydrology and land cover was developed by Regional Water Board staff to help estimate historical pollutant loading (Butkus 2011). The land cover and hydrology that existed in the Laguna watershed prior to significant European settlement was investigated to help assess natural background sources. Historical ecological analysis can provide a better understanding of former conditions to support habitat restoration and water quality management goals and objectives. The analysis of pre-settlement conditions provides context for setting TMDL allocations for desirable and feasible future conditions.

Pre-European settlement in the Laguna watershed was defined as the period of time prior to the General Land Office surveys conducted during the mid-19th century. The pre-settlement spatial data model was designed to delineate the boundaries between six land cover categories (Table 2 and Figure 4).

Table 2. Laguna Watershed Pre-European Settlement Land Cover Areas during a Wet Climate Year

Land Cover Category	Acres	Percent
Forest	84,515	51.9%
Oak Savanna	28,823	17.7%
Rangeland	24,292	14.9%
Perennial wetlands	16,969	10.4%
Riverine wetlands	5,145	3.2%
Streams & Open Water	3,045	1.9%
Total	162,789	100.0%

Pollutant Loading Rates Parameterization

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).

The estimated pollutant loads by land cover that were measured from 2009-2010 sampling data are presented as box plots and load duration curves (Butkus, 2010). Box plots provide a concise graphical display summarizing the distribution of a data set (Helsel and Hirsch, 2002). The top and bottom of the box represent the lower and upper quartiles with the band near the middle of the box showing the median. The whiskers represent the 10^{th} and 90^{th} percentiles. The mean is shown as a cross system on the box plot. Load duration curves are a useful tool identifying pollutant loading over the entire flow regime of a river (USEPA, 2007). A load duration curve provides a visual display of the relationship between flow and pollutants. The load duration curve allows for characterizing water quality at different flow regimes. Using the load duration curve, the frequency and magnitude of water quality standard exceedances, allowable loadings, and size of load reductions are easily presented and can be better understood.

The distributions of the total phosphorus and total nitrogen unit area loads are compared by land cover as box plots in Figures 5 to 8. Loads from all land covers show non-normal, left-skewed distributions. Mean loads are often higher than the 75^{th} percentile. In general, higher dry period nutrient loads were observed from agricultural areas. However, wet period nutrient loads from agricultural areas were lower than other land covers, including rangeland and sewered residential.

Load duration curves are presented for each land cover to represent estimated changes in annual loads due to climatic conditions in Figures 9 to 24. The hydrologic year was defined as April 1 through March 31 of the following year (Haith et al., 1992). The return period was based on the frequency of annual wet period days to dry period days from the 72-year precipitation record. Estimates of the range of loads across the range of climatic conditions were derived from the distributional metrics of the 2009 -2010 loading measurements. Many of the load duration curves show about twice the load is exported during extreme wet years as compared to extreme dry years.

4. Model Corroboration

Regional Water Board staff used four approaches to corroborate the LCLM loading rates:

1. Land use specific loading rates published in scientific literature
2. Land use specific loading rates derived in the development of the 1995 TMDL.
3. Dry weather loading rates estimated from independent samples collected in 2008.
4. Wet weather loading rates estimated from a dynamic watershed loading model.

This evaluation showed that pollutant loading estimated using the LCLM was reasonably corroborated by each of the other four loading estimates compared.

1. Published Land Cover Loading Rates

Staff assessed separate loading rates between wet and dry periods for each land cover from published annual loading rates and compared the published rates to the annual loads from measurements made in the Laguna watershed during 2009-2010. Published values of annual loading rates were assumed to represent a median hydrologic year. Published loading rates were compared to estimates of loading derived from Laguna watershed measurements using a median hydrologic year on the land cover load duration curves (Figures 9 to 24).

Event mean concentrations (EMC) represent the concentration of a specific pollutant contained in storm water runoff coming from a particular land cover type within a watershed. EMCs are reported as a mass of pollutant per unit volume of water (usually mg/L). These numbers are generally calculated from local storm water monitoring data. Annual loading rates represent the average total amount of pollutant delivered annually into a system from a defined area. Annual loading rates are also know as export coefficients and represent an annual loading rate reported as mass of pollutant per unit area per year (e.g., lbs/ac-yr).

Loading rates for land uses can vary widely depending on precipitation, source activity, and soils. Published values of EMCs or annual loading rates are often used for pollutant loading assessments since collecting the data necessary for calculating site-specific values can be cost-prohibitive. If site-specific numbers are not available, regional or national averages are often used. The accuracy of published regional or national averages may be questionable due to the specific climatic and physical characteristics of individual watersheds. Different land uses can exhibit a wide range of variability in nutrient export (Beaulac and Reckhow, 1982).

Published EMC values were used to derive wet period load estimates using the median 24-hr storm event. The Rational Method was used to estimate flows for calculation of EMC loads (Burien et al., 1999). Land use specific runoff coefficients were selected from McCuen (1998). The median 24-hr precipitation was 0.36 inches measured as the 50 percent return probability for wet days (40 CFR 122.21(g)(7)(ii)) using the continuous precipitation record from 1995-2010 (Butkus, 2010). The 24-hr storm duration was assumed to be much greater than the time of concentration when applied to an one acre area as required for application of the Rational Method. Wet period loads estimated from published EMCs were added to dry period loads to estimate annual loading rates for presentation on the load duration curves. Dry period loads were derived from the measured median unit area loading rates (NCRWQCB, 2010). Annual loading rates derived from the published EMC and 2009 sample data were presented as a median hydrologic year for presentation on the load duration curves.

Land cover loading estimates derived from the LCLM were compared visually to other published estimates on the load duration curves (Figures 9 to 24). The mean published loading values were placed on the curves at the median return period since hydrologic data were not available. Tables 3 to 9 present the citations and data used for comparison to measured loading rates.

Table 3. Published Land Cover Nutrient Loading Rates for Forested Lands

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	0.211	0.017	0.741	2.552	1.231	37.025
Rast & Lee (1978)		0.045	0.089	0.892		
Loehr et al. (1989)		0.006	0.785		0.892	5.353
Young et al. (1996)	0.045	0.001	0.089		0.803	4.550
Letcher et al. (1999) from SKM&WBM Oceanics (1998)	0.178			1.606		
Letcher et al. (1999) from Gourley et al. (1996)	0.089				0.892	
Line et al. (2002)	0.115			0.635		

Table 4. Published Land Cover Nutrient Loading Rates for Rangelands

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	1.012	0.071	2.900	14.748	2.516	34.322
Rast & Lee (1978)	0.446			1.784		
Loehr et al. (1989)		0.045	0.223		0.446	12.491
Young et al. (1996)	0.089	0.002	0.357	3.123	2.409	5.888
Letcher et al. (1999) from SKM&WBM Oceanics (1998)		0.178	0.535	0.892		
Letcher et al. (1999) from Baginska et al. (1998)	0.294					
Letcher et al. (1999) from Gourley et al. (1996)	0.134			1.338		
Harper (1998)	0.891			1.911		
Brezonik and Stadelmann (2001)						49.901

Table 5. Published Land Cover Nutrient Loading Rates for Cropland & Pasture

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	1.338	0.089	16.595	7.717	0.865	
Rast & Lee (1978)	0.446			1.784		
Loehr et al. (1989)		0.045	2.587		1.874	
Young et al. (1996)	0.981	0.446	0.803	2.677	2.141	
SKM&WBM Oceanics (1998)		0.178	1.338	8.922		
Baginska et al. (1998)	0.714					
Gourley et al. (1996)		0.178	1.784		1.338	
Line et al (2002)	1.391			3.137		
Harper (1998)	0.467			2.174		

Table 6. Published Land Cover Nutrient Loading Rates for Orchards & Vineyards

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	1.012	0.071	2.900	14.748	2.516	71.017
Rast & Lee (1978)	0.446			1.784		
Loehr et al. (1989)		0.054	2.587		1.874	71.017
Young et al. (1996)				3.123		
Letcher et al. (1999) from SKM&WBM Oceanics (1998)	1.338			8.922		
Letcher et al. (1999) from Gourley et al. (1996)	1.784			2.677		3.569
Harper (1998)	0.486			1.832		

Table 7. Published Land Cover Nutrient Loading Rates for Non-Sewered Residential

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	1.062	0.170	5.558	8.895	1.320	34.322
Rast & Lee (1978)	0.892			2.230		
Loehr et al. (1989)		0.687	1.963		4.461	6.513
Young et al. (1996)	0.357	0.089	0.981	2.230	0.892	5.888
Letcher et al. (1999) from SKM&WBM Oceanics (1998)	0.178			0.892		
Letcher et al. (1999) from Gourley et al. (1996)	0.625			1.784		
Line et al (2002)	0.892			3.032		
Bladys et al (1998)	0.797			2.664		
Guerard & Weiss (1995)	1.329			6.166		
LADPW (1999)	0.688			3.986		
Harper (1998)	0.756			3.468		
Brezonik and Stadelmann (2001)		0.497	13.157		1.465	19.044

Table 8. Published Land Cover Nutrient Loading Rates for Sewered Residential

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	1.062	0.170	5.558	8.895	1.320	37.025
Rast & Lee (1978)	0.892			2.230		
Loehr et al. (1989)		0.687	1.963		4.461	71.017
Young et al. (1996)	0.357	0.089	0.981		0.892	2.230
Letcher et al. (1999) from SKM&WBM Oceanics (1998)	1.338			8.922		
Letcher et al. (1999) from Gourley et al. (1996)	1.160			1.784		
Line et al. (2002)	1.181			4.523		
Bladys et al. (1998)	1.032			3.949		
Guerard & Weiss (1995)	1.862			9.421		
LADPW (1999)	0.606			4.098		
Harper (1998)	1.372			5.482		
Brezonik and Stadelmann (2001)		0.435	4.247		1.266	

Table 9. Published Land Cover Nutrient Loading Rates for Commercial Urban

Citation	Total Phosphorus (lbs/ac/yr)			Total Nitrogen (lbs/ac/yr)		
	Mean	Min	Max	Mean	Min	Max
Reckhow et al. (1980)	1.062	0.170	5.558	8.895	1.320	34.322
Rast & Lee (1978)	0.892			2.230		
Loehr et al. (1989)		0.089	6.781		1.695	6.513
Young et al. (1996)	0.357	0.089	0.981	2.230	0.892	5.888
Letcher et al. (1999) from SKM&WBM Oceanics (1998)	0.892			6.691		
Letcher et al. (1999) from Gourley et al. (1996)	1.160			1.784		
USEPA (1983)	2.046			12.991		
Smullen et al. (1999)	2.004			12.549		
Line et al. (2002)	1.828			8.298		
Bladys et al. (1998)	1.284			7.694		
Guerard & Weiss (1995)	2.191			15.555		
LADPW (1999)	2.856			14.466		
Harper (1998)	3.038			17.550		
Brezonik and Stadelmann (2001)		1.768	5.094		11.322	20.379

2. Waste Reduction Strategy Land Cover Loading Rates

The original TMDL was based on results from an assessment of the Laguna (CH2M HILL, 1994). Pollutant loads were estimated for both storm event runoff and dry period base flows for six land cover categories (Table 10). These loading rates were derived from a combination of calibrated water quality modeling and source inventory assessment. The loading rates based on land cover were normalized to unit per area load using the areas published by CH2M HILL (Table 11).

Table 10. Pollutant Loads From CH2M HILL (1994)

Pollutant	Land Use	Storm Event (lbs/yr)	Dry Periods (lbs/yr)	Total Annual Load (lbs/yr)
Organic Matter	Urban	5,960,000	0	5,960,000
	Wastewater	7,030	0	7,030
	Non-irrigated Agriculture	427,000	0	427,000
	Dairy	6,050,000	9,410	6,059,410
	Septic	0	0	0
	Open Space	287,000	0	287,000
Total Nitrogen	Urban	246,000	0	246,000
	Wastewater	26,400	398,700	424,400
	Non-irrigated Agriculture	117,000	0	117,000
	Dairy	179,000	530	179,530
	Septic	10,100	21,700	408,800
	Open Space	43,100	0	43,100
Ammonia	Urban	21,400	0	21,400
	Wastewater	3,510	53,100	56,610
	Non-irrigated Agriculture	6,070	0	6,070
	Dairy	179,000	90	179,090
	Septic	2,520	99,400	102,430
	Open Space	1,250	0	1,250

Table 11. Unit Area Land Cover Pollutant Loading Rates From CH2M HILL (1994)

Pollutant	Land Use	Storm Event (lbs/ac/yr)	Dry Periods (lbs/ac/yr)	Total Annual Load (lbs/ac/yr)
Organic Matter	Urban	196.9	0	196.9
	Non-irrigated Agriculture	8.6	0	8.6
	Septic	8.2	0	8.2
	Open Space	8.1	0	8.1
Total Nitrogen	Urban	2.4	0	2.4
	Non-irrigated Agriculture	0.3	0.7	13.1
	Septic	0.7	0	0.7
	Open Space	0.1	0	0.1
Ammonia	Urban	0.1	3.2	3.3
	Non-irrigated Agriculture	0.04	0	0.04
	Septic	196.9	0	196.9
	Open Space	8.6	0	8.6

Regional Water Board staff compared annual loading rates derived by CH2M HILL (1994) to total nitrogen annual loads derived from the LCLM. The CH2M HILL annual load estimates were derived from mean summer base flows and a calibrated model of the 1992-1993 winter storms. Regional Water Board staff assumed the unit area annual loading rates estimated by CH2M HILL represented the 1992-1993 hydrologic year. These data were represented on the load duration curves at a return frequency of 0.21. The return frequency specifies the *percent of time* those *values* have been *met or exceeded*. The use of *"percent of time"* provides a uniform scale ranging between 0 and 100. Thus, the return period for the 1992-1993 hydrologic year implies that 79 percent of all observed annual loads equal or exceed the loads shown in Table 3.11.

The total nitrogen load duration curves that present the 1995 TMDL loading rates developed by CH2M HILL are as follows: 'Open Space" land use loading estimates are presented on the 'Rangelands' land cover load duration curves (Figures 10 & 18). 'Non-irrigated Agriculture' land use loading estimates are presented on the 'Cropland & Pasture' land cover load duration curves (Figures 11 & 19). 'Septic' land use loading estimates are presented on the 'Nonsewered Residential Urban' land cover load duration curves (Figures 13 & 21). 'Urban' land use loading estimates are presented on the 'Commercial' land cover load duration curves (Figures 15 & 23).

3. Dry Weather Loading Rates From Independent Samples

Regional Water Board staff sampled nutrient concentrations of the major tributaries draining to the Laguna shown in Table 12 (NCRWQCB, 2008). These data were not used in the development of the LCLM. The sampling was conducted to measure the distributional qualities of pollutant concentrations in runoff from major tributaries to the

Laguna. Samples were collected during the summer of 2008 which represented drought conditions for the watershed. Samples were collected near the mouth of each tributary to represent base flow from the sub-basins monitored. The land cover loading model appears to corroborate well with the dry weather measured loading based on the statistical hypothesis tests applied.

Table 12. Laguna Tributary Sampling Locations

Tributary Name	Sampling Location
Abramson Creek	Guerneville Road
Blucher Creek	Lone Pine Road
Brush Creek	Highway 12
Colgan Creek	Llano Road
Copeland Creek	Commerce Blvd
Cotati Creek	Delano Park Bridge
Calder Creek	Joe Rodata Trail
Gossage Creek	Highway 16
Hinebaugh Creek	Labath Avenue
Matanzas Creek	Brookwood Road
Mark West Creek	Slusser Road
Peterson Creek	Guerneville Road
Piner Creek	Fulton Road
Turner Creek	Daywalt Road
Vine Hill Creek	Laguna Road
Washoe Creek	Derby Lane
Wilfred Creek	Stony Point Road
Windsor Creek	Mark West Station Road

Each of these tributary sub-basins represents a mix of different land uses. The concentrations measured from each of the sub-basins also represent that mix of land uses. The proportions of each land cover in the sub-basin were compiled for use in model corroboration. The National Elevation Dataset (USGS, 2006) 10-meter resolution topography layer was used to delineate sub-basins that drain to the sampling locations using the flow-line vector data to adjust the channel routing within the elevation data. The area of each selected land cover was determined for each sub-basin.

The proportions of each land cover in the sub-basin were applied to the unit per area loads for an estimate on the loading rates for each sub-basin. Monte-Carlo simulation was used to estimate the distribution of loads through uniform random selection of measured dry weather unit area loads. Monte Carlo Simulation is a stochastic method that accounts for the inherent variability of data sets. Dry weather loads were calculated from the probability distributions of measured concentrations applied to the estimated site base flow. Base flows were estimated from the mean 3-day antecedent flow at the

USGS gaging location at Trenton-Healdsburg Road scaled proportionately based on the drainage areas of the site and the gage.

The unit per area loads distributional forms were evaluated using the one-sample Kolmogorov-Smirnov hypothesis test. The test compares the shape and location of cumulative distribution frequency to other distribution samples. All unit per area loads were found to follow a natural log distribution.

Two different hypothesis tests were applied to compare the estimated dry weather loading from the land cover model to the measured dry weather loads. First, the Mann-Whitney test was used to assess whether measured and estimated data sets have the same population medians. This statistical test is a distribution-free inferential statistical method that does not require the population to follow a normal distribution. The test null hypothesis is that the two samples are drawn from identically distributed populations. The test is similar to performing an ordinary parametric two-sample *t* test, but is based on ranking the data set. The Mann-Whitney tests failed to detect any significant differences ($\alpha = 0.05$) between measured loads and loads estimated by the land cover model for all sub-basins and constituents assessed.

The second hypothesis test applied was the Z-test. A Z-test evaluates whether the sample mean is the same as the population mean. All data were natural log transformed before assessment since the Z-test requires normally distributed data. Two-tailed probabilities returned from the Z-test shows that almost all comparisons failed to find a significant difference ($\alpha = 0.05$) between the natural log-means of observed and measured populations. Only one percent of the Z-test results inferred that the estimated versus measured sub-basin load log-means were different (5 out of 483 tests with 69 samples with 7 constituents). The land cover loading model appears to corroborate well with the dry weather measured loading based on both of the statistical hypothesis tests applied.

4. Wet Weather Loading Rates From the GWLF Model

The fourth approach used by Regional Water Board staff to corroborate the LCLM loading rates was the Generalized Watershed Loading Functions (GWLF) model, which was specifically used to estimate pollutant loading from mixed land cover watersheds (Haith et al., 1992). Enhancements to the original model have been incorporated into the BasinSim model (Dai et al., 2000). These enhancements include in-stream routing, a sediment transport component, and the Muskingum-Cunge method for flow routing.

The results from the GWLF model output provide an additional estimate of tributary loading to the Laguna and are summarized by Butkus (2010). The GWLF model used the independent dry period loads measured in 2008 for ground water and base flow concentrations. The GWLF model simulates wet period loading using dynamic runoff flows, sediment delivery, and land use-based state variables and parameters.

The GWLF model results provided an estimate of continuous loading of nutrients for 18 tributary sub-basins in the Laguna watershed. The estimated annual loading rates derived with the LCLM model were compared to the annual loading rates estimated by the GWLF model. Four model performance metrics were used to evaluate the difference between the two estimates for each tributary sub-basin. The review of all four performance metrics demonstrates that the LCLM and GWLF models overall produce generally similar estimates of pollution loads, with a wide variation between tributary load estimates. Overall, the GWLF model over-estimates both total phosphorus and total nitrogen as compared to the LCLM estimates.

5. Model Application

Comparison of Current Loads by Land Cover & Climate

The LCLM was applied to produce load duration curves for each land cover to represent estimated changes in annual loads over a range of stream flow conditions in Figures 9 to 24. These load duration curves were based on samples collected during wet periods and dry weather periods. The median total phosphorus loading rates for wet and dry weather period are compared for each land cover class in Figure 25. The loading rates during wet weather are much larger for most land covers classes, except Orchards & Vineyards which has similar, but low loading rates.

The median total phosphorus loading rates for each land cover are compared with different y-axis scales for wet and dry weather periods in Figure 26. Wet weather loading rates show no obvious pattern except for the low values for the Orchards & Vineyards land cover class. The patterns indicate that managed and disturbed land generally have higher loading rates during dry weather than natural areas (i.e., Forest and Rangeland land cover classes). Management of dry weather loading may be more important that wet weather loading since the critical conditions for eutrophication impacts are during dry weather periods. The two agricultural land cover classes (Cropland & Pasture, Orchards & Vineyards) show the highest total phosphorus loading rates during the critical dry weather periods.

The median annual total phosphorus loads for wet and dry weather periods was derived for the entire Laguna watershed based on the acreages of the individual land cover classes (Figure 27). The large wet weather loads for unmanaged land covers is due to the large acreage of those areas in the watershed (i.e., Forest & Rangelands). The lowest annual dry load was measured from Commercial & Services land cover classes. Dry weather base flow from these areas is likely to contain runoff from over-irrigation from treated domestic water flowing onto impervious surfaces. The largest annual dry loads are the two agricultural land cover classes (Cropland & Pasture, Orchards &

Vineyards). The same two land covers also showed the highest loading rates (Figure 26). Dry weather base flow from these areas is likely to contain recycled wastewater.

Comparison of Current Loads to Pre-Settlement Loads

Load duration curves were developed for each of the historical open water catchments from the loading distributions derived for each of the land cover categories. Current and pre-settlement load duration curves were developed to compare each of the historical open water catchment areas (Butkus, 2010). These load duration curves represent the net load delivered to wetland areas prior to discharge to receiving waters.

Regional Water Board staff applied the loading rate estimates to current and pre-settlement land cover areas within four catchment basins of the Laguna watershed. The catchment areas are based on the area of the watershed that drained to the historical open water areas of the mainstem Laguna and were delineated by combining the subwatersheds derived from the National Elevation Dataset (USGS, 2006) 10-meter resolution topography layer. The four catchment areas are listed in Table 13 and shown in Figure 28. Combining all four catchments cover the whole Laguna watershed draining to the Russian River.

Table 13. Catchments for Historical Open Water Areas

Historical Catchment	Major Tributaries	Acres	Percent of Watershed
Cunningham Lake	Copeland Creek, Blucher Creek	49,817	29%
Sebring Lake	Santa Rosa Creek	68,402	39%
Ballard Lake	Mark West Creek	36,337	21%
Lower Laguna Catchment	Windsor Creek	18,973	11%

Within the four catchment areas, Regional Water Board staff applied an estimated reduction in pollutant loads due to wetland assimilation. Staff then compared the results for current loads to pre-settlement loads. The following sections describe these efforts.

Wetland Assimilation of Pollutant Loads

As part of the conceptual model, Regional Water Board staff estimated the reduction of pollutant loads due to attenuation of nutrients by natural processes in both riparian wetlands and perennial wetlands.

Riverine Wetlands

Riverine wetlands are known to reduce pollutants from surface water runoff and groundwater (Naiman and Decamps, 1997). USEPA (2005) surveyed peer-reviewed scientific literature containing data on the effect of riparian wetland buffers on nitrogen concentration in streams and groundwater. Nitrogen removal effectiveness varied widely among the different riparian zones studied. Surface removal of nitrogen was partly related to buffer width, but was only one factor controlling nitrogen removal effectiveness. Subsurface removal of nitrogen was not related to buffer width. Subsurface removal of nitrogen in riparian buffers was often high, especially where anaerobic conditions promote microbial denitrification. Buffers of various vegetation types were equally effective at removing nitrogen in the subsurface but not in surface flow. The mean nitrogen removal effectiveness of forested riparian wetlands was found to be 85 percent with a standard error of 5.2 percent (USEPA, 2005).

Riverine wetland areas can be important sinks for phosphorus and suspended sediment. USEPA (1993) compiled representative research results to document the effectiveness of riparian areas in reducing other pollutant loads. Riparian areas provided a median of 65 percent removal of phosphorus load (USEPA, 1993). The primary mechanism for phosphorus removal is the deposition of phosphorus associated with sediments (Brinson et al., 1984; Walbridge and Struthers 1993). Dissolved phosphorus is primarily removed from runoff through adsorption by clay particles (Cooper and Gilliam, 1987). USEPA (1993) found that riparian areas can remove up to 50 percent of the suspended sediment loads.

David W. Smith Consulting (1990) estimated that ninety-two percent (92%) of the riparian areas have been lost in the Laguna and Santa Rosa Plain. Pollutant loading reduction from riparian wetlands was assumed to represent the maximum amount of assimilative capacity possible based on published effectiveness. Based on USEPA published estimates of pollutant load removal, pre-settlement total phosphorus and total nitrogen loads were reduced by 65 percent and 85 percent, respectively. Pollutant loading reduction from current riparian areas was reduced proportionally with the percent loss of these areas assuming the same degree of loss in landscape assimilative capacity as compared to pre-settlement conditions. Therefore, estimates of current total phosphorus and total nitrogen loads were reduced by 2.8% and 1.2%, respectively, by current riparian areas.

Perennial Wetlands

Perennial wetland microbial populations can transform and remove nutrients from runoff from the pre-settlement landscape. The conceptual model for estimating pre-settlement nutrient loading is based on the reduction of loading by perennial wetland areas before discharge to receiving waters. Hydrologic conditions are extremely important to wetlands structure and function by affecting anaerobic bacterial activity and nutrient availability. Physical wetland features, such as hydroperiod, water depths, and saturation duration, affect processes that support the biotic functions of the wetland system.

PREWet, a simple wetland model developed by the U.S. Army Corps of Engineers, was used to estimate the amount of water quality improvement provided by the perennial wetlands (Dortch and Gerald, 1995). With basic characteristics about the wetland, pollutant removal efficiency can be computed for total suspended solids, biochemical oxygen demand, and nutrients. The removal efficiency depends on the wetland detention time and the removal rate for the constituent. The model calculates removal rate coefficients based on ambient conditions and a number of processes, such as microbial metabolism, adsorption, volatilization, denitrification, and settling. The model computes wetland outflow concentrations for each constituent. Current perennial wetland areas were identified form the spatial data compiled by the 2003 County of Sonoma County General Land Use Plan.

Load Reductions from Wetland Assimilation

Reduction in loads from both riverine and perennial wetland areas was applied to the current and pre-European settlement load duration curves derived for each of the historical open water catchment areas in Butkus (2010). The load duration curves presented show the net load delivered to wetland areas prior to discharge to receiving waters. These catchment loads were reduced based on the catchment-specific riverine and perennial wetland areas.

Results of pollutant load reduction from wetland removal were compared for the median return period (Table 14). Most of the pollutant load removal by wetland assimilation has been lost due to the smaller areas of wetland found currently as compared to pre-settlement conditions.

Table 14. Wetland Loading Assimilation

Historical Catchment	Total Phosphorus			Total Nitrogen		
	Pre-Settlement Load Removal	Current Load Removal	Change in Load Reduction	Pre-Settlement Load Removal	Current Load Removal	Change in Load Reduction
Cunningham Lake	89%	6%	-83%	73%	5%	-68%
Sebring Lake	75%	8%	-67%	33%	6%	-27%
Ballard Lake	68%	3%	-65%	8%	2%	-6%
Lower Laguna Catchment	77%	8%	-69%	38%	7%	-31%
Laguna Watershed	77%	6%	-71%	38%	5%	-33%

Nutrient Loading to Receiving Waters

Catchment loading rates to the receiving water after wetland assimilation was compared visually with load duration curves (Figures 29 to 32) and are shown in Table 15 for the median return period. Current nutrient loads to receiving water have increased by several orders of magnitude over pre-settlement times.

Table 15. Current and Pre-Settlement Nutrient Loading Rates

Historical Catchment	Total Phosphorus			Total Nitrogen		
	Pre-Settlement Load (lbs/ac-yr)	Current Load (lbs/ac-yr)	Change in Load (%)	Pre-Settlement Load (lbs/ac-yr)	Current Load (lbs/ac-yr)	Change in Load (%)
Cunningham Lake	0.04	2.26	4,921%	0.04	3.68	8,524%
Sebring Lake	0.11	1.90	1,602%	0.12	3.67	3,018%
Ballard Lake	0.13	1.38	972%	0.13	2.19	1,553%
Lower Laguna Catchment	0.05	1.81	3,430%	0.06	2.94	4,666%
Laguna Watershed	0.09	1.86	2,481%	0.10	3.25	4,218%

Total annual phosphorus loads were derived for a median return period year for the entire Laguna watershed area to include the effect of wetland assimilation (Table 16; Figure 33). Estimates of wetland assimilation of land cover loads are similar for both pre-settlement and current conditions. A small percentage reduction (i.e., 6%) to the high current land cover load results in a similar load reduction as a large percentage reduction (i.e. 77%) to the relatively low pre-settlement land cover load. Even if all wetland assimilation function could be returned to the landscape, the annual loading would still be 23 times greater due to the conversion of land use.

Table 16. Current and Pre-Settlement Annual Total Phosphorus Loading

Period	Land Cover Load (lbs/year)	Wetland Load Removal (%)	Wetland Assimilation (lbs/year)	Receiving Water Load (lbs/year)
Pre-settlement	15,024	77%	-11,586	3,438
Current	302,499	6%	-19,069	283,430
Current with Pre-settlement wetland assimilation	302,499	77%	-232,924	69,574

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Figures

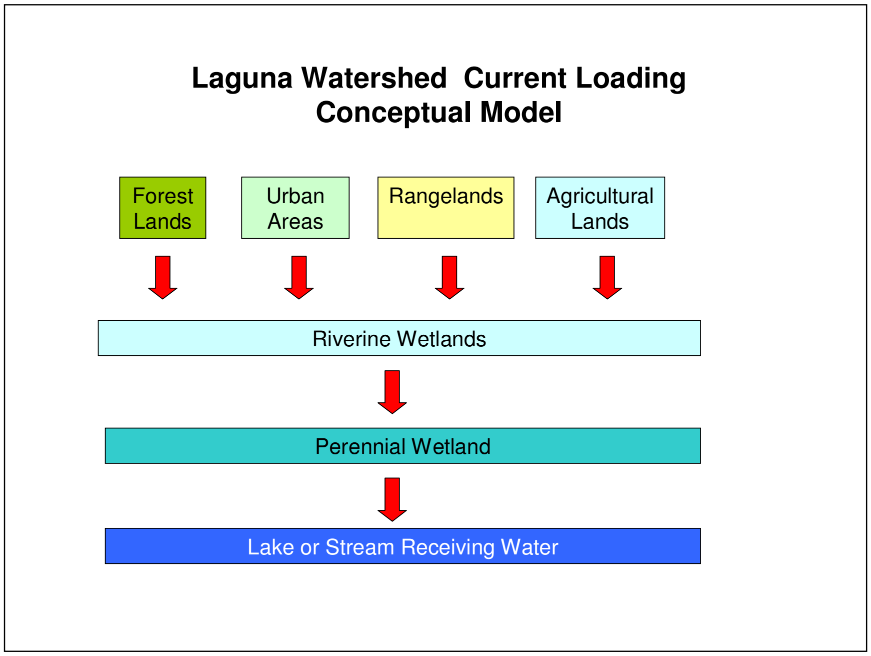

Figure 1. Laguna Watershed Current Loading Conceptual Model

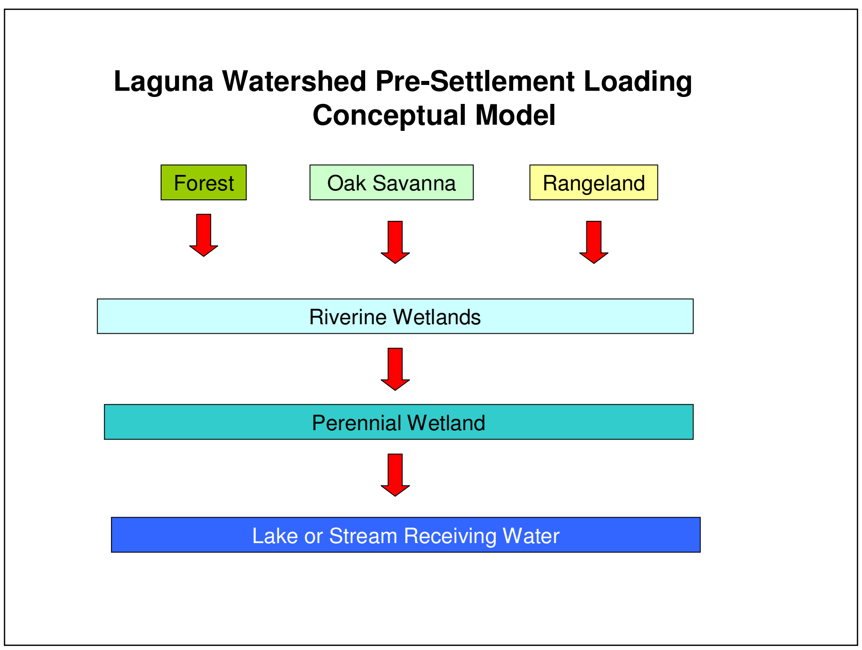

Figure 2. Laguna Watershed Pre-European Settlement Loading Conceptual Model

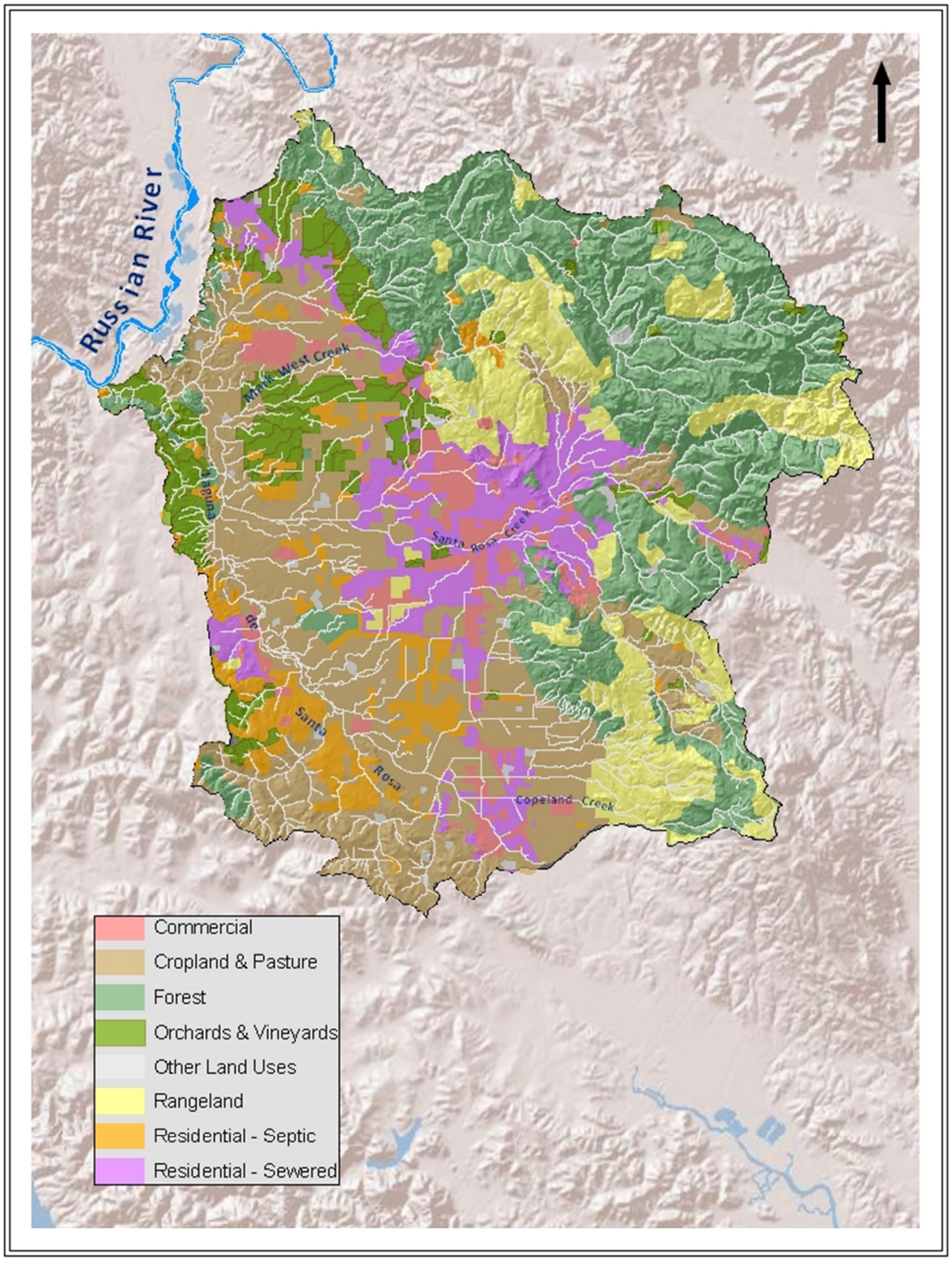

Figure 3. Current Laguna Watershed Land Cover Areas

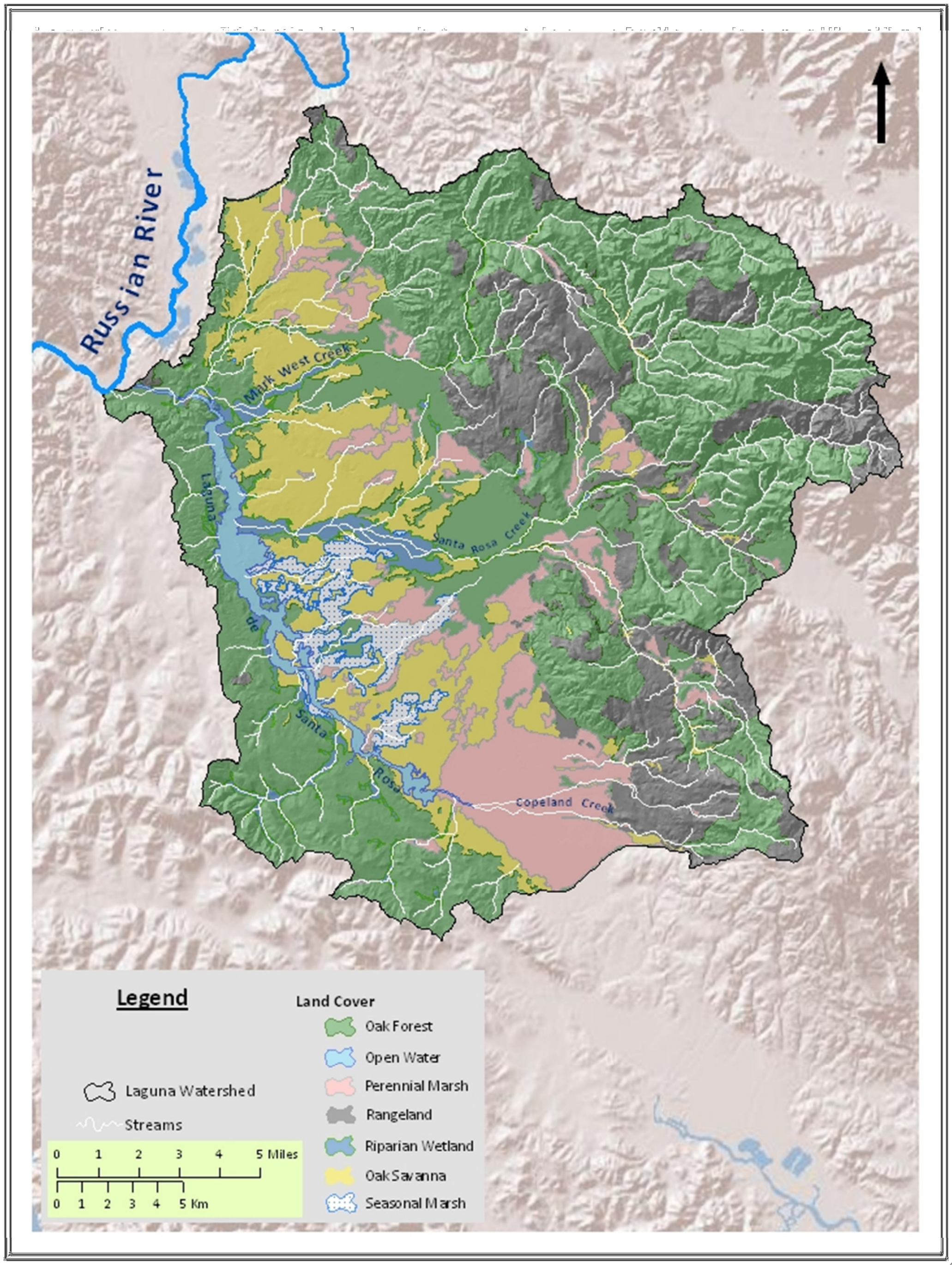

Figure 4. Laguna Watershed Land Cover Map prior to European Settlement

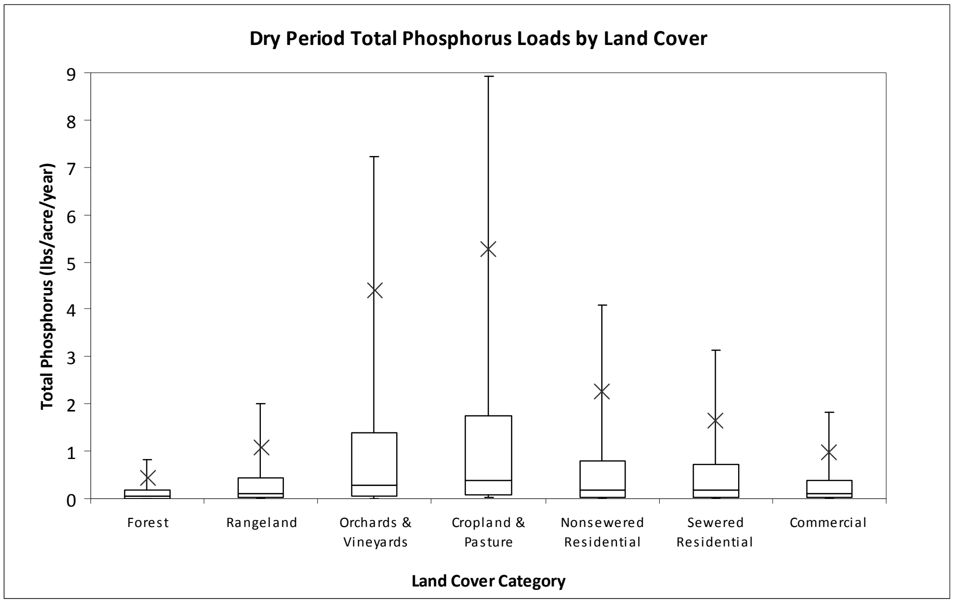

Figure 5. Dry Period Total Phosphorus Load from Selected Land Covers
Box plots provide a concise graphical display summarizing the distribution of a data set (Helsel and Hirsch, 2002). The top and bottom of the box represent the lower and upper quartiles with the band near the middle of the box showing the median. The whiskers represent the 10^{th} and 90^{th} percentiles. The mean is shown as a cross system on the box plot.

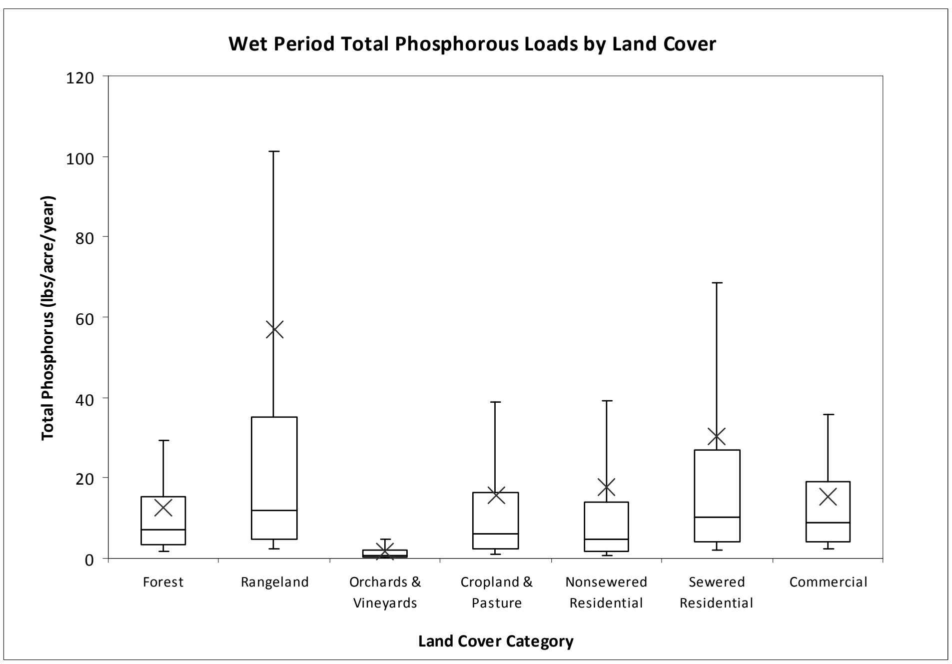

Figure 6. Wet Period Total Phosphorus Load from Selected Land Covers
Box plots provide a concise graphical display summarizing the distribution of a data set (Helsel and Hirsch, 2002). The top and bottom of the box represent the lower and upper quartiles with the band near the middle of the box showing the median. The whiskers represent the 10^{th} and 90^{th} percentiles. The mean is shown as a cross system on the box plot.

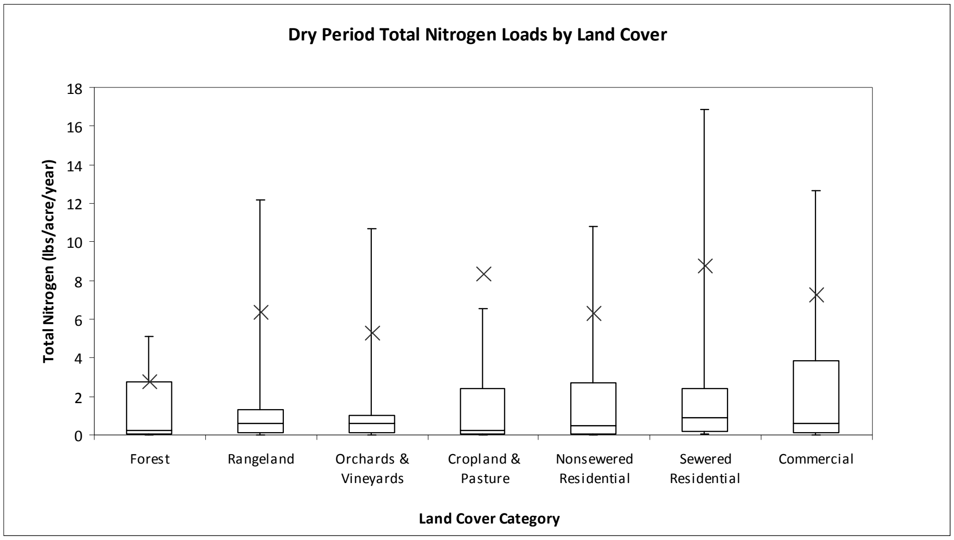

Figure 7. Dry Period Total Nitrogen Load from Selected Land Covers
Box plots provide a concise graphical display summarizing the distribution of a data set (Helsel and Hirsch, 2002). The top and bottom of the box represent the lower and upper quartiles with the band near the middle of the box showing the median. The whiskers represent the 10th and 90th percentiles. The mean is shown as a cross system on the box plot.

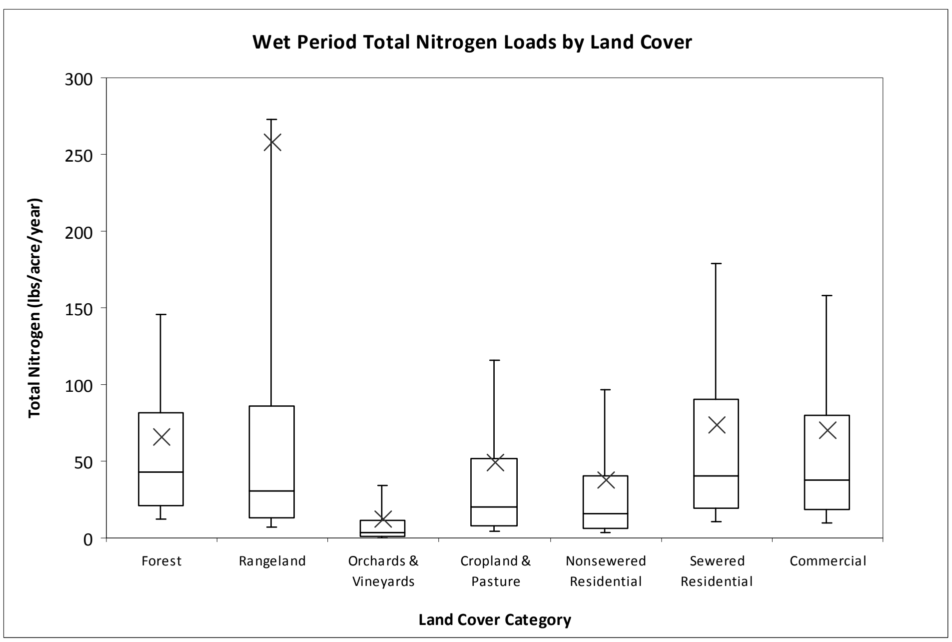

Figure 8. Wet Period Total Nitrogen Load from Selected Land Covers
Box plots provide a concise graphical display summarizing the distribution of a data set (Helsel and Hirsch, 2002). The top and bottom of the box represent the lower and upper quartiles with the band near the middle of the box showing the median. The whiskers represent the 10th and 90th percentiles. The mean is shown as a cross system on the box plot.

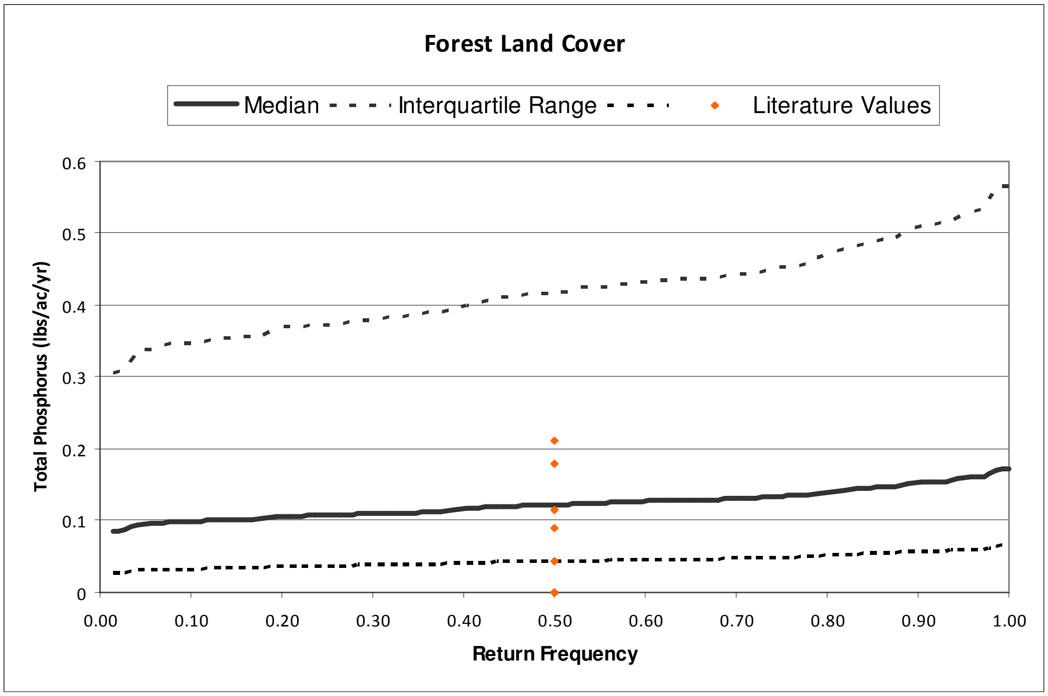

Figure 9. Forest Land Cover Total Phosphorus Load Duration Curve

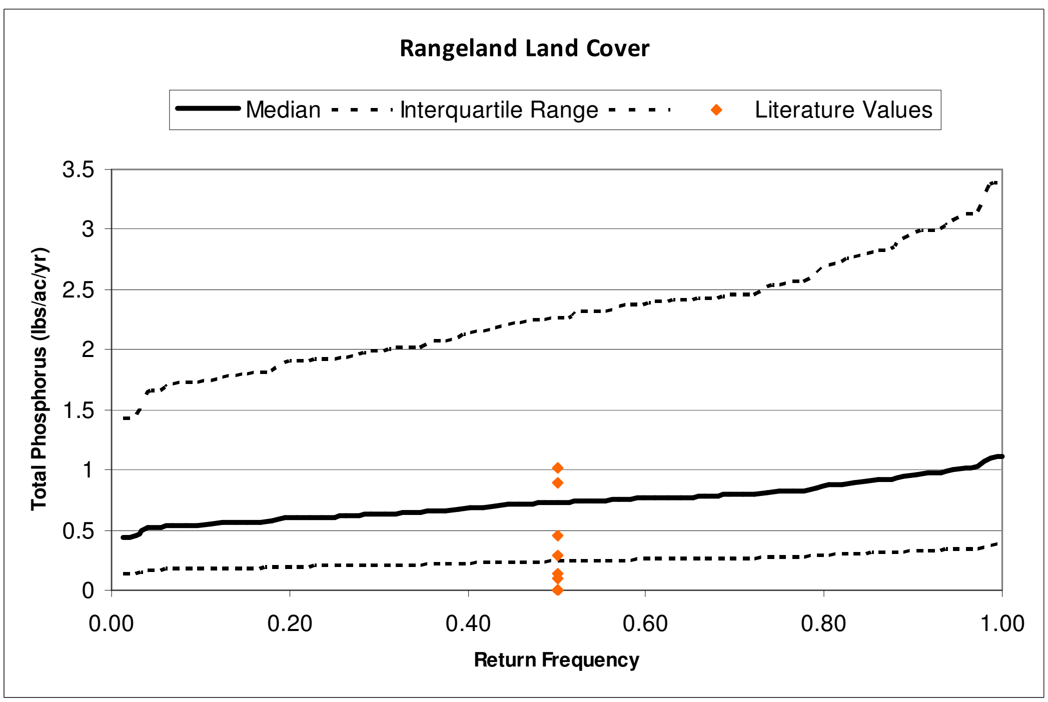

Figure 10. Rangeland Land Cover Total Phosphorus Load Duration Curve

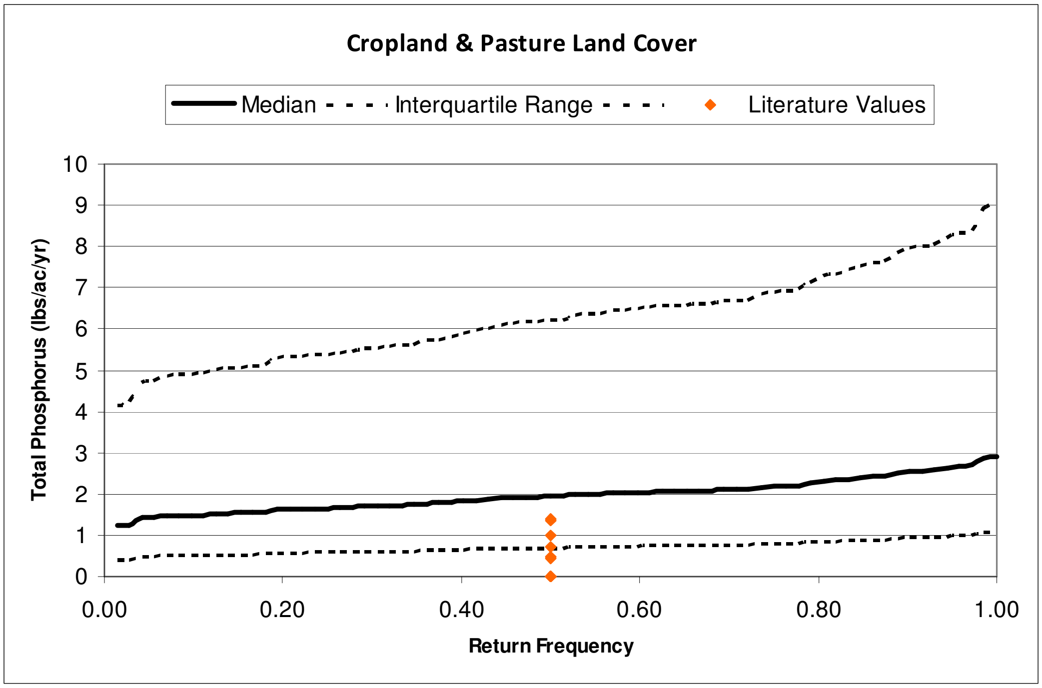

Figure 11. Cropland & Pasture Land Cover Total Phosphorus Load Duration Curve

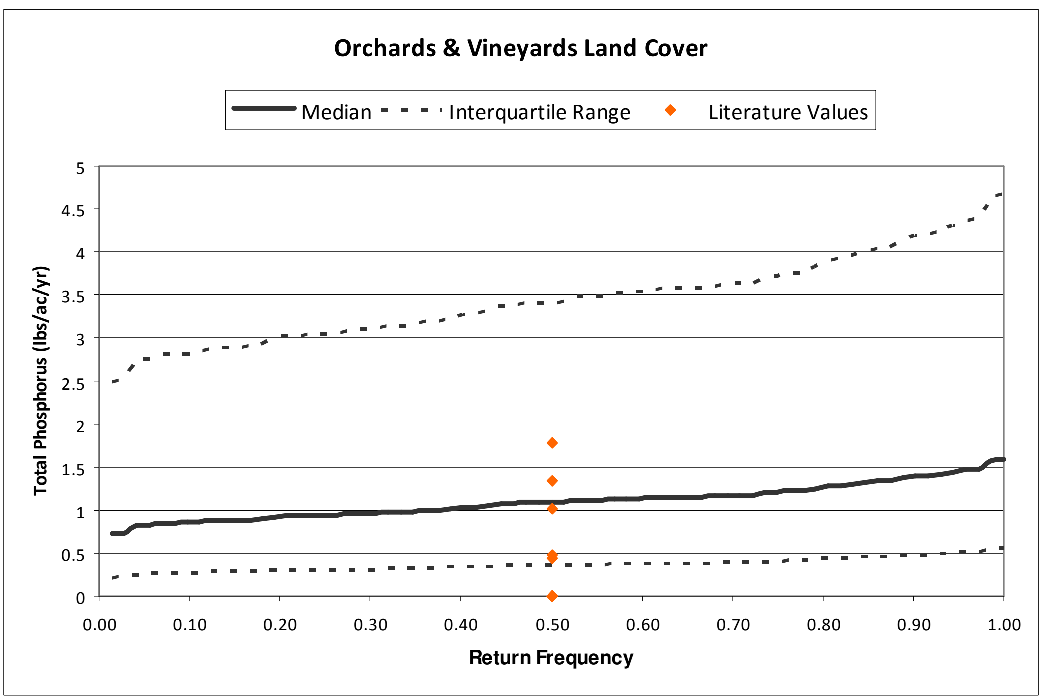

Figure 12. Orchards & Vineyards Land Cover Total Phosphorus Load Duration Curve

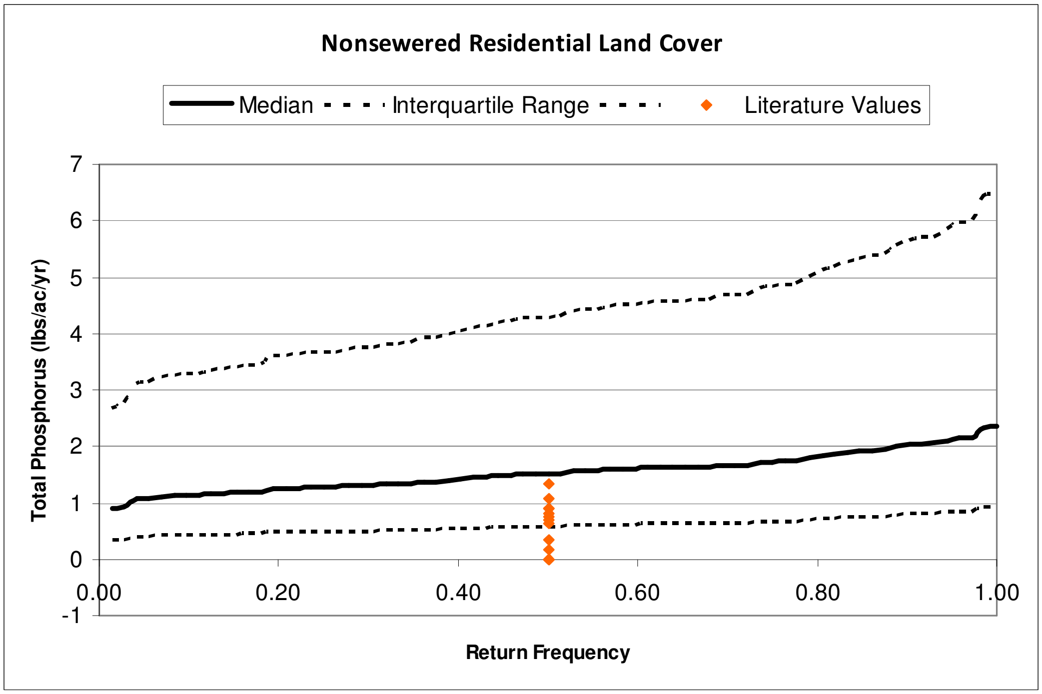

Figure 13. Nonsewered Residential Land Cover Total Phosphorus Load Duration Curve

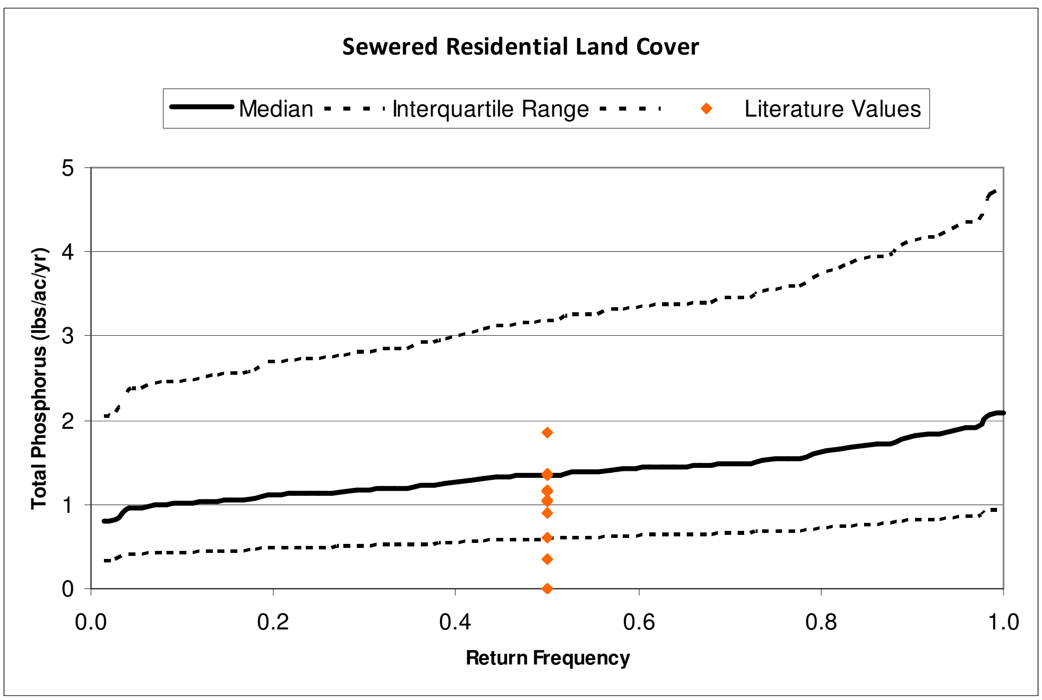

Figure 14. Sewered Residential Land Cover Total Phosphorus Load Duration Curve

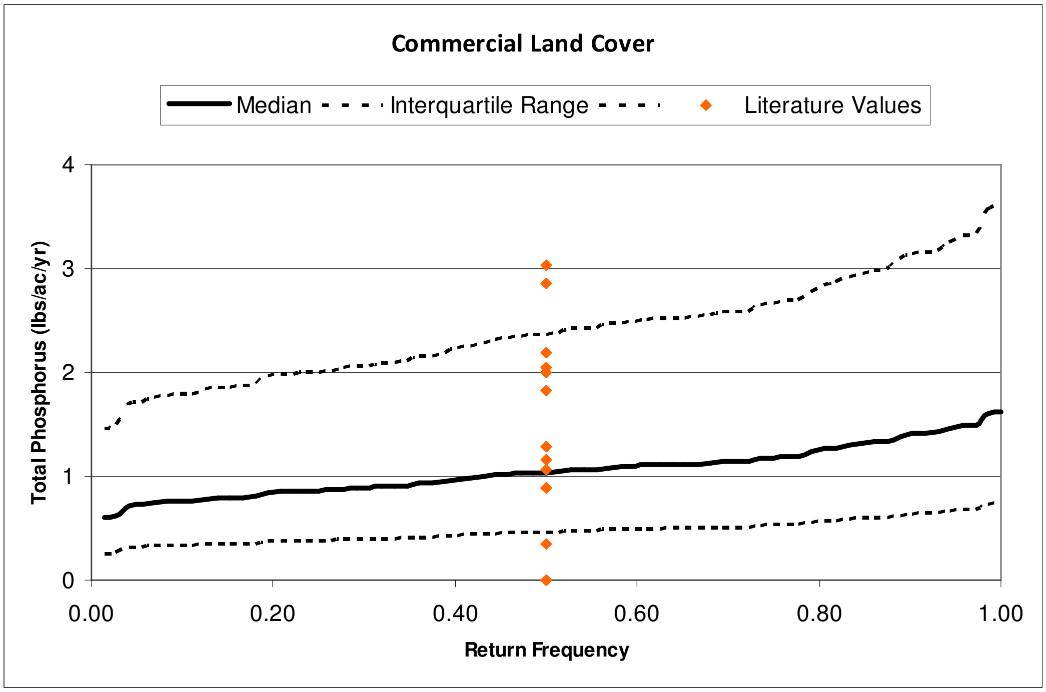

Figure 15. Commercial Land Cover Total Phosphorus Load Duration Curve

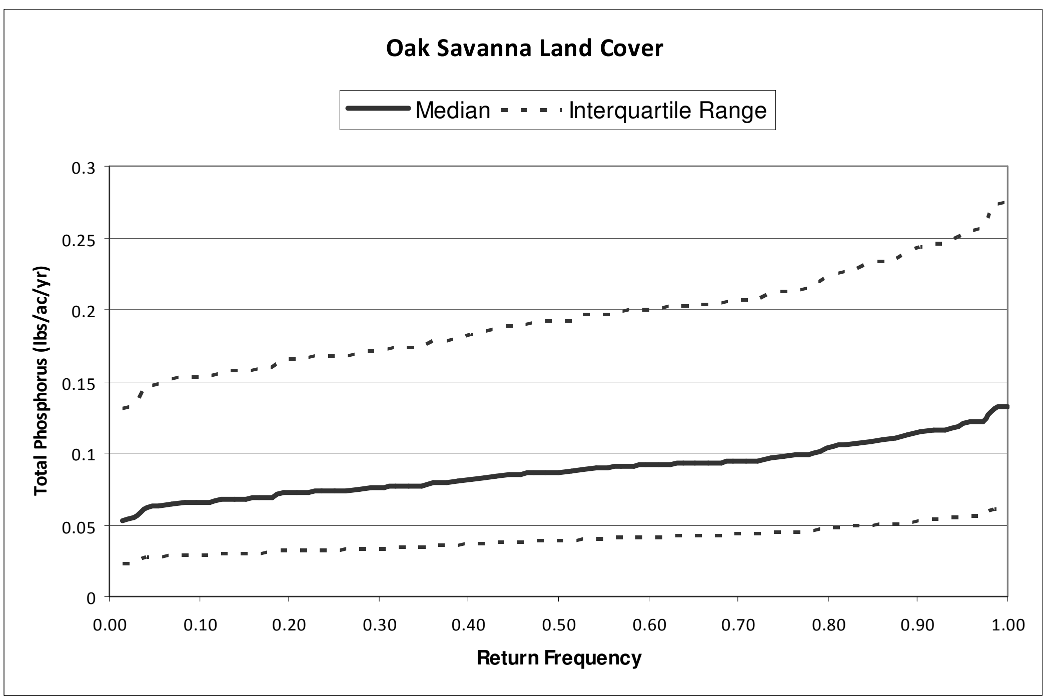

Figure 16. Oak Savanna Land Cover Total Phosphorus Load Duration Curve

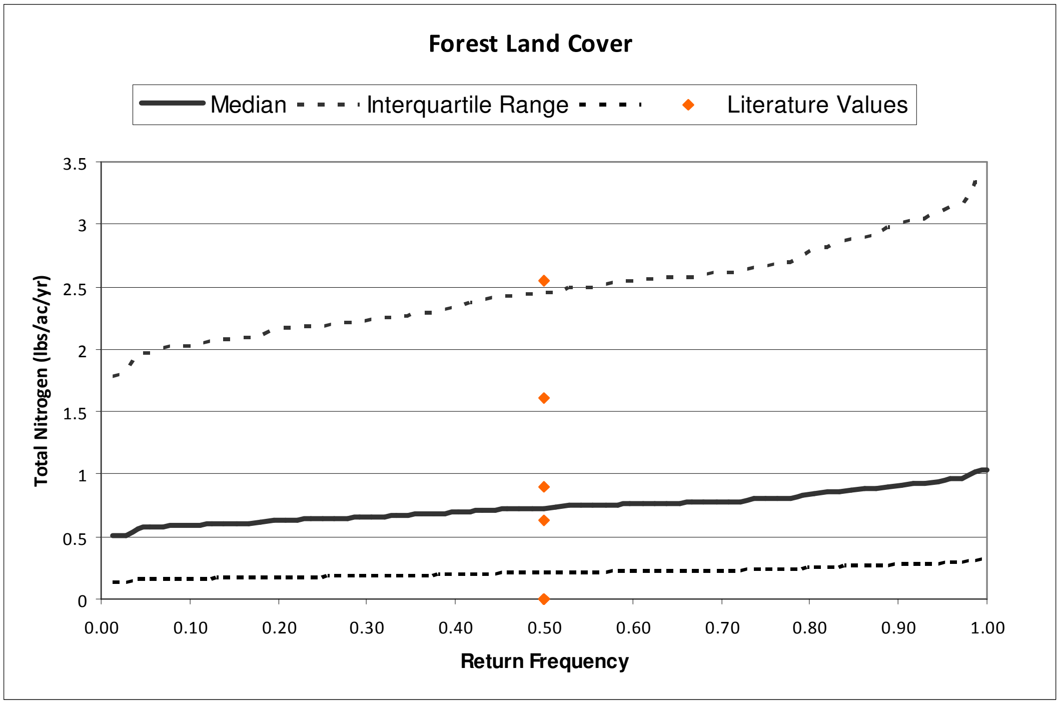

Figure 17. Forest Land Cover Total Nitrogen Load Duration Curve

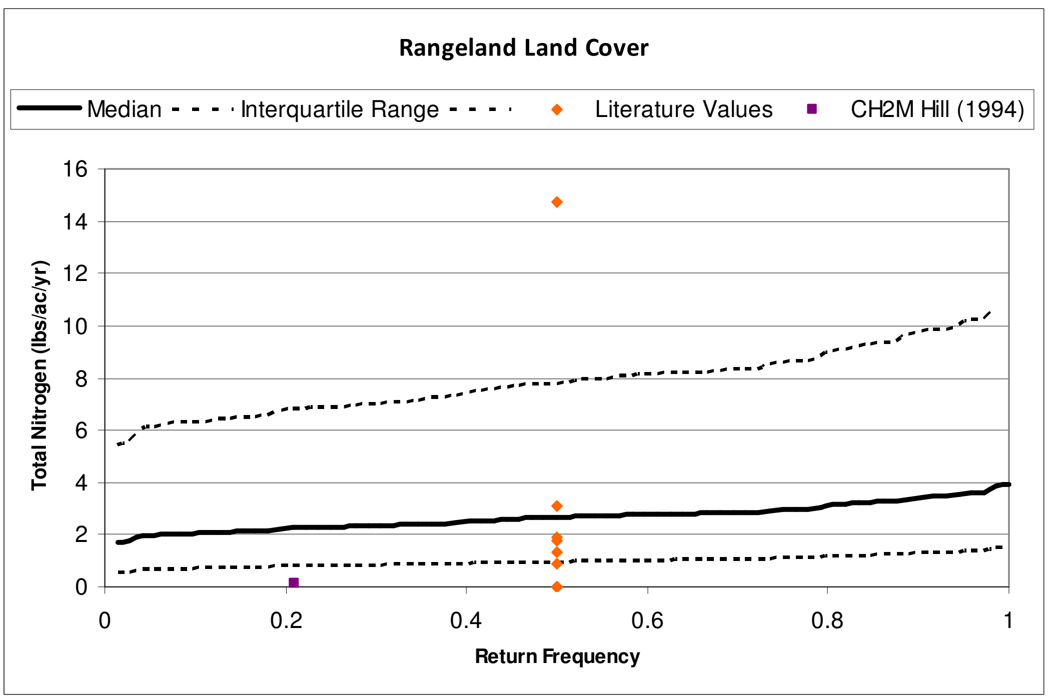

Figure 18. Rangeland Land Cover Total Nitrogen Load Duration Curve

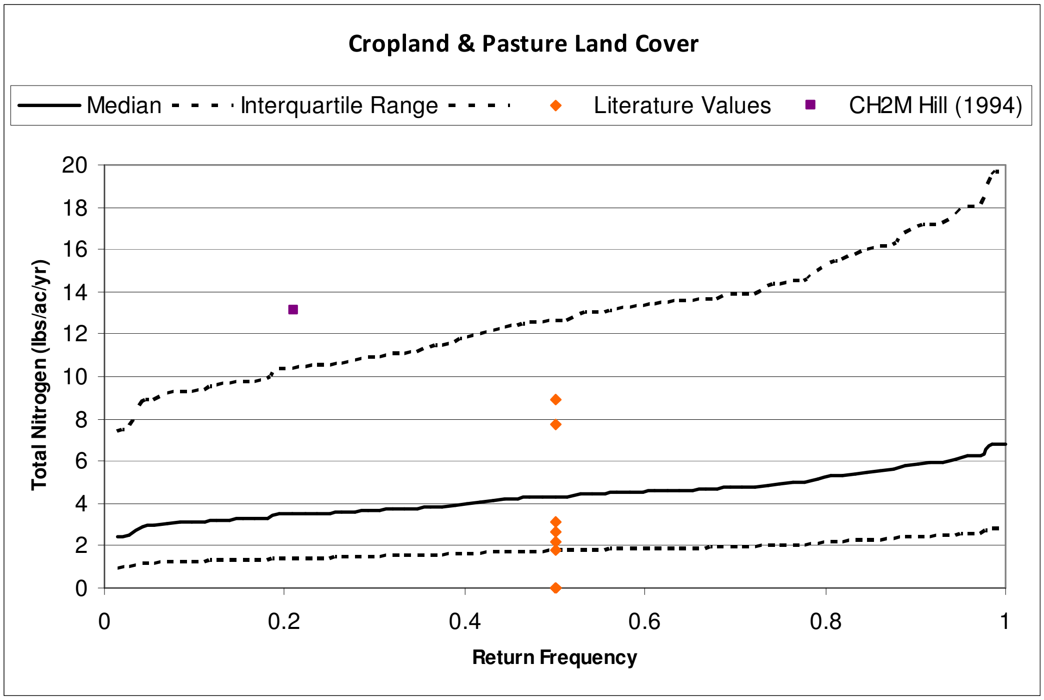

Figure 19. Cropland & Pasture Land Cover Total Nitrogen Load Duration Curve

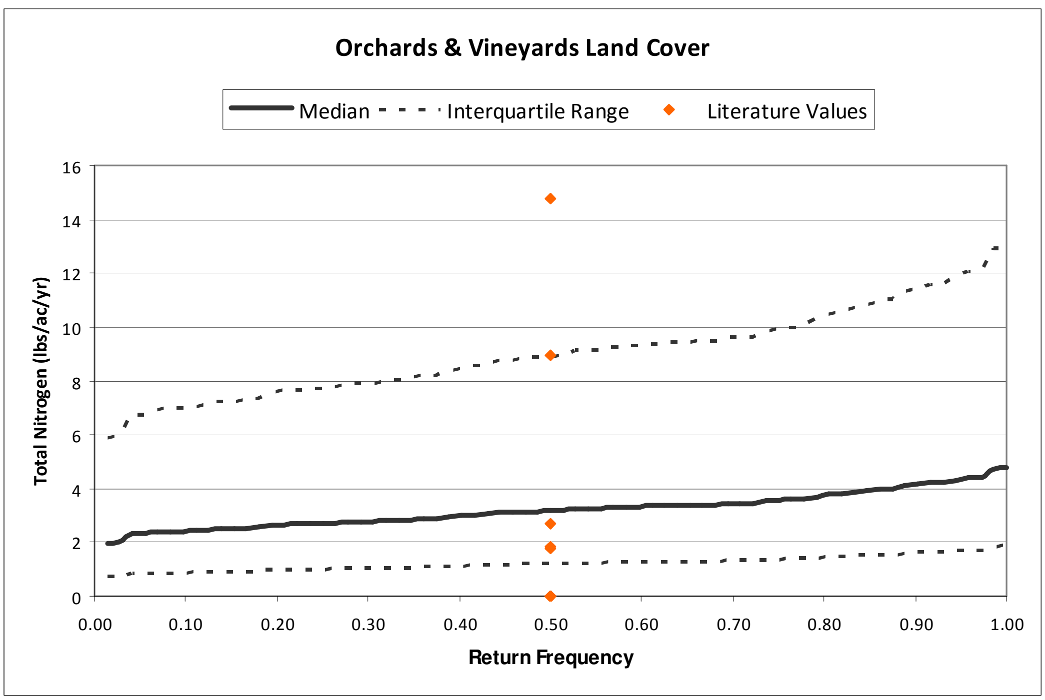

Figure 20. Orchards & Vineyards Land Cover Total Nitrogen Load Duration Curve

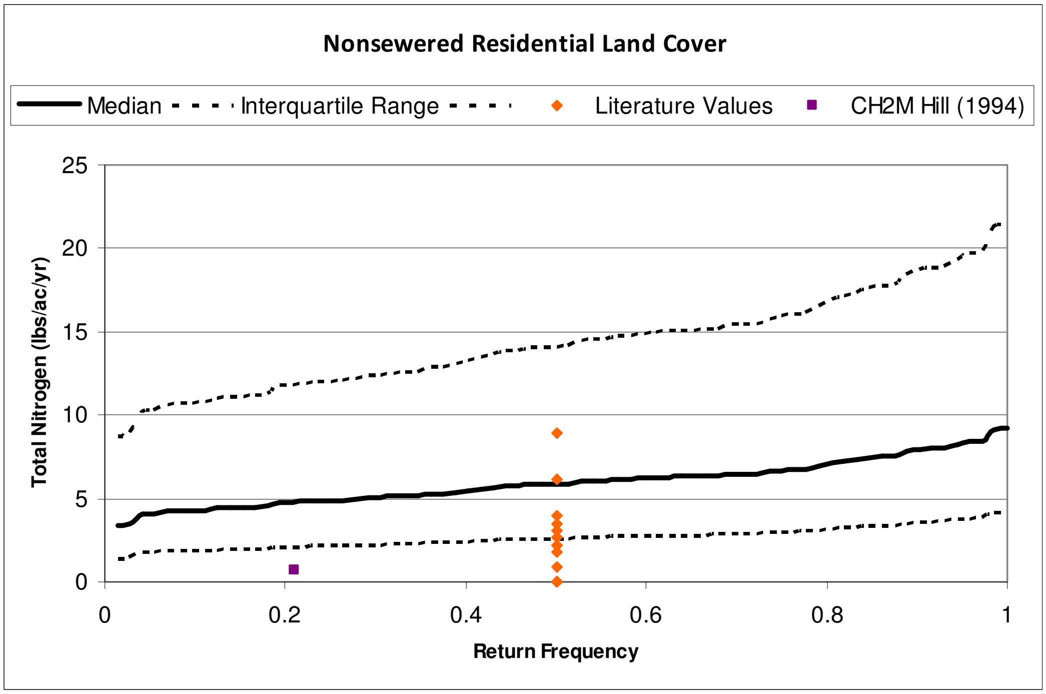

Figure 21. Nonsewered Residential Land Cover Total Nitrogen Load Duration Curve

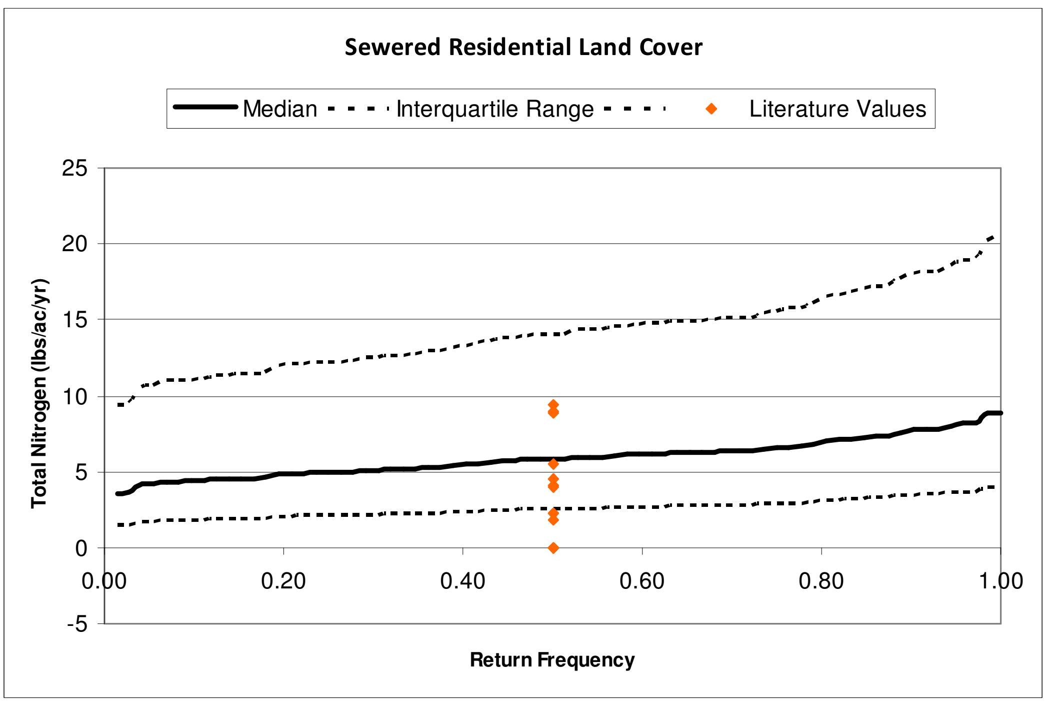

Figure 22. Sewered Residential Land Cover Total Nitrogen Load Duration Curve

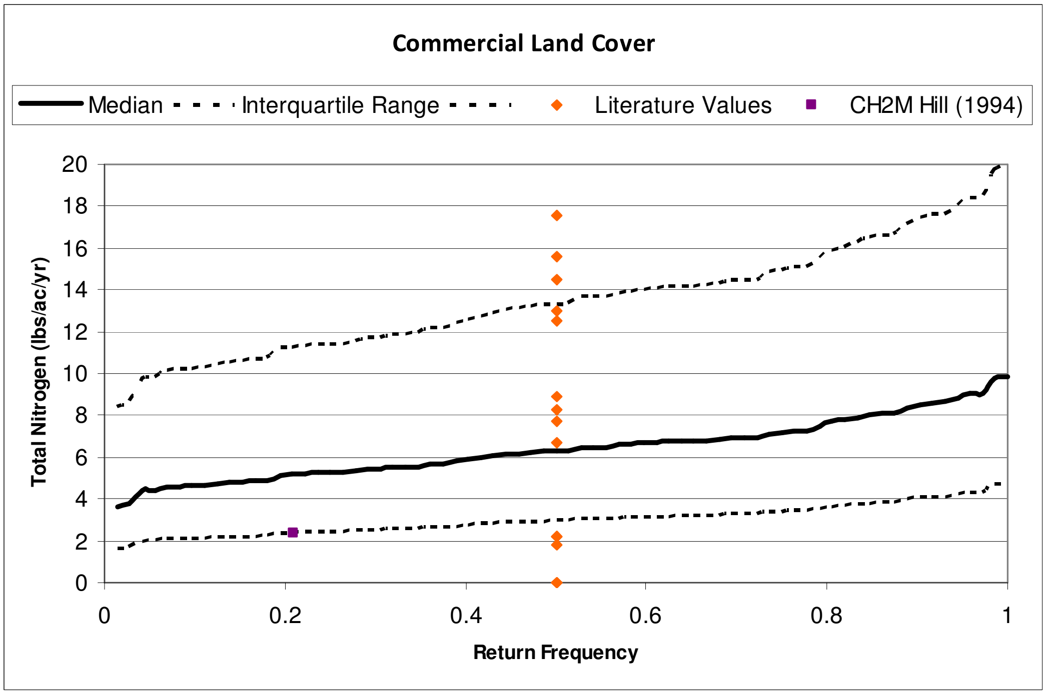

Figure 23. Commercial Land Cover Total Nitrogen Load Duration Curve

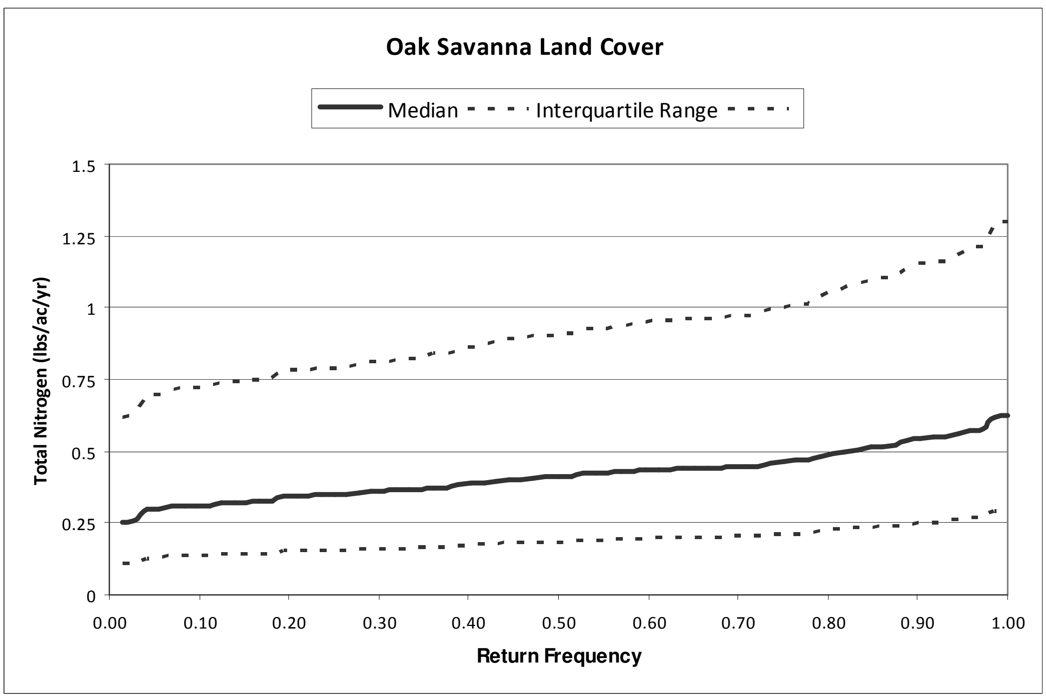

Figure 24. Oak Savanna Land Cover Total Nitrogen Load Duration Curve

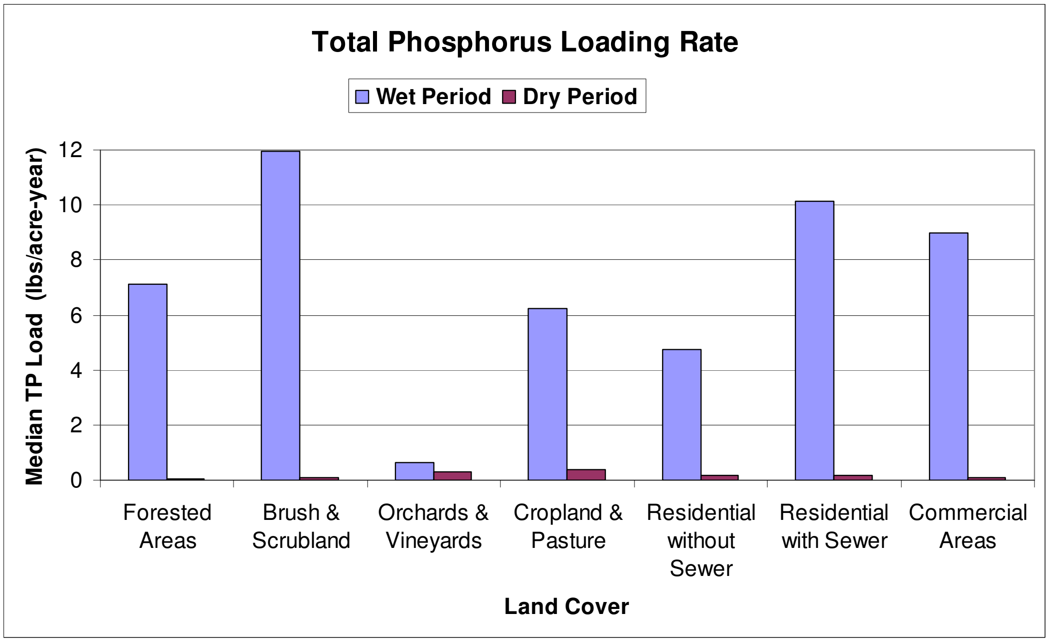

Figure 25. Median Wet and Dry Period Total Phosphorus Loading Rates by Land Cover

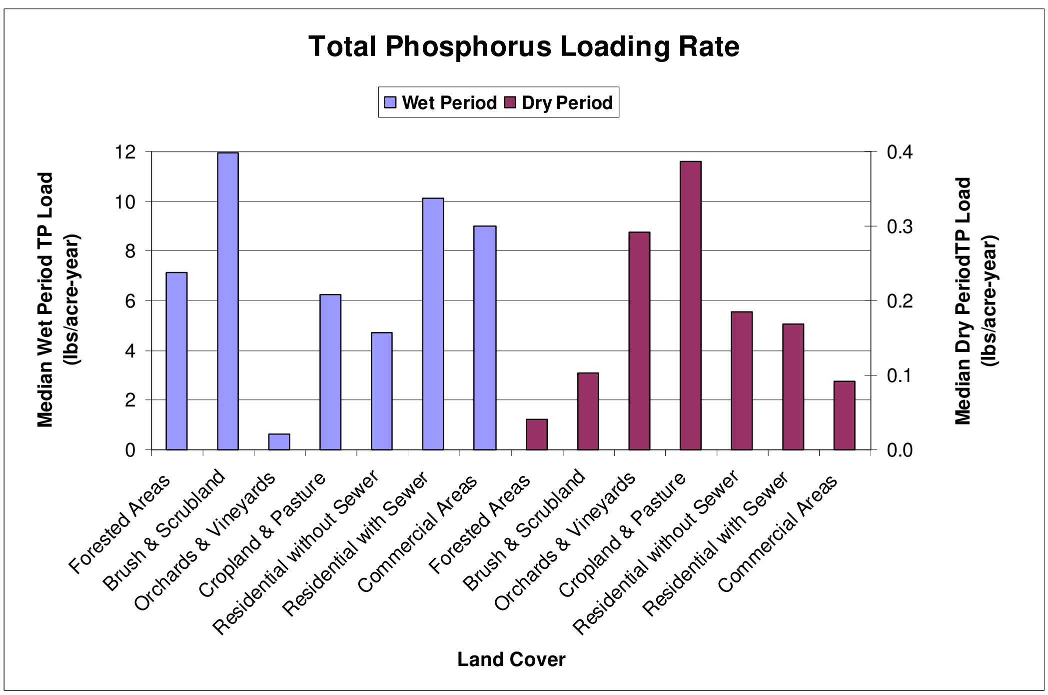

Figure 26. Land Cover Median Total Phosphorus Loading Rates by Wet and Dry Period

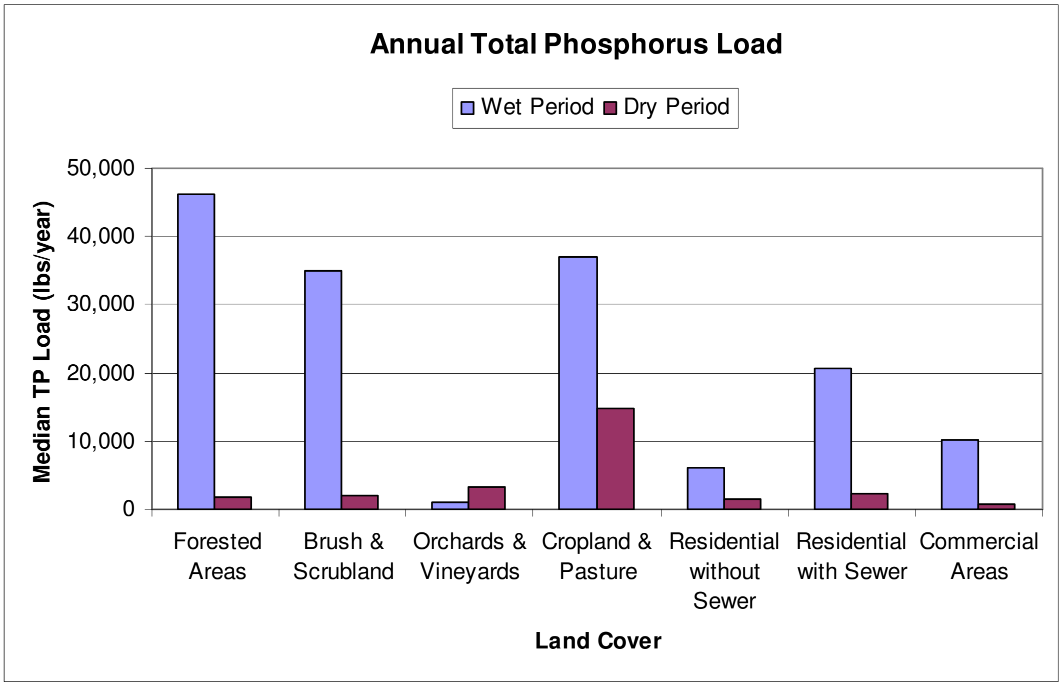

Figure 27. Median Wet and Dry Period Total Phosphorus Annual Loading by Land Cover

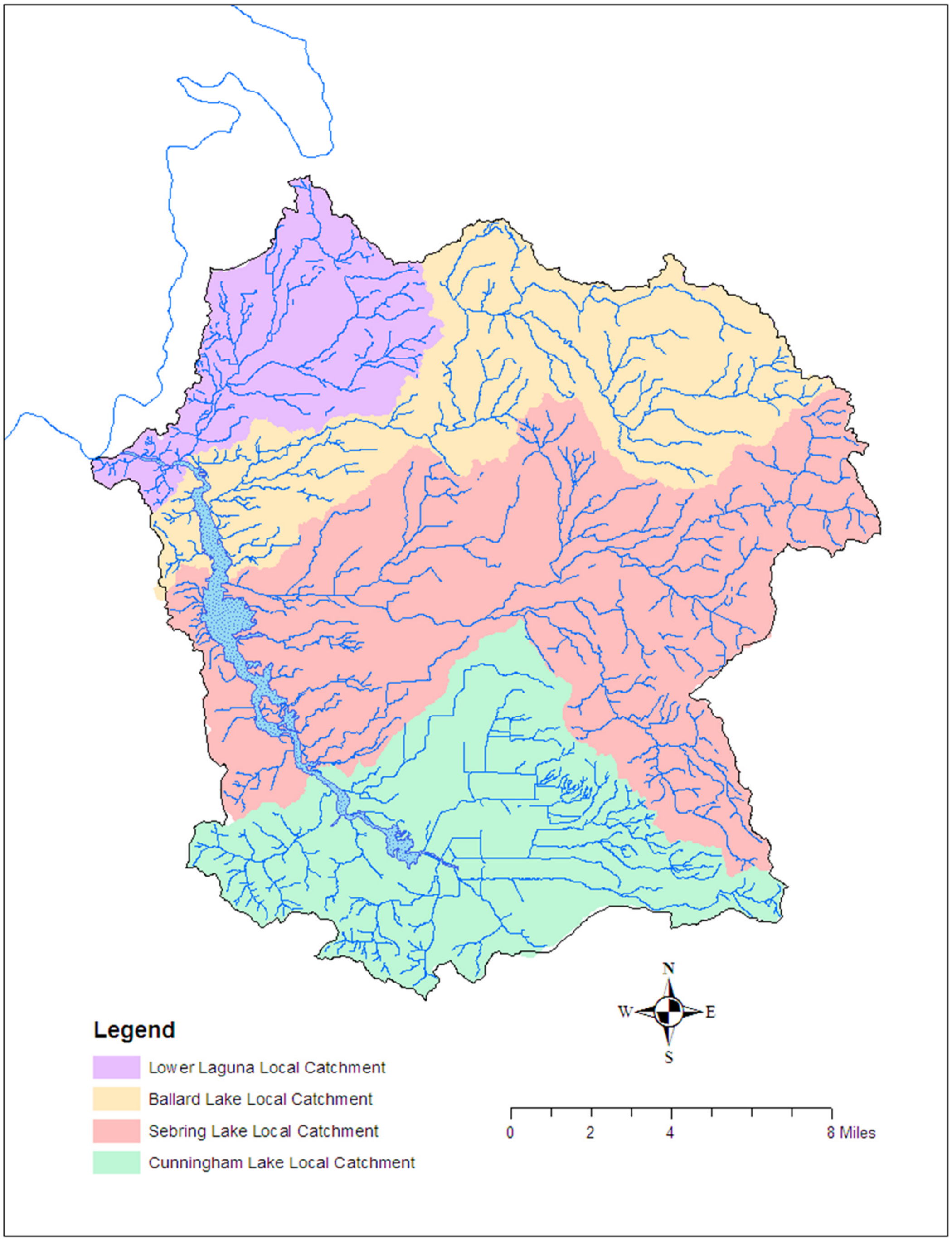

Figure 28. Catchment Areas of Historical Open Water Areas.

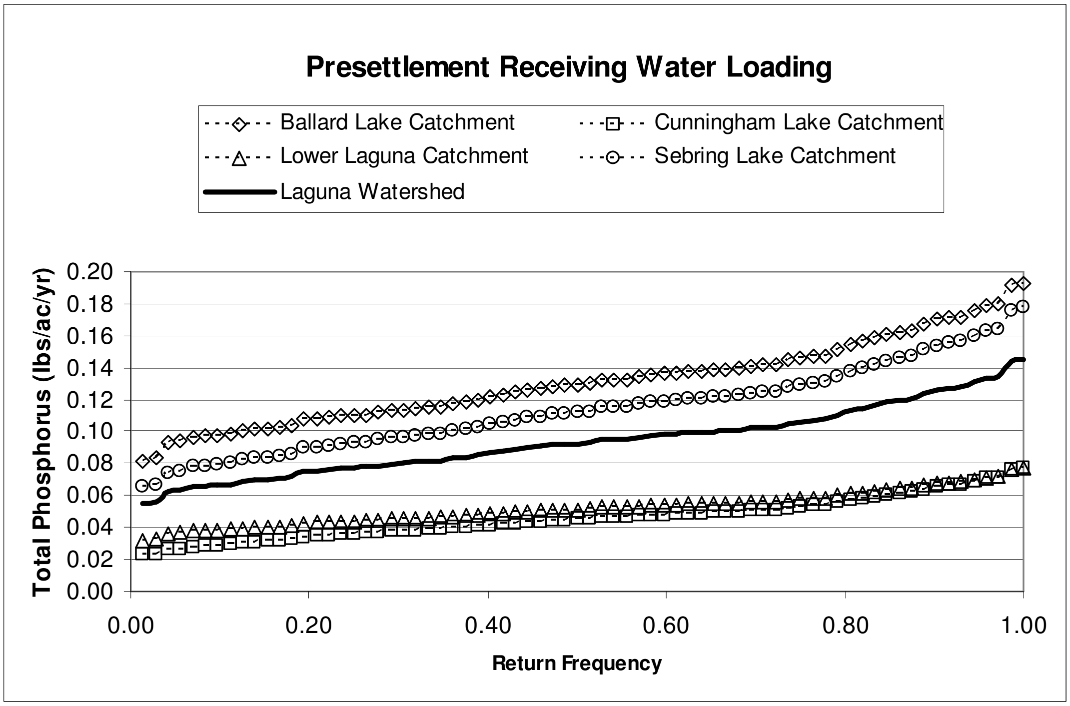

Figure 29. Pre-settlement Total Phosphorus Receiving Water Loading by Catchment

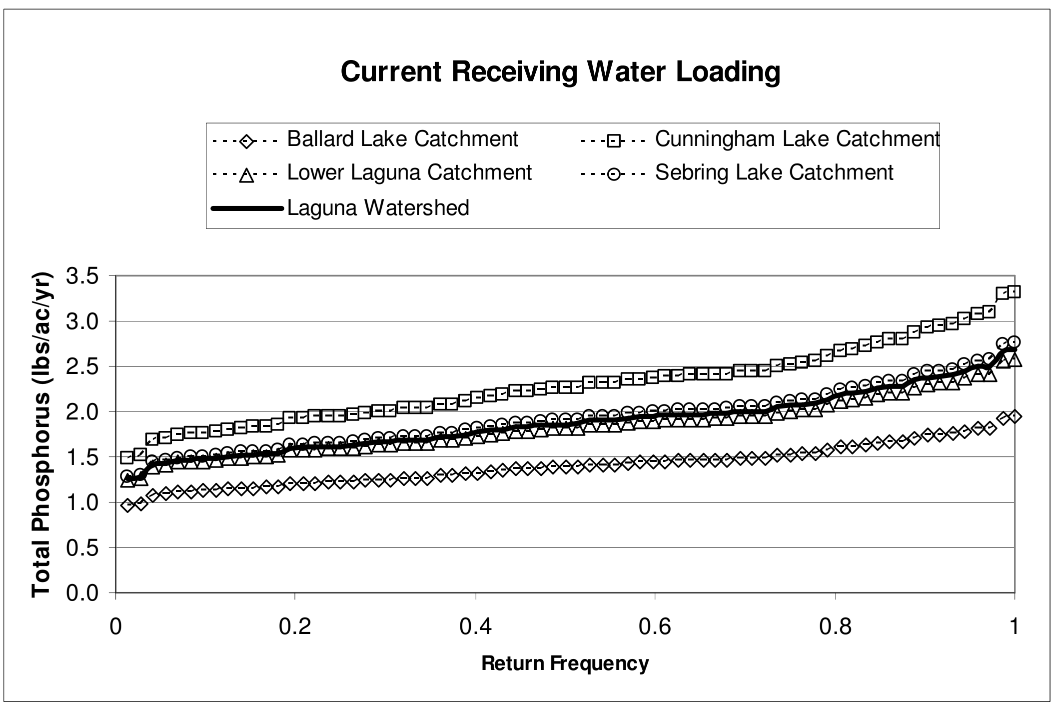

Figure 30. Current Total Phosphorus Receiving Water Loading by Catchment

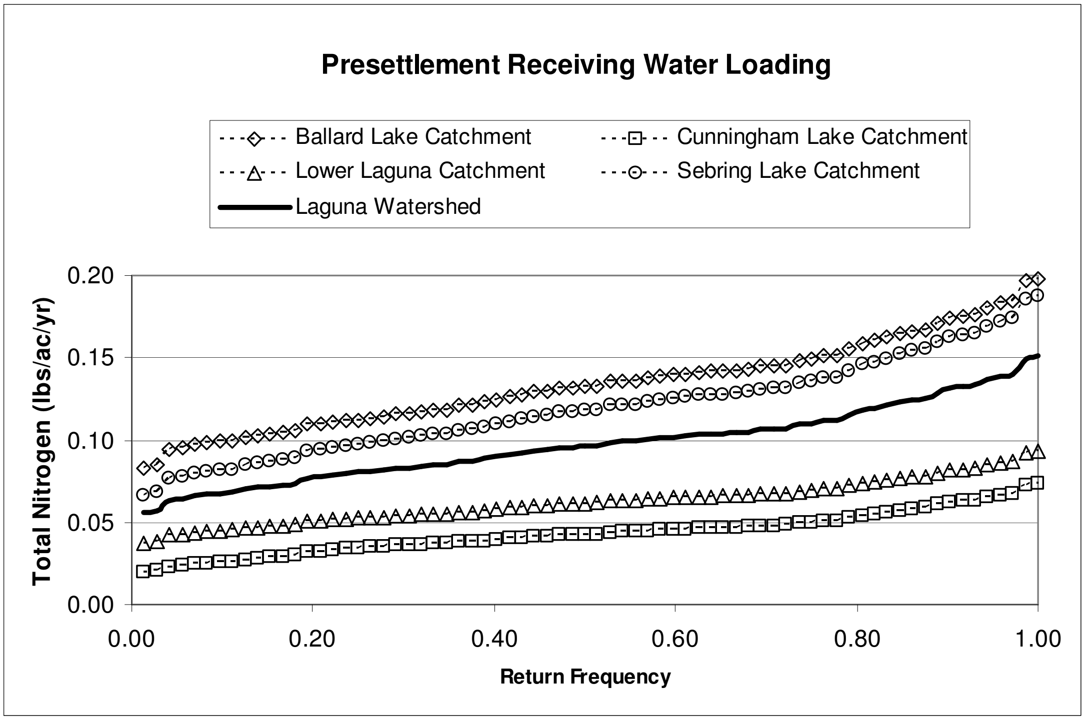

Figure 31. Pre-settlement Total Nitrogen Receiving Water Loading by Catchment

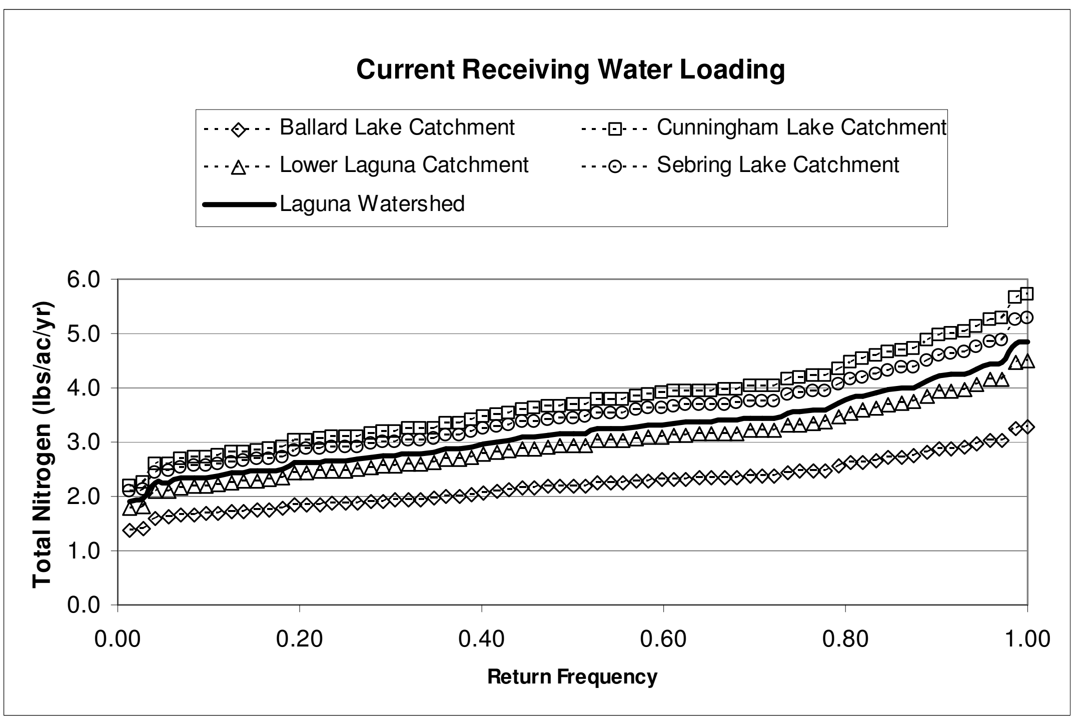

Figure 32. Current Total Nitrogen Receiving Water Loading by Catchment

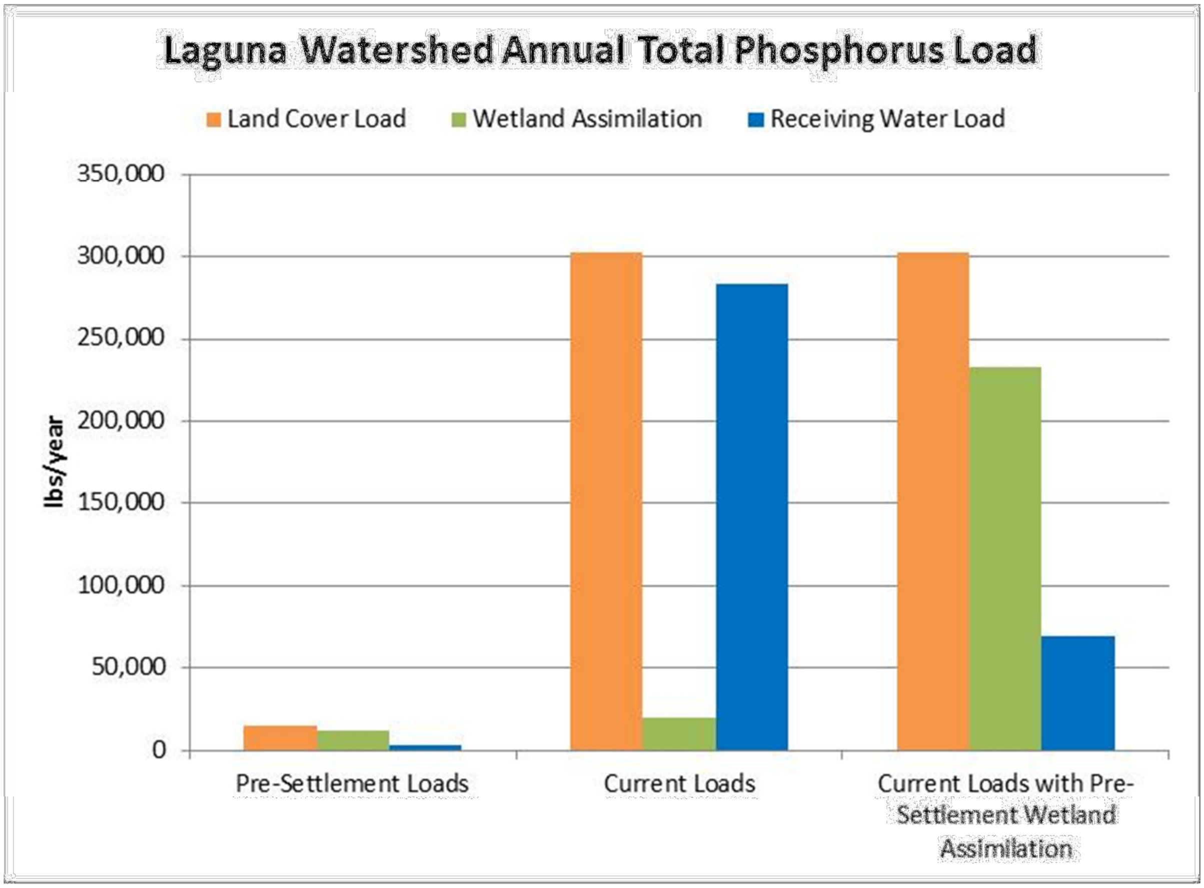

Figure 33. Current and Pre-settlement Laguna watershed Annual Total Phosphorus Loads