Executive Summary 1

1.1 Project goals

The Laguna de Santa Rosa watershed embodies a complex system of physical, hydrological, chemical and biological processes that are closely linked to many direct and indirect impacts from the largest concentration of human settlements in Sonoma County. The Laguna is wedged between five expanding urban centers: Cotati, Rohnert Park, Sebastopol, Santa Rosa, and Windsor. Much of the Laguna de Santa Rosa and its watershed tributaries have been altered, and now reflect numerous historic and contemporary human caused modifications to natural processes. Many of these alterations have rendered the watershed as impaired, with negative impacts to natural hydrology, sedimentation, flood capacity, water quality and valuable ecosystem services for wildlife and humans. This degraded system, historically extremely rich and diverse, now performs at a sub-optimal level and active restoration is needed to turn the tide for improvement of "Beneficial Uses" identified in the North Coast Regional Water Quality Control Board Basin Plan.

The Laguna de Santa Rosa Foundation, in collaboration with Philip Williams and Associates (PWA) and Tetra Tech, and with guidance from North Coast Regional Water Quality Control Board and a Technical Advisory Group developed a conceptual framework to address the following goals:

1) Improve our understanding of the Laguna system for basin scale planning and management;
2) Gather and analyze available data;
3) Identify data gaps, appropriate system indicators, monitoring regimes, and restoration targets; and
4) Specify further modeling efforts focused on the watershed.

The impetus to this process is the project's important role in launching the Laguna Total Maximum Daily Load (TMDL) study to address water quality concerns, and to ensure that the appropriate watershed-scale scope is used for the TMDL-related work. This report addresses the following project objectives:

- Prepare a list of detailed management objectives to guide future restoration, model development and data collection activities;
- Establish a comprehensive project database to consolidate and organize existing information to support assessment and model development;

- Develop a suite of conceptual models to identify key factors and processes driving existing and future conditions within the basin with regard to hydrology and sedimentation, water quality, and ecosystem processes;
- Perform data gaps and uncertainties analysis to identify the information needed to complete an assessment and modeling analysis of the basin, including those assessments and tools needed for TMDL development;
- Develop model selection and development recommendations to ensure that the chosen approach addresses the needs of all of the modeling objectives;
- Prepare monitoring recommendations to provide a basis for data collection prioritization.

1.2 Role of conceptual models

In the highly complex Laguna de Santa Rosa watershed system, predictions are only possible by close examination of all system components. Our understanding of the linkages among these components is made tangible through a series of steps that progress from the conceptual model addressed in this report to dynamic modeling simulations in the near future:

- Conceptual models are developed to illustrate all system components and recognizes linkages between the initial drivers (stressors), the intermediate outcomes (response components or effects), and ultimate impacts (final outcomes or attributes);
- The conceptual models are developed in conjunction with a parallel process of identifying the important and relevant management questions and restoration priorities to be addressed;
- Preliminary restoration objectives and key uncertainties are then described, and data gaps and information needs are clarified and monitoring recommendations are developed;
- The conceptual models are used to guide selection of dynamic/fully automated simulation models that are capable of simulating all of the key components and linkages that have been identified;
- The monitoring plan is then implemented to address key uncertainties, data gaps, and to provide the dynamic model with the information necessary to simulate various management scenarios;
- The dynamic models are then calibrated to achieve an adequate level of predictability of outcomes according to specific input parameters. Model calibration is achieved when the model can successfully replicate a quality assured monitoring database of the targeted system (e.g., the Laguna);
- This final step ensures that the watershed stewards can use the model to explore various management options and that the model outcome is reasonably realistic and dependable.

This report mainly addresses the conceptual part of these modeling approaches and so serves as comprehensive summary of the current understanding of how the Laguna de Santa Rosa watershed system works, what is yet missing from our understanding and how we might go about filling data gaps and addressing key uncertainties. The conceptual models developed through this project describe key elements and processes of the Laguna ecosystem, such as hydrologic and sediment delivery processes, water quality functions and ecosystem dynamics. These preliminary conceptual models clarify how these processes potentially impact water quality and flood protection objectives and ecosystem function. We align these identified processes with management goals and identify key uncertainties and related data gaps that need to be addressed by future research and monitoring regimes. Additionally, we make suggestions of the types of fully automated and dynamic simulation models needed in the next step to realistically predict outcomes from our actions aimed at restoring system functions.

In short, the goal of the conceptual model method is to reduce the processes and stressors of the system to a collection of concepts or hypotheses that then can be more clearly and readily addressed. Taken together, these concepts form a representation, in reduced form, of how the system works. The attempt here is to develop a broader modeling framework by focusing the lens on all of the topics addressed separately in previous studies. This project therefore develops a basis for a comprehensive assessment, modeling, and preliminary planning framework to coordinate basin-scale activities for flood protection, ecosystem health, water quality (including development of TMDLs), and water management for the Laguna de Santa Rosa. Accordingly, it is a direct extension of the Laguna de Santa Rosa Foundation's (LSRF) watershed management plan (Honton and Sears 2006), and serves as a valuable technical basis to the North Coast Regional Water Quality Control Board's development of Laguna de Santa Rosa Total Maximum Daily Load (TMDL) regulatory thresholds for parameters currently on the 303(d) list of water quality impairments. This report thus represents the official initiation of the Laguna TMDL regulatory and implementation process.

1.3 Nexus with basin scale planning goals

While development and implementation of TMDLs are important components of an overall restoration strategy other planning components are needed in restoring Beneficial Uses in the Laguna watershed. Other components need to be addressed: flood management, sediment management, open space and biodiversity, and maintenance of a working landscape. It is clear that the surrounding communities have now begun to recognize the value of retaining the Laguna as a viable ecosystem to enhance water quality, flood protection, and ecological function. The 2007 Laguna Science Symposium included a brainstorming session of technical and public participants to identify future research and study needs and rank the importance of selected topics. To develop a comprehensive basin scale plan for the Laguna watershed was selected by more participants than any other single topic. This project is the first step in the development of this comprehensive plan by addressing the first three of the following basin scale goals:

- Flood protection
- Water Quality Planning (TMDL process)

- Ecosystem Restoration
- Water Management

This report was developed to provide a conceptual framework and current technical knowledge base to the following planning objectives:

Flood protection planning: Evaluation of current flood capacity, and informing plans for protecting and enhancing flood capacity for the future. The hydrology and hydraulics of the watershed are continuously changing due to increased storm water flow associated with development and to climate change, which is predicted to increase the severity of weather events (drought and storms). Models are needed to predict flood risk under different storm scenarios, sustainability of different engineered solutions (such as setting back levees). Good modeling tools, supported by good topographic, land-use and monitoring data, will be essential for robust long-range planning.

Water quality assessments: Assessment of the impact of pollutants from both point and non-point sources on the Beneficial Uses designated for the Laguna de Santa Rosa and on attainment of related water quality objectives. This would include studies of dissolved oxygen, temperature, nutrients, organic matter and sediments to identify which constituents impair Beneficial Uses in Laguna waters so that a Waste Load Allocation (WLA) can be performed. Once the has been completed the North Coast Regional Water Quality Control Board (NCRWQCB) will develop an implementation plan to achieve the allocation targets for each TMDL constituent. These studies will include pollution control planning that incorporates the relationship between land-use, pollutant loading, and water quality impairments; evaluate the capacity of the watershed to absorb or process pollution inputs; and prioritize remediation options for non-point source pollution and for point source pollution addressed through discharge permits. Of particular interest is the relationship between nutrient and sediment loads, physical habitat changes, and the nuisance levels of the invasive macrophyte water primrose (invasive *Ludwigia* sp). The planning and assessment framework needs models to describe baseline conditions, in-channel and surface-water flow rates under different land-use conditions and season, as well as sediment delivery and transport models.

Restoration planning: Developing ecological and physical baseline characterizations of the watershed, and preparing guidelines and success criteria for restoring environmental and ecological function of Laguna waterways and uplands to support biological diversity. Such guidelines and criteria would address physical improvements, such as stabilizing channels, and reducing sediment inputs, and biological enrichments such as restoring vegetative buffer zones, adjusting top-down aquatic food web dynamics to favor maximized nutrient uptake, controlling invasive species, and establishing and/or (re)connecting wildlife corridors. The focus would include interrelated basin-scale issues that are not adequately addressed with reach specific modeling efforts, describe baseline water and food web dynamics, predict future basin-wide conditions, and evaluate feasibility of engineered solutions (such as restoring channel contours and reconfiguring watersheds to reduce directly connected impervious areas).

1.4 Laguna function: past and present

The Laguna watershed is surrounded by two actively uplifting ranges in a Mediterranean climate. As such it is likely that it naturally had relatively high levels of sediment production prior to European settlement in the 19th century. However, although the Laguna watershed naturally generates large amounts of sediment, the natural drainage system that existed prior to European settlement ensured that much of that sediment was deposited on the alluvial fan surface of the upper Santa Rosa Plain, rather than in the lower Laguna waterways. Land use change and the creation of drainage and flood control channels, while making the Santa Rosa Plain more habitable and productive, has mobilized more sediment and shifted the focus of deposition to the lower tributaries and the Laguna itself. Figure 1-1 is a conceptual model of the physical processes affecting the Laguna prior to settlement; figure 1-2 is a conceptual model of the physical processes affecting the Laguna after settlement.

Through our analysis and discussion of hydrology and sedimentation in section 4 of this document, we anticipate that future land use changes in the watershed will further impact hydrologic and sediment processes by changing runoff volumes and peak discharges, and by increasing sediment production in the upper watershed and mobilization along the channels. The combined effect of increased sediment generation and transport capacity in the watershed and increased potential for deposition in the Laguna has several implications. Increased deposition of sediment causes an increase in flood elevation for any given water discharge. This increases flooding in low-lying areas of the Laguna and causes water to back up into the tributaries, creating increased flooding in the tributary watersheds. These changes threaten the Laguna both as a wetland and as a flood detention basin, with implications both in the Laguna and downstream in the Russian River.

With regard to water quality, historical accounts of the Laguna de Santa Rosa describe a productive low gradient system that included a mosaic of open channels, wetlands, and lake like features. The historic Laguna was likely a highly productive warm-water system, supporting wildlife and human use of the Laguna for fishing and recreation. The water quality conceptual model for the Laguna developed by the project team in section 5 of this document identifies the mainly anthropogenic drivers or stressors that have caused water quality conditions in the Laguna to decline over time. The water quality conceptual model focuses on two components, nutrients and organic matter which, in combination with other hydrologic and physical habitat factors, have resulted in conditions that have caused a degradation of Laguna ecosystem function that is unsupportive of "Beneficial Uses" that are assigned to the Laguna in the North Coast Basin Plan. The water quality conceptual model illustrates the linkage between the stressors and the Beneficial Use endpoints. Between these two model endpoints are a series of environmental conditions and responses that can be measured to assess the status of the Laguna's Beneficial Uses.

With focus on Laguna ecosystem function, historic accounts describe the Laguna de Santa Rosa watershed as containing extremely high levels of biodiversity, mainly due to an array of diverse community types rooted in an assortment of equally diverse underlying geology and microclimates. At present, the Laguna watershed is still host to a wide variety of plant communities providing habitat for a suite of other organisms that remain. In section 6 we sketched out a conceptual model of biological diversity over time (Figure 1-3) as a means to understand loss and gain of ecologic potential according to anthropogenic actions causing system degradation or improvement. Over the charted period from 1800 to

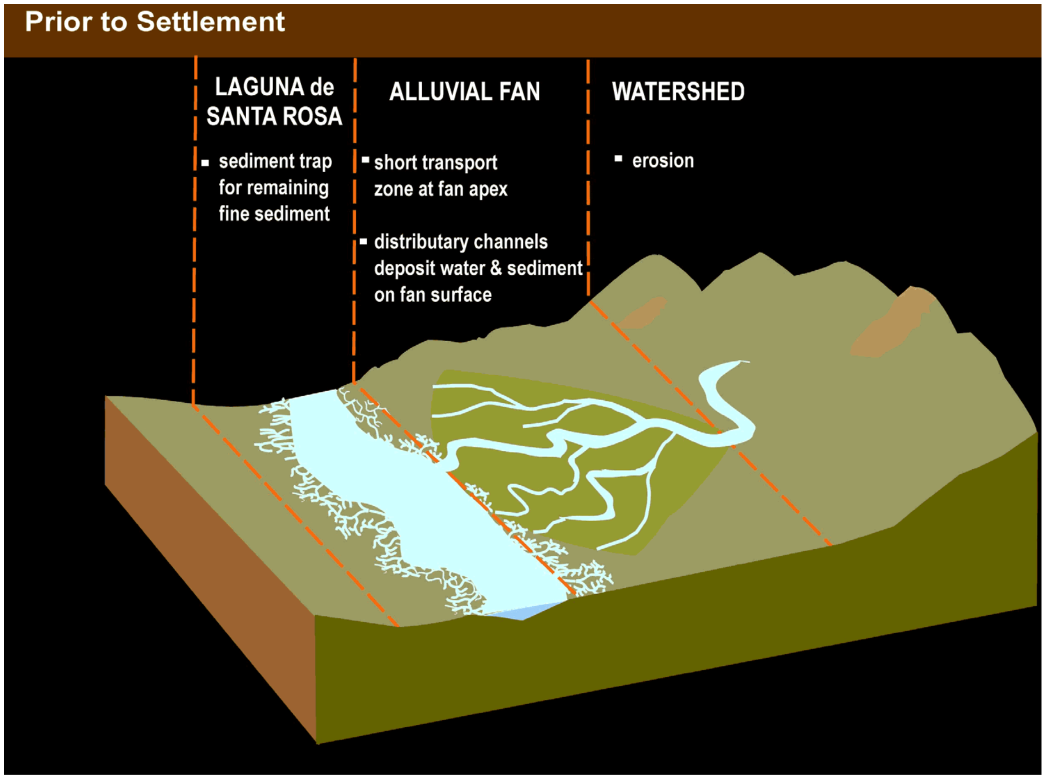

Figure 1-1 Conceptual model of physical processes affecting the Laguna prior to settlement

~2000 biodiversity loss has occurred in eight stages, with rapid declines occurring in five stages, each stage followed by a period of new stability at a lower level. At the very end of the 20th century, a reversal of the downward trend is shown in the last stage, with a hopeful upward trend beginning. Two projected trend-lines are plotted for the future, one at the existing plateau, the other at a slightly higher level. The lower trend line predicts a future based on the status quo; the upper trend line predicts a future based on the promulgation of Laguna TMDLs, implementation of the Santa Rosa Plain Conservation Strategy, and progress made towards the goals set forth in the Restoration and Management Plan.

1.5 Analysis of available data

In section 4, we present results of several recent and current studies on the hydrology and sedimentation in the Laguna system. These include the PWA (2004) study on the sedimentation, rate, and fate in the Laguna, the ongoing USGS study of the 2006 new year's flood, the ongoing NASA/AMES SWAT model development of the Laguna watershed, and the 2002 and 2003 US Army Corps of Engineers' studies on the hydrology of Santa Rosa Creek and Laguna de Santa Rosa watershed, respectively. We summarized available hydrologic and sediment data in the watershed and provided a comparative analysis of different sediment yield estimates. We presented our perspective on sediment yield in the Laguna based on several local and regional estimates and provided a rough sediment budget. The sediment budget is primarily based on the previous study on the rate of sedimentation in the Laguna (PWA, 2004) which had estimated a deposition rate and sediment yield in

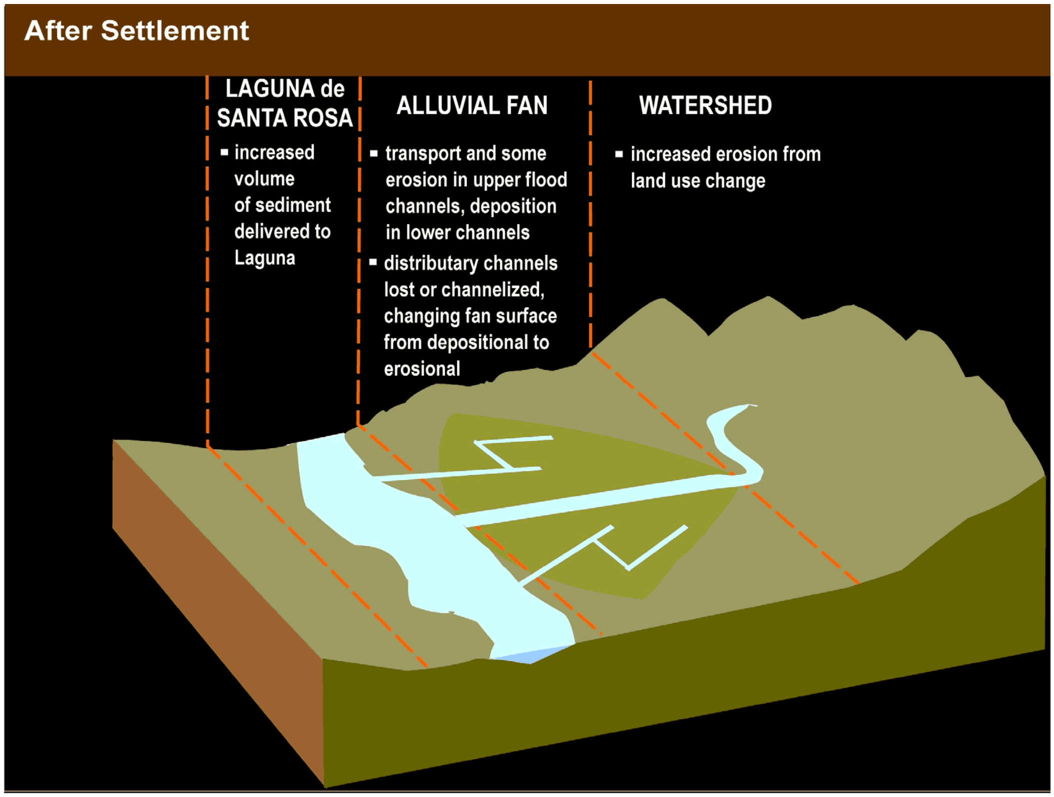

Figure 1-2 Conceptual model of physical processes affecting the Laguna after settlement

the watershed using multiple approaches: repeated floodplain cross-sections in the Laguna, measured sediment deposition in Matanzas Reservoir, other sediment yield estimates in the surrounding basins, PSIAC sediment yield estimations for the upper Laguna watersheds and turbidity sensors installed at three USGS gages during 2002-2003. Though all these sources had different types and degrees of error and uncertainty attached to them, there was an encouraging convergence of estimates for sediment yield in the Laguna.

The water quality section 5 evaluates two key elements of the conceptual model: 1) nutrient and organic loading, and 2) dissolved oxygen (DO). For the first time, datasets from different agencies and organizations were compiled to assess spatial and temporal trends for nutrients and dissolved oxygen in the Laguna for three time periods:

- 1989 to 1994: This period represents the Laguna prior to the implementation of the Waste Reduction Strategy
- 2000 to 2005: Monitoring during this period will capture the effect of the Waste Reduction Strategy
- 2004-2006: During this period the City of Santa Rosa reduced discharge to the Laguna de Santa Rosa from its wastewater treatment plant and diverted this discharge to the Geysers Project.

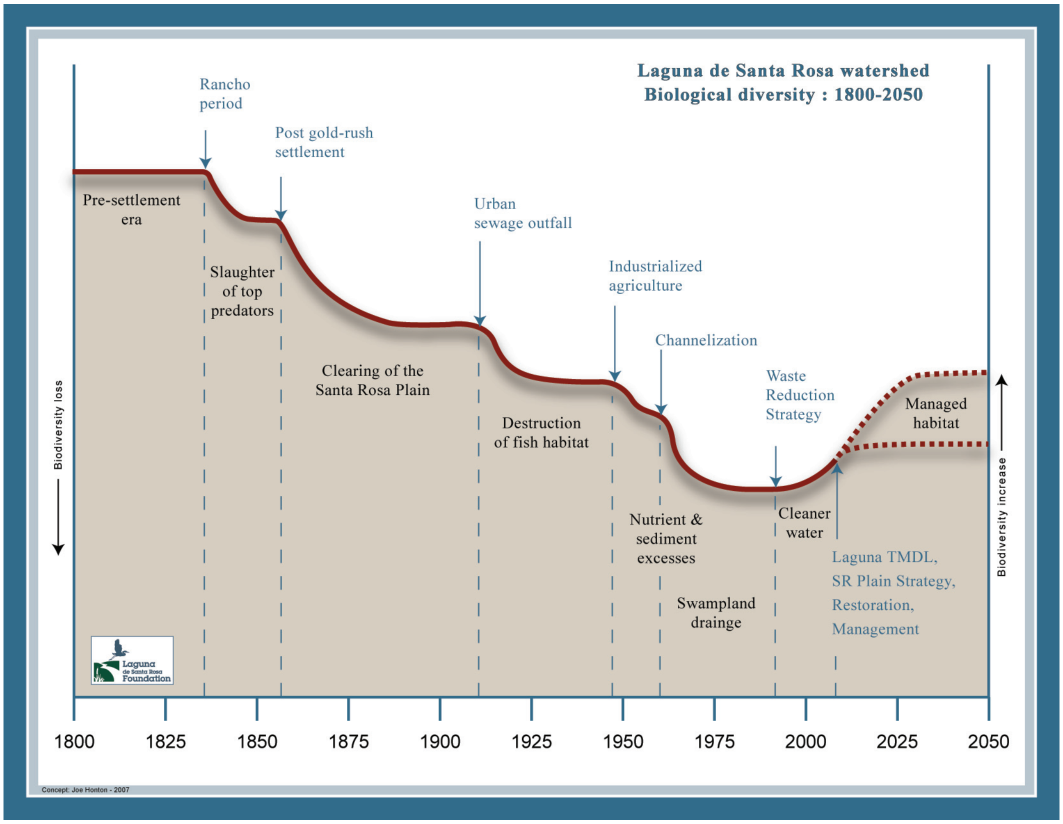

Figure 1-3 Conceptual model of biological diversity over time

The following organizations provided quality assured data, which was compiled into a consolidated project data set:

- City of Santa Rosa Wastewater Treatment Plant;
- City of Santa Rosa Stormwater Monitoring Program;
- Sonoma County Water Agency;
- North Coast Regional Water Quality Control Board – various projects;
- The Laguna de Santa Rosa Foundation - *Ludwigia* Abatement Project;
- California Department of Fish and Game.

Combining data from these various sources into an integrated database allowed the project team to assess temporal and spatial trends for nutrients and dissolved oxygen.

Efforts at compiling existing Laguna ecosystem data, presented in section 6 focused on the recently published reference sources within *Enhancing and Caring for the Laguna* (Honton and Sears 2006), and on available GIS layers in the Laguna Foundation geo-database. Additional information was obtained via the Russian River Interactive Information System (RRIIS), from the Sonoma County Water Agency website, and was made available to us by City of Santa Rosa staff and USDA/ARS researchers. Data analysis was focused on available Laguna de Santa Rosa watershed fish and aquatic habitat surveys from the Sonoma county water agency and California Department of Fish and Game, and biotic indicator surveys such as aquatic macroinvertebrates, and bioassays, performed by the City of Santa Rosa

Stormwater monitoring program. The United States Department of Agriculture- Research Service's invasive *Ludwigia* sp. research program and the Laguna de Santa Rosa Foundation's invasive *Ludwigia* sp. control program provided current data on the physiology, ecology and herbicide and mechanical removal control success of this invader.

1.6 Addressing management questions

With focus on basin plan Beneficial Uses and restoration goals recognized in the Laguna restoration and management plan (Honton & Sears 2006) we identified a suite of key management questions for sedimentation and hydrology, water quality and ecosystem processes. These key management questions are presented in section 3, and each question is followed by a discussion of the current key uncertainties and data gaps in order to guide the development of the Laguna TMDL study and implementation of the Laguna restoration goals.

Key data gaps related to hydrologic processes stem from uncertainties related to discharge estimates along the Laguna and its tributaries due to inadequate stage-discharge relationships, overbank flows, and presence of bi-directional flows and backwater effects both from the Russian River. The flood flow hydrology of the system is not well established and information on the frequency, duration, and seasonality of floodplain inundation along the Laguna de Santa Rosa does not presently exist. No evaluation of transport capacity has been developed that would allow estimation of the delivery of bedload and suspended load to the Laguna from each sub-watershed. Sediment transport along the mains tem Laguna has not been studied. Locations of sediment deposition and subsequent impairment of beneficial uses have not been catalogued. A critical uncertainty about the hydrologic and sedimentation processes in the Laguna is the lack of information on the volume and frequency of water and sediment received from the Russian River during high flow conditions.

For water quality, key data gaps and uncertainties remain mainly with regard to a significant geographical and temporal limitation in the available data for dissolved oxygen (DO) and nutrient dynamics in much of the Laguna. Thus, background/baseline DO conditions remain unknown, and the duration and magnitude of lethal to stressful DO level zones and the presence of refuge habitats remain uncertain. There is also uncertainty regarding the significance of each of the individual risk cofactors that each in part contribute to low DO conditions. How much of low DO conditions is due to sediment processes is still unknown. The relative importance of terrestrial and aquatic sources of organic carbon is difficult to determine without further study, and background loadings of BOD and organic carbon have not been determined. The relative contribution of aquatic sources to organic/inorganic nitrogen is not clear without reliable loading estimates. Nitrogen oxygen demand needs to be studied more broadly through the Laguna in order to verify the conceptual model prepared for one location (SEB3). The role of wind mixing and the location and magnitude of impoundments affecting oxygen dynamics in the water column need study. The absence of a reference site and knowledge about the direction and dynamics of the aquatic food web makes assessment of whether the Laguna DO objectives are achievable in the absence of human disturbance uncertain, necessitating development of a calibrated model to infer the expected DO regime under natural conditions.

With regard to nutrient loadings, it is yet unclear whether nitrogen and phosphorous ever become limiting to algal or macrophyte growth, and what the relative contributions are of food web dynamics and other cofactors. Appropriate levels of algal and macrophyte densities to support cold water fish are yet unknown in the Laguna. Realistic loading estimates from all possible sources (groundwater, atmospheric depositions, septic tanks, agriculture, urban runoff, internal nutrient cycling, and factors that affect bioavailability of nutrient loads) still need to be established for the Laguna. Internal nutrient loading rates and loading rates from wet and dry season groundwater sources are unknown.

The degree to which riparian buffer zones will reduce loadings still needs to be explored in more detail, and their current extent in the Laguna quantified. Fish biomass estimates for the Laguna and fish contribution to re-suspension of sediments in to the water column are data gaps. Whether or not the Laguna main stem can support anadromous fish passage, and how the Laguna aquatic and terrestrial food web communities are affected by levels of pollutant bioaccumulation, low DO conditions, high nutrient input, and invasive species such as invasive *Ludwigia* sp. is yet unclear. With regard to Laguna biodiversity, there is no clear understanding of aquatic, semi-aquatic and terrestrial food web dynamics due to the absence of a current ecological baseline. Without such a baseline and study of food web links that would aid in the understanding of community structure and ecosystem energy dynamics it will be impossible to predict how the watershed will be affected by changing climate patterns.

The contribution of factors such as hydrology, sediment delivery, degraded channel morphology, riparian degradation, and excess nutrients to the accelerated growth and spread of invasive *Ludwigia* sp. in the Laguna has not yet been quantified. How invasive *Ludwigia* sp. affects food web dynamics and other biotic processes is still unknown. Whether nutrient sources for invasive *Ludwigia* sp. originate from the sediment or the water column is as yet unquantified, as well as its specific contribution to mosquito growth and the spread of the mosquito associated West Nile virus.

1.7 Conceptual model development

Using the available data and preliminary estimates of rates and loadings within the context of management and restoration goals we developed a suite of conceptual models of the hydrologic and sedimentation, water quality and ecosystem processes within the Laguna watershed. For some cause-effect linkages, the nature and direction of the effect was identified within the model.

Sedimentation and Hydrology

The conceptual models were developed to describe the anthropogenic influences on sediment processes and surface water hydrology and their consequences. We explored the spatial variability in physical processes in different parts of the watershed by developing "Operational Conceptual Models" that delineate the cause-effect relationships by identifying the key anthropogenic drivers, linkages, and outcomes. These models were developed for two geomorphic domains in the watershed: the Lower Laguna Watershed and the Upper Laguna Watershed. The Upper Laguna Watershed consists of headwater zones of tributary channels to the Laguna and the main stem tributary channels and represents sediment production and transport zones. The Lower Laguna Watershed consists of the main channel of Laguna and its floodplain, including the lower reaches of the tributary channels and floodplains. We also explored the temporal variability of physical processes in the Laguna de

Santa Rosa watershed and articulated a temporal conceptual model of the Laguna, briefly summarizing the evolution of the system over time.

Ecosystem

An in-depth study of the interplay between functional ecosystems and clean water and the underlying physical and biological forces is provided in Enhancing and Caring for the Laguna (Honton & Sears 2006), and a brief summary is given in section 4 of this document, where we've developed two broad conceptual models of the relationships between physical and biotic processes related to water quality: again, one for the Upper Watershed (eastern and western mountain tributaries) and one for the Lower Watershed (the central Santa Rosa plain tributaries, main stem Laguna de Santa Rosa and its floodplain). We also addressed more detailed dynamics at a community scale by reviewing a suite of developed knowledge base logic networks and by developing a conceptual model of the invasive aquatic plant *Ludwigia* sp. (water primrose), having infested lower, nutrient-rich, slow-moving areas of the Laguna de Santa Rosa watershed. This model serves as a conceptual framework for aquatic nuisance species invading degraded water habitats. Showing the interrelated drivers and stressors of this invasion will aid in focusing research questions and adaptive management in controlling its impact and extent.

Water Quality

A conceptual model for nutrient loading (Figure 1-4) identified several sources that contribute nutrients and in some cases organic material to the Laguna.

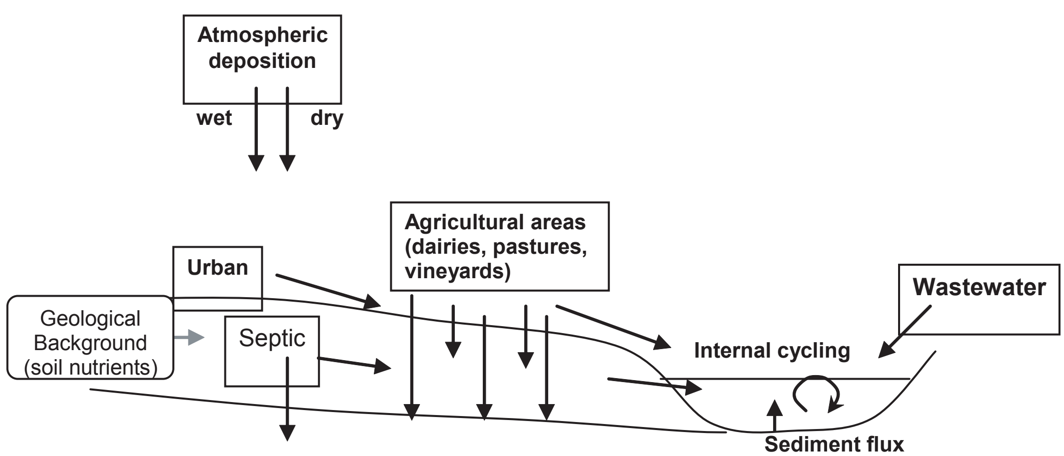

Figure 1-4 Potential point and non-point sources of nutrients/BOD in the Laguna watershed

Sources of nutrients include:

- Municipal wastewater discharge – is a point source that contributes to loadings of nitrogen, phosphorus and BOD during the 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;
- 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;
- 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 septic systems;
- Septic effluents - can contribute to nutrient and BOD loadings; 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.

1.8 Findings

Based on a comparison of historic and current cross-sections surveyed at nearby locations, we estimated that the Laguna channel and floodplain filled in by approximately 1.5 feet between 1956 and 2002, representing a loss of flood storage of 54 ac-ft/yr (PWA, 2004). In a subsequent companion study, long-term floodplain accumulation was also assessed taking sediment cores along the Laguna floodplain northeast of Timberhill Road and analyzing them for ^{210}Pb activity (Aalto, 2004). The results indicated that annual sediment accumulation on the floodplain was approximately 2.5 millimeters up to 15 feet from the channel and was typically in the range of 1 to 2 millimeters. Although less than the approximately 10 millimeters per year of deposition rate estimated for the whole Laguna floodplain (PWA, 2004), the coring results are within an order of magnitude of deposition rates obtained from cross-section and sediment yield analyses. Estimates of sediment yield for the same system typically vary by an order of magnitude. In addition, coring analysis was performed for one location on the floodplain, and therefore, represents a higher resolution approach and spatial refinement of our system-wide deposition rates. Therefore, we propose that these estimates represent an approximate range of deposition rates along the Laguna floodplain and vary spatially. In terms of spatial patterns of deposition along the main stem Laguna, we hypothesize that the reach upstream of the Santa Rosa Creek and the Delta Pond had one of the highest deposition rates due to the backwater created by the confluence of flows and the constriction of the floodplain at this location. This hypothesis appears to be supported by the preliminary map of deposition potential currently being developed by the USGS (Lorraine Flint, pers. com.)

Our best estimate of the available data is that the average sediment yield in the Laguna watershed is approximately 150 to 200 ac-ft/yr or 0.6 to 0.8 ac-ft/sq-mi/yr. Approximately 50 percent of the sediment produced is stored in the watershed (mostly as coarse sediment in the headwaters or fine sediment in lower flood control channels), 25 percent settles out in the Laguna and 25 percent is delivered to the Russian River. Of the 50 percent of sediment stored in the watershed, a fraction is deposited as fine sediment along the downstream reaches of the majority of the Laguna tributaries including Blucher, Colgan, Bellevue/Wilfred, Five, Hinebaugh, and Copeland Creeks, as well as more upstream reaches of Windsor and Mark West Creeks (PWA, 2004). In terms of relative sediment contribution of each watershed, our analysis indicated that most sediment–approximately 40 percent of the total Laguna yield, consistent across the two different methods–comes from Santa Rosa Creek (PWA, 2004). This is anticipated since Santa Rosa Creek has the largest watershed area and its steep headwaters are underlain by erodable rocks on a tectonically active block. Sediment yield from the Mark West Creek watershed represents 20 to 35 percent of the total Laguna yield (PWA, 2004). Although Mark West Creek has the steepest gradient and appears to have a high level of natural erosion, it has also historically been one of the least developed areas in the watershed. Therefore, its relative sediment contribution has been less than the surrounding subwatersheds. However, given the recent urban and agricultural development in the watershed, it is also the most sensitive area to future land use changes. The Laguna watershed at Llano Road, which includes Gossage, Washoe, Bellevue/Wilfred, Hinebaugh, Crane, and Copeland Creeks, is estimated to contribute 10 to 25 percent of the total Laguna yield (PWA, 2004).

To address the temporal variability in sediment processes in the Laguna, we assessed sediment yield in the Laguna watershed for several historic land use conditions. We estimated that the pre-European sediment yield was approximately one quarter of the current sediment yield (PWA, 2004). Based on assumptions of a 20 percent growth in urban area and vineyard production over the next 50 years, we forecast a 30 percent increase in sediment yield (PWA, 2004). While modifications to the watershed have delivered more sediment to the Laguna, the Laguna main stem has also been modified. Over time the Laguna has been straightened and channelized in places, increasing its transport capacity locally. However, the fundamental control on the Laguna de Santa Rosa is the area approximately 1,500 feet north of the Trenton Road crossing–at Ritchurst Knob–where the channel is constrained by a bedrock outcrop and forced to take a circuitous route to its confluence with the Russian River. Making the Laguna system more efficient upstream does not overcome this bottleneck and therefore any measures to increase transport capacity along the main channel would be ineffective in removing sediment. Solutions to sediment accumulation in the Laguna will most likely succeed if they focus on controlling sediment sources and delivery into the Laguna system rather than attempting to increase delivery out of the system.

With regard to water quality, we developed preliminary loading estimates from the various source categories for several nutrient related parameters including ammonia, nitrate, total nitrogen, phosphate, total phosphorus, and BOD. Due to the lack of appropriate data estimates were not developed for all of the conceptual model source categories. In some cases the estimates were obtained from other studies conducted on the Laguna. The methodology for developing each source category loading estimate is provided. The estimates are preliminary and are meant for use to compare the approximate relative potential size of the various source categories. The loading estimates for the source categories developed by the project team are included in the table below:

Table 1-1
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).

The source loading table illustrates that the Laguna receives a large amount of nutrients and BOD from surrounding land uses and discharges into the Laguna. These sources have enriched the sediments and have likely contributed a higher level of eutrophication than would be expected under natural background conditions. No one category is consistently the largest contributor for all parameters. We were unable to develop estimates for categories that are likely significant contributors such as internal cycling from the sediments into the water column. We were also unable to develop estimates for total phosphorus from dairies and pastures which are likely sources to the Laguna. In addition, further analysis is needed to determine the actual impact of loading from each category. For example, urban stormwater via Santa Rosa Creek is estimated to be the single largest contributor of nutrients and BOD to the Laguna. However, the impact from Santa Rosa Creek stormwater loads may be less than other sources due to the location and conditions under which the loading occurs. That is, storm flows in Santa Rosa Creek are discharged into the Laguna below where the most problematic conditions exist and may pass through to the Russian River without depositing a significant fraction of the nutrients or organic load within the Laguna. These source loading estimates will need to be refined and further evaluated as part of the TMDL development process.

Results of the spatial and temporal nutrient analysis have been summarized in Table 1-2. The table presents longitudinal conditions along the Laguna channel from the upper Laguna above Llano Road, the middle Laguna on the western edge of the Santa Rosa plain to just beyond Delta Pond in the North, to below the confluence with Santa Rosa Creek (lower Laguna). To evaluate temporal trends, annual mean concentrations for each of these reaches are presented for three different time periods: 1) pre-Waste Reduction Strategy, 2) post-Waste Reduction Strategy, 3) reduced Laguna reclaimed water discharge due to Geyser project. For most parameters at most sites the temporal trend is decreasing concentrations from the earlier time period (1989–1994) through the latest time period (2004–2006). The longitudinal pattern suggests that the middle portion of the Laguna retains nutrients to a greater extent than the reach below Santa Rosa Creek. This suggests that the Waste Reduction Strategy and the diversion of the wastewater treatment plant discharge out of the Laguna to the Geysers have successfully reduced nutrient concentrations at most locations within the Laguna. However, the mean concentrations for each parameter from the 2004–2006 time-period remain well above the average concentrations for other waters within the region that are ecologically similar to the Laguna.

Table 1-2 Nutrient concentraiton trends for the upper, middle, and lower Laguna

Location / Sampling Period	Mean Total Phosphorus - mg/L		
	1989-1994	2000-2005	2004-2006
Above Llano Road - Upper Laguna	0.58	0.63	0.59
At Highway 12 - Middle Laguna	1.80	1.23	0.79
Below Santa Rosa Creek - Lower Laguna	0.73	0.80	0.65
Location / Sampling Period	Mean Nitrate (NO3) - mg/L		
	1989-1994	2000-2005	2004-2006
Above Llano Road - Upper Laguna	1.27	0.91	1.13
At Highway 12 - Middle Laguna	1.18	2.71	0.89
Below Santa Rosa Creek - Lower Laguna	1.43	1.18	0.75
Location / Sampling Period	Mean Ammonia (NH3) - mg/L		
	1989-1994	2000-2005	2004-2006
Above Llano Road - Upper Laguna	1.70	0.10	0.55
At Highway 12 - Middle Laguna	2.00	0.25	0.38
Below Santa Rosa Creek - Lower Laguna	0.20	0.07	0.28
Location / Sampling Period	Mean TKN - mg/L		
	1989-1994	2000-2005	2004-2006
Above Llano Road - Upper Laguna	1.14	1.10	1.20
At Highway 12 - Middle Laguna	7.60	1.40	1.38
Below Santa Rosa Creek - Lower Laguna	2.35	1.21	0.97

Data for dissolved oxygen (DO) for several locations and time periods were analyzed for the project. While results vary from year to year and between locations, a clear pattern of pervasive and severe low DO conditions are evident. Despite the positive trend in nutrient conditions within the Laguna, DO conditions continue to decline at several locations. For some stations there is no clear trend but conditions remain critical for significant periods of time each year. At times the diurnal pattern suggests that the photosynthesis and respiration cycle result in cyclic DO minimums that could be lethal to most aquatic life. At other locations, a persistent low DO suggest oxygen demand from decaying organic material and sediment processes is the dominant process. An example of the declining trend in DO conditions is illustrated below for the Laguna station near the Todd Road bridge.

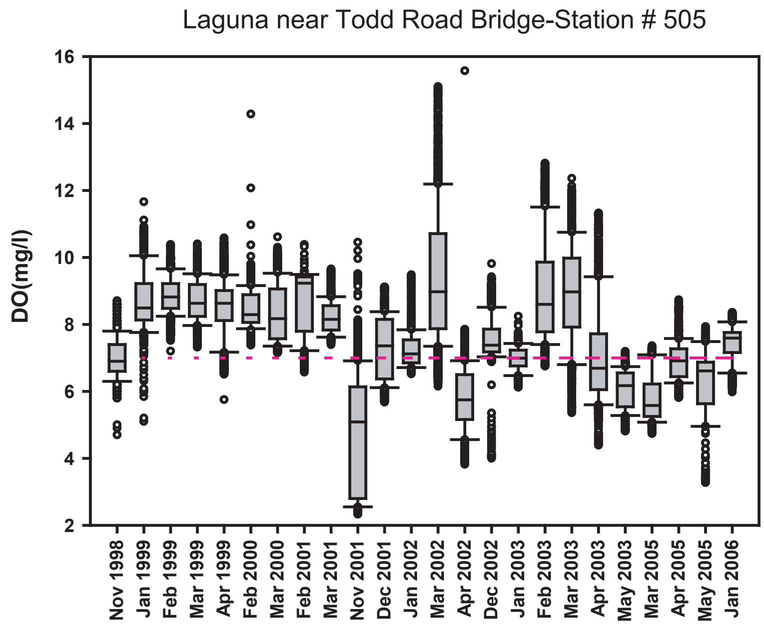

Figure 1-5 Range of DO concentrations at Laguna near Todd Road bridge

Various physical, chemical and biological factors contribute to the DO conditions within the Laguna. These factors include flow, temperature, channel geometry, channel morphology, riparian vegetation, wind fetch, organic and chemical oxygen demand, and biological food web dynamics (algal and macrophyte abundance). The relative contribution of each these factors are variable for different locations along the Laguna. The project team developed three different conceptual models to describe potential dissolved oxygen processes for three typical Laguna scenarios. The scenario for the Laguna at Occidental Road (LOR) is presented below.

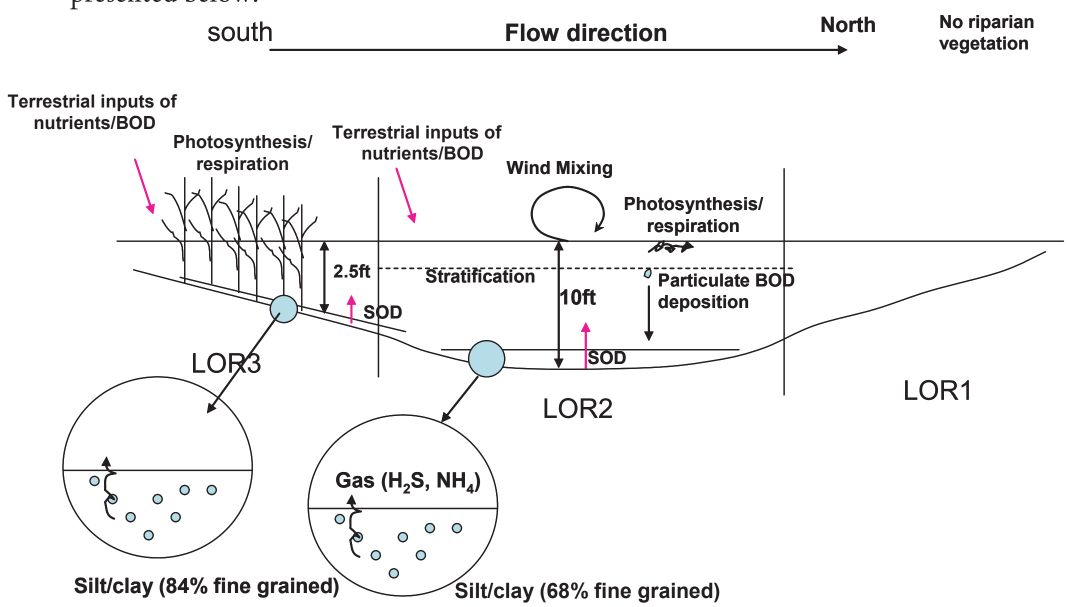

Figure 1-6 Preliminary conceptual model for the Laguna at Occidental Road (LOR)

The model illustrates two of the dominant factors contributing to low DO: macrophytes and algal photosynthesis and respiration; and oxygen consuming processes in the fine sediments. The unsheltered reach is also subject to periodic wind mixing which increases water column DO. A comprehensive map of conditions for the entire Laguna is not possible at this time but sufficient data is available to confirm a serious problem with DO relative to support of Beneficial Uses.

In section 6 we examine upland, riparian, and stream and other knowledge bases logic networks developed for the Russian River watershed, of which the Laguna is the largest tributary. These logic networks and our additional conceptual models make it clear that anthropogenic actions affect physical, hydrological, chemical, and biological factors in conjunction at all levels of investigation through various linkages and effect strengths. The complexity of these logic networks and conceptual models shows that an improvement in system function will likely result from an interplay of a few major or many minor factors (see, for example, figure 1-7). We here list the key drivers as they relate to the three conceptual models for the Upper and Lower Watershed and for invasive *Ludwigia* sp. persistence we described in section 6, in an attempt to illustrate this interplay of major and minor factors.

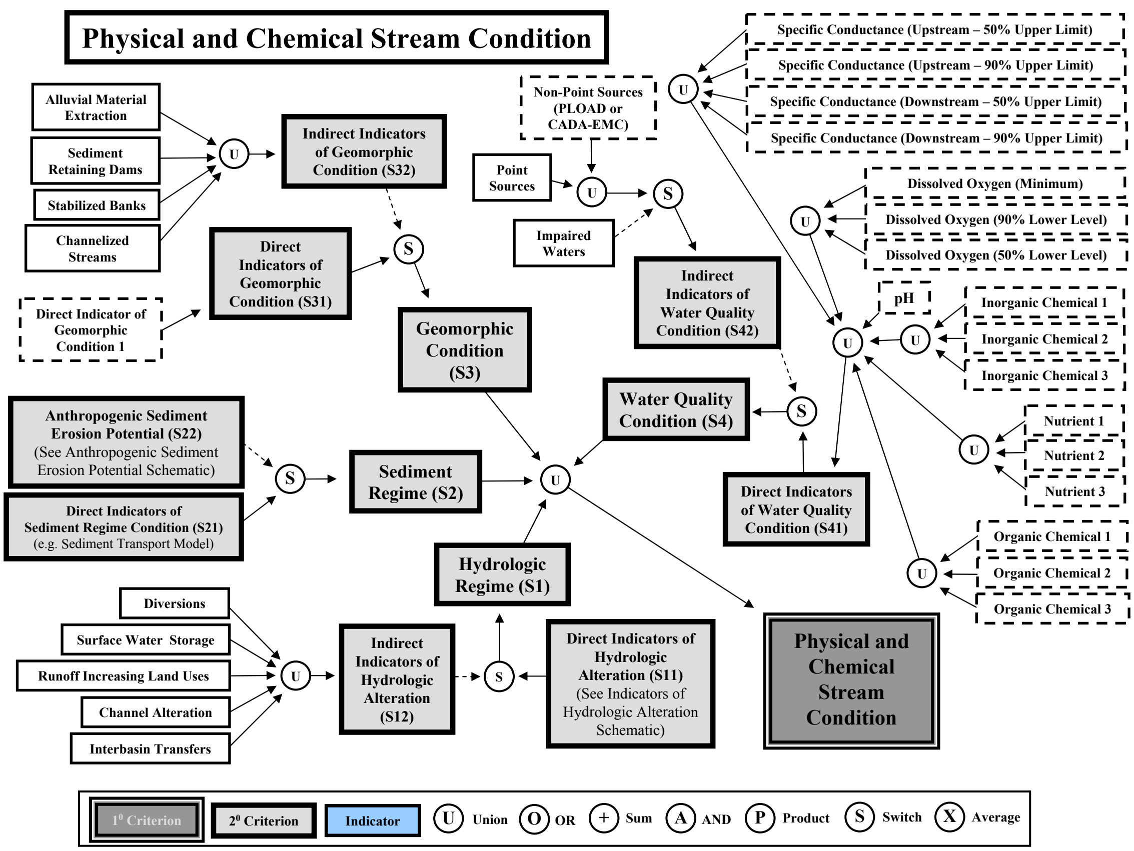

Figure 1-7
Physical and chemical stream condition knowledge base schematic
(Smith 2006)

The key drivers in the Upper Laguna Watershed include:

- A highly active geology, hillside grazing, unpaved roads and driveways where winter storms trigger landslides.
- Inadequately sized culverts that trigger sheet and rill erosion and cause fish passage barriers.
- Historic cinnabar mines and naturally occurring serpentine soils that leach mercury into the waterways.
- Exotic invasive species introductions that can cause shifts in native plant communities, the loss of natural competitive population checks, and the potential for local extirpation of species and extinction of endemics.
- Existing and planned recreational trails that can act as a repeated source for the introduction of new pathogens or invasive plants (from footwear and tire treads).
- Small ranches (ranchettes) that increase human presence in the rural parts of the watershed, so disrupting corridor dynamics, and adding pollutants to soil, air, and water.
- Fire suppression and change in fire regime, leading to the latent potential for large-scale catastrophic fires including the potential for massive erosion, and the certain shift in the diversity of upland communities.

The key drivers in the Lower Laguna Watershed include:

- Urban and rural residential encroachment that led to the loss of riparian buffer zones and the straightening and constricting of channels for flood control, resulting in elevated temperatures in oxygen poor waters, killing aquatic fauna and displacing fish and birds to cooler habitats, and causing a greater than normal reliance on the flood plain to buffer high winter flows.
- Flashy stream flows exacerbated by impervious soils, such as rooftops, streets, and parking lots, that also add oils, metals, and other car pollutants.
- Urban and rural backyard run off and road maintenance activities contributing pesticides, herbicides and other pollutants.
- Agricultural operations in the floodplain exacerbating the loss of riparian corridors, adding nutrients to the system, and keeping water in areas well past their normal drying period due to subsurface flow coming from nearby irrigated fields, negatively affecting species specially adapted to California's climate pattern.
- Recycled water discharged into the Laguna, leading to elevated nutrient levels in the water column and potentially including yet unregulated chemical compounds, such as estrogenic and other pharmaceuticals, and cosmetics that may harm humans and wildlife; the long-term accumulation of sediment phosphorus; and keeping water levels artificially high throughout the year.

- The introduction of non-native plants such as invasive *Ludwigia* sp., *Lepidium latifolium* and others, causing a shift in the native plant community and the loss of natural competitive population checks, potentially decreasing biodiversity.
- Sustained growth, spread, and novel introductions of invasive *Ludwigia* sp. and other macrophytes in the water column, thriving in high nutrient conditions and potentially exacerbating low dissolved oxygen conditions.

Key drivers in the invasion of non-native *Ludwigia* sp. are identified as:

- Altered hydrology, via increased water movement through the system, providing a suitable home for invasive aquatic macrophytes such as invasive *Ludwigia* sp.
- Altered hydraulics, via flood conveyance channels, providing higher than normal system velocities, causing floating living plant fragments to break free and be distributed downstream. These alterations allow the plant to reach new locales forming nascent populations that may eventually develop into vast monocultures.
- The recurrent introduction of invasive *Ludwigia* sp. into the system, via the re-distribution of plant fragments during floods downstream, through natural transport by wildlife (e.g. seeds or shoots get moved via birds), or via inadvertent human introductions from backyard ponds.
- Altered channels leading to sections with slow or stagnant flows, where, coupled with high nutrient levels in both water column and substrate and light availability, young invasive *Ludwigia* sp. plants take root and thrive, potentially causing explosive growth rates, causing large monocultures.
- Absence of associated invasive *Ludwigia* sp. herbivores and plant competitors from their native range causing a lack of a potential natural check to population expansion resulting in vast monoculture-like mats of invasive *Ludwigia* sp., and as an ecosystem engineer (Crooks 2002) completely change the dynamics of the system.
- Weather fluctuations, that may either favor invasive *Ludwigia* sp. growth during frost-free winters, or depress its growth during cold frosty winters. More investigation of this phenomenon is warranted.

A comprehensive modeling framework will be necessary to evaluate management strategies for improving hydrologic, sedimentation, water quality, and ecosystem conditions within the Laguna. The report recommends a multiple model framework because the number of factors that are affecting theses processes cannot be simulated using a single model.

1.9 Project recommendations and next steps

We developed preliminary responses for the most pressing management questions using available information, and identified substantial data gaps and key uncertainties. The conceptual models that we developed to evaluate these questions suggest that it is the cumulative effect of many factors that have led to the decline of environmental conditions within the Laguna. We reviewed the work of existing studies, which all reflect the general paucity of data available for the Laguna (e.g. watershed dynamics and history, water quality, hydrology, sedimentation, groundwater, biodiversity, among others), and outline the need for continued and expanded data gathering via standardized monitoring regimes and specified data collection efforts throughout the watershed. These data will further our understanding by better characterizing the complex dynamics of the Laguna system and will provide an improved level of predictability of the natural system fluctuations in the face of increasing urbanization and climatic change.

We provide general guidance on proposed monitoring activities. A more detailed Laguna monitoring and quality assurance plan is recommended as a priority next step. We recommend that the key data gaps and uncertainties related to hydrology and sedimentation in the Laguna are addressed primarily through monitoring and field work in order to establish an extensive baseline for all relevant processes. Hydrodynamic modeling initiatives in the Laguna proper should build on the current USGS and City of Santa Rosa models. However, we recommend that independent one-dimensional hydraulic and sediment transport models of the tributaries are initiated to address key questions on hydrology, sediment transport, and flood management in the Upper Laguna Watershed. Tributary models would provide further information on the hydrologic and sediment processes along the channels and on the hydrologic and sediment delivery to the Laguna. The first step of such an effort would involve refinement of hydrologic conditions in the tributary watersheds.

The recent 2006 New Year's flood presents a unique opportunity to calibrate existing or future hydraulic models for high flow conditions, and therefore to establish the flood hydrology of the tributaries. In addition, using data from the recently installed gauges, tributary hydraulic models can be used to establish the continuous and low flow hydrology of the tributary systems. Field surveys of channel and floodplain cross-sections and longitudinal profiles along the main stem Laguna, field surveys of rates of bed and bank erosion and aggradations along the tributary channels, continuous sampling of suspended sediment and bedload, as well as observations and measurements of sediment deposition along the mainstem Laguna and tributaries are identified as key indicators to assist in the development of a comprehensive management plan and a TMDL study. We also recommend preparation of a county- or city-wide hydrograph modification management plan that would regulate the future change in hydrologic and sediment delivery due to new developments with the goal of minimizing the potential channel instability and erosion along tributaries. Preparation of such a plan may involve more detailed field work on the relative sediment contribution from different processes and could lead to future efforts to trap sediment in the upstream watershed before it is transported down to flood control channels.

To reduce key water quality uncertainties for nutrient loading and DO conditions within the Laguna, a focused monitoring program will be required. A key to obtaining enough monitoring data to address key questions will be to better coordinate existing data collection activities through the development of a comprehensive monitoring plan. High priority monitoring activities for water quality and related aquatic food web dynamics are included in the list below:

- Longitudinal characterization of sediment conditions within the Laguna including mineral composition, organic content, nutrient content, and depth.
- Collection of information to better inform the dissolved oxygen conceptual models including DO measurements and the site factors such as macrophytes and algal densities, riparian cover, and channel conditions.

- Characterization of aquatic food webs in impaired lake-like and riverine sections of the Laguna. Addressing top-down food web dynamics within restoration may help shift abundance of certain trophic levels and so aid in faunal nutrient uptake and removal.
- Improved characterization of key loading categories including sediment cycling, stormwater sources, agricultural inputs (e.g., dairies, vineyards) and irrigation infiltration to base flow.
- Improved mapping of the Laguna floodplain including hydrologic connections to potential pollutant source areas.
- Biotic indicator monitoring at increased geographical and time scales in order to better establish the biotic potential at degraded and restored sites, so examining the underlying causes of decreasing Laguna biodiversity.
- Continued study of invasive *Ludwigia* sp. spread, population dynamics, physiology, and ecology, and its function in the altered food web.

As no single model can adequately capture the complexity of the watershed's hydrological, chemical, and ecological processes, a set of overlapping models will ultimately need to be developed to give decision makers a suite of tools that will enable them to make prudent and effective management decisions. The preliminary modeling framework includes the uplands or watershed processes that deliver sediment and pollutants to the stream network. The stream network will include flow conditions and channel processes. Finally, water quality and aquatic ecosystem processes will be addressed by another model. Such a dynamic modeling framework will so help to evaluate how different management scenarios will impact each component. Such an adaptive modeling framework is an iterative loop that guides long term management through a series of incremental modeling/decision-making steps. The conceptual models we developed help to clarify which stressors must be addressed to make meaningful progress in restoring ecosystem integrity. In order to help implement and evaluate the success of future adaptive management strategies we proposed relevant indicators for key system components and processes, and included monitoring recommendations to provide a basis for data collection prioritization.

The results of this report can be used to begin development of a suite of comprehensive basin scale planning activities. This will require that the following steps be taken in the next phase of this process:

Stakeholders and agencies partnerships:

- Support and develop an understanding among those that must play a role in the development of a comprehensive watershed plan.
- Create an integrated Laguna planning and implementation team that includes local stakeholders, and local, regional, state, and federal agencies.

Historical and baseline ecological analysis:

- Expand the current knowledge base on the physical and ecological history of the Laguna watershed and establish a contemporary ecological baseline for the Laguna to provide a better understanding of background conditions that can be used to develop scientifically defensible habitat restoration and water quality management objectives.

Targeted monitoring to addressing high priority data gaps

- Coordinate data gathering by stakeholders.
- Develop a monitoring program to address key uncertainties and component indicators identified within this report.
- Develop a monitoring and modeling grant to complement the TMDL framework to be developed by the North Coast RWQCB.

Preliminary restoration project recommendations

- Identify initial enhancement projects and strategies that can be implemented prior to the completion of the comprehensive modeling framework.
- Set restoration targets.
- Establish specific restoration success criteria.
- Prioritize component models for further development.

Adaptive Management

- Use long-term monitoring results to measure management and restoration success against set criteria and periodically adjust management strategies accordingly.