Assessment and Management Questions 3

Early in the development of this report, the project team considered a wide field of assessment and management questions related to water quality and watershed processes. This early step in the analysis provided a framework for prioritization of what could be addressed in this report. Questions were asked along six lines:

- Hydrology
- Sedimentation
- Dissolved oxygen
- Nutrients, macrophytes, and algae
- Biological diversity
- Invasive *Ludwigia* sp.

For each question, a general narrative response is provided, with a discussion of the analysis of the data that was called upon to support that discussion. But in answering these questions, there were limits to the confidence that could be assigned to the analysis; thus, key uncertainties and "data gaps" are enumerated for each question. These key uncertainties provide an assessment of where new data collection efforts are needed. Within the limits of the available data, a working hypotheses is proposed for each question.

3.1 Hydrology questions

Management questions related to hydrologic and sediment processes in the Laguna, key uncertainties and data gaps to address these questions, and the hypotheses implicit in the questions are described in the following paragraphs.

Question 3.1.1 What are flood peaks, volumes, and durations throughout the watershed, and how do the interactions from subregions affect flood hazards?

Most recently, draft estimates for peak discharges, flood volumes, and flow hydrographs for the 2-, 10-, 25-, 50-, and 100-year flow events at Santa Rosa Creek at Willowside, Windsor Creek at Pool Creek, Mark West Creek at Old Redwood Hwy, Blucher Creek at Hwy 116, Colgan Creek at Llano Road, and Laguna de Santa Rosa at Llano Road have been developed by the USACE using hydrologic modeling. Updated estimates for several additional streams are expected from studies being conducted the City of Santa Rosa as part of the Southern Santa Rosa Drainage study Based on the simulations of watershed hydrology, there is significant interaction between the flood peaks of the Laguna de Santa Rosa and its tributaries. For the simulated storm conditions, this study suggested that in large flood events Santa Rosa Creek, Colgan Creek at Llano Road, and Blucher Creek peak first, quickly followed by the Laguna de Santa Rosa at Llano Road; then Windsor Creek at Pool Creek; and lastly, Mark West Creek at Old Redwood Highway. Because the peaks all occur within about a 4-hour period and the flood hydrographs extend over 16 to 36 hours, peak flows reach the lower Laguna within a narrow time period, which would result in a rapid rise in flood waters. In the December 2005 – January 2006 flood event, peak stages on Santa Rosa Creek, the Upper Laguna, and Colgan Creek were reached within 1.5 hours of each other.

The City of Santa Rosa is working with FEMA to initiate a new flood insurance study of many of the eastside drainages tributary to the Laguna upstream of Sebastopol. This study is expected to develop new hydrologic, hydraulic, and flood hazard information for a portion of the Laguna watershed. Completion of the study is expected within approximately the next two years (Lori Urbanek, pers. comm.).

The Sonoma County Water Agency is also in the process of updating its manual for flood control. This effort is expected to include updates of isohyetal maps for precipitation to include more recent rainfall records and revision of the intensity-duration-frequency relationships for precipitation in the County, including the Laguna de Santa Rosa watershed (Chris Delaney, pers. comm.).

Key Uncertainties and Data Gaps

The estimates for discharge along the Laguna de Santa Rosa and Santa Rosa Creek are subject to significant uncertainty because stage-discharge relationships are inexact due both to overbank flows and the presence of bi-directional flow or ponded water conditions. Backwater effects along the Laguna are significant during flood events. When water levels in the Laguna are high, these control the downstream water surface in the tributaries, affecting flood conditions upstream. The streamflow record at these stations for calibration of hydrologic modeling is also very short; the record at other locations is even shorter or non-existent. The USACE Draft Laguna Basin Hydrology Assessment (2003) did not develop estimates of peak discharge and volume information at other locations (e.g. confluences of other tributaries and points of interest along Laguna). Another unknown that will be key to understanding the interaction of the Laguna de Santa Rosa and the Russian River during flood events is the direction, timing, and magnitude of flow from and to the Russian River. Lastly, information on the frequency, duration, and seasonality of present-day floodplain inundation along the Laguna de Santa Rosa does not presently exist.

Hypothesis

Hydrologic and hydrodynamic simulation models will be capable of simulating flood conditions in the basin adequately once sufficient spatially-distributed calibration and verification data over a sufficiently long period is collected and interactions between the Russian River and Laguna de Santa Rosa are better understood.

Question 3.1.2 What is the present flood storage capacity of the Laguna, and what are the conveyance capacities of the tributary channels?

Relative to the estimated flood storage volume of 80,000 acre-feet provided by the Laguna during the 1964 flood, and assuming a loss of storage volume over a similar period of 54 acre-feet per year (PWA, 2004), we estimate a flood storage volume of approximately 77,500 acre-feet. New information on floodplain topography has been developed and it would be possible to develop a new stage-storage curve for the Laguna that would refine this estimate. Combined with a better understanding of interactions between the Laguna and the Russian River derived from future monitoring data, hydrodynamic modeling of the system would provide a still better estimate of the actual effect of storage in the Laguna on flood attenuation for downstream communities along the Russian River.

In addition, a better understanding of the hydrodynamics of the Laguna itself will be needed to fully understand its role in providing flood storage. Encroachments into the floodplain may limit the effectiveness of flood storage in the Laguna. One such encroachment may be the Delta pond just upstream of the confluence of the Laguna with Santa Rosa Creek. This holding pond creates an apparent bottleneck in the movement of floodwaters, and may thereby reduce the effectiveness of upstream flood storage in the Laguna.

We are aware of hydraulic modeling that has been conducted for Santa Rosa Creek, as well as Colgan and Roseland Creeks. Santa Rosa Creek was designed to convey the 16,500 cfs flow estimated in 1965 to be the 100-year peak flow at Willowside Road at the time of design with an additional 3-4 feet of freeboard in the leveed reach. (City of Santa Rosa, 1992). The present capacity of the channel given the development of extensive in-channel vegetation and deposition of sediment is unknown. The 2004 study of Colgan and Roseland Creeks (Winzler & Kelly, 2004) found that significant reaches of the channels were insufficient to pass their design discharges, an estimated 100-year peak flow at the time of their design. The City of Santa Rosa is working with FEMA to initiate a new flood insurance study of many of the eastside drainages in southern Santa Rosa, tributary to the Laguna upstream of Sebastopol. This study will develop new hydrologic, hydraulic, and flood hazard information for a portion of the Laguna watershed. Completion of the study is expected within approximately the next two years.

Key Uncertainties and Data Gaps

The flood flow hydrology of the system is not well established, and the dynamics of interaction between the Laguna and the Russian River is not well understood. Both of these elements will significantly affect the actual flood storage function of the Laguna de Santa Rosa.

Hypothesis

The flood storage volume of the Laguna continues to provide significant flood attenuation benefits to the communities downstream along the Russian River, though it has likely declined since the 1964 flood; part of this detention capacity is produced by overbank flooding along the lower reaches of the Laguna’s tributary channels.

Question 3.1.3 Is it likely that present and/or expected future condition low flows, especially in the Lower Laguna Watershed do or will impair beneficial uses (e.g., habitat, invasive species, species of concern, etc.)?

Summer season flows in the Laguna system appear to be elevated compared to historic conditions. One potential source of this runoff is irrigation of urban and agricultural lands upstream. There may be linkages between the abundance of some species and the changed habitat conditions triggered by the presence of elevated summer flows. The spread of *Ludwigia*, for example, may be fostered in part by the growth of persistently wetted channel area.

Shallow groundwater aquifer conditions can interact with streamflows, augmenting them if the water table is higher than water levels in the stream, and lowering them if the water table is lower. A 1958 investigation by the USGS suggested that groundwater was contributing to streamflows in the Santa Rosa Plain. Shallow groundwater levels may have declined from historic conditions as a result of the history of extraction in the Santa Rosa Basin and the urbanization of significant portions of the high recharge areas in the watershed, but the present interaction of these two systems is unknown.

Key Uncertainties and Data Gaps

The recorded data on historic summer low flows is limited to a short record at a single station along Santa Rosa Creek. Historic descriptions of the waterways of the Laguna may provide another source of information to help evaluate the probability of an increasing trend in summer low flows. The current USGS groundwater study may also provide insight on the present-day interaction between surface and groundwaters within the portion of the watershed occupying the Santa Rosa Plain.

Hypothesis

Summer low flows in the Laguna are elevated over historic conditions and contribute to a decline in certain beneficial uses, including the spread of *Ludwigia*.

Question 3.1.4 How will future modifications within the watershed affect flood conditions and the future hydrologic regime?

Development of presently undeveloped lands and an increase in impervious area in the watershed upstream of the Laguna is expected. The apparent increase in summer low flows will therefore likely grow in the future as one potential source of this runoff is irrigation of developed lands upstream. Flood flows are also expected to increase, as development is associated with increased runoff peaks and volumes. If encroachments are allowed in the 100-year floodplain, or tributary flood flows are contained within levees or similar structures, particularly in their currently flood-prone lower reaches, flooding may increase as a result of lost flood attenuation. Containment of tributary flows also has the potential to increase the ability for those flows to transport sediment to the Laguna as shear stresses increase.

New land, stormwater, and sediment management requirements and programs may reduce the effect of these anticipated changes, as would creation or restoration of flood detention storage. Increasing scarcity or cost of delivered water may also result in limiting the growth of or even reducing the use of water for irrigation, thereby potentially limiting the anticipated increase in summer low flows.

Key Uncertainties and Data Gaps

Projecting development levels or management decisions into the future is always highly uncertain. The potential for future development to increase summer low flows is unknown. The extent and magnitude of future flooding conditions under potential development scenarios are non-existent.

Hypothesis

Flood storage capacity in the Laguna de Santa Rosa will decline while flood peaks are increase; summer low flows will increase.

Question 3.1.5 How will climate change affect flood conditions and the hydrologic regime in general?

Climate change is expected to shift California's precipitation earlier in the year; such a change would similarly shift the peak of a typical annual hydrograph earlier in the year.

Key Uncertainties and Data Gaps

Regionally-specific rainfall intensity and quantity projections are not available.

Hypothesis

Climate change will result in change in the hydrologic regime, triggering evolution of the habitats in the Laguna and ecosystem functions and services provided by the Laguna.

3.2 Sedimentation questions

Management questions related to sediment processes in the Laguna, key uncertainties and data gaps to address these questions, and the hypotheses implicit in the questions are described in the following paragraphs.

Question 3.2.1 What is the magnitude of bedload contribution from each source (e.g., roadside ditches, landslides, gullies, creek banks, etc.) and each geographic subregion, and how are these expected to change in the future?

PWA (2004) found that the largest source of bedload inflow to the lower Laguna is from the Santa Rosa Creek subbasin, followed by the upper Laguna and its tributaries above Llano Road, Mark West Creek, Windsor Creek, Blucher, and Colgan Creek subbasins. Increases in peak flows or changes in climate may increase sediment supply from each of these features.

Key Uncertainties and Data Gaps

No data has been collected that would allow analysis of these contributions by feature and subbasin. No evaluation of transport capacity has been developed that would allow estimation of the delivery of bedload to the Laguna from each subbasin. Projecting development levels or management decisions into the future is always highly uncertain. Regionally-specific rainfall intensity and quantity projections are not available.

Hypothesis

The magnitude of bedload contributions by source varies by subwatershed. For the lower gradient eastside stream crossing the Santa Rosa Plain, sediment delivery to the lower Laguna from each subbasin is transport-limited.

Question 3.2.2 Where are the present sediment deposition areas within stream channels and the floodplain that impair other beneficial uses, and how are these expected to change in the future?

Sediment deposition occurs in locations where supply exceeds transport capacity, such as upstream of hydraulic constrictions and at reductions in channel gradient. Beneficial uses may be affected by deposition in that flood hazards may be aggravated or desirable habitat features may be changed or lost (e.g., upstream of Delta Pond, significant aggradation may have enhanced ponding, creating more favorable conditions for the growth of *Ludwigia*.) As reported in PWA (2004), only a very short record of sediment removal quantities and locations by the SCWA exists. Anecdotal reporting from SCWA maintenance staff may help to focus on apparent depositional areas; these would then need to be assessed for their potential impairment of beneficial uses. It is likely that the growth of in-channel vegetation in the channels that cross the Santa Rosa Plain has reduced their sediment transport capacity and thereby increased sedimentation rates. It is possible that this shift has decreased delivery to the Laguna itself.

Key Uncertainties and Data Gaps

Locations of sediment deposition and impairment of beneficial uses resulting from such deposition have not been broadly catalogued. Nor has the effect of increased growth of in-channel vegetation on sedimentation and transport capacity been evaluated. Changes in future deposition patterns in the Laguna de Santa Rosa and its tributaries in the future will most likely be the result of site-specific land management decisions, which are extremely difficult to project.

Hypothesis

Areas that are presently depositional and where deposition impairs beneficial uses will likely persist into the future except where site-specific intervention is sufficient to alter the hydraulic conditions at that location.

Question 3.2.3 What management interventions would most effectively address sediment sources of concern without impairing other beneficial uses?

PWA (2004) recommends the use of sediment traps at the apex of the alluvial fans feeding sediment into the tributaries of the Laguna. The clearest impairment of downstream beneficial uses is the result of excess, not limited, sediment supply, and management of a specific site for sediment removal would cause far less habitat disturbance compared to sediment removal along an extended reach of creek. It would also avoid the flood hazards that might be created if sediment-laden water were routed onto the floodplain, as occurred under natural conditions. However, such sediment traps may not be the most effective or cost-effective way to address sedimentation conditions at distant locations, such as the Laguna itself. They may also be impractical if they could not be sized to capture a sufficient portion of the sediment that would be delivered over the course of a rainy season.

Key Uncertainties and Data Gaps

To address impairment at a given site by source or upstream controls, an understanding of the source of sediment at that location must be developed. If the largest sources of sediment causing beneficial use impairment at a given site could be identified, then management interventions could be evaluated for effectiveness and cost relative to benefit.

Hypothesis

A better understanding of the relative contribution of the sources of sediment causing impairment would allow prioritization of management measures by cost-effectiveness.

3.3 Dissolved oxygen

Management questions related to dissolved oxygen, as an impairment to beneficial uses of the watershed,together with key uncertainties and data gaps to address these questions, and the hypotheses implicit in the questions are described in the following paragraphs.

Question 3.3.1 Where in the watershed (which stream sections) and when (what time period) and where (in the water column) does the DO impairment occur?

Based on the limited data, DO impairment was observed above Santa Rosa Creek with critical sections between the Laguna at Occidental and above Santa Rosa Creek, and the Laguna near Stony Point Road and above D Pond discharge. DO impairment can occur in both the winter and summer months. The lowest DO is usually observed in deeper water near the sediment/water interface. In extreme cases, an anoxia zone of several feet was developed in deeper water. However, more systematic continuous monitoring of DO is needed. Dissolved oxygen is likely to be negatively impacted under existing conditions; however, background or baseline potential is unknown.

Key Uncertainties and Data Gaps

The dissolved oxygen monitoring program was not comprehensive and it is not known whether there are other locations or time periods where DO is below desired objectives. There is also uncertainty regarding the spatial extent and the completeness (channel cross-section) of the depressed dissolved oxygen zones. Background/baseline DO conditions within the Laguna remain somewhat uncertain, but this could be better evaluated using a dynamic watershed/water quality model.

Hypothesis

Reduced nutrient and BOD loading, improved hydraulic flow, and improved habitat conditions, would improve DO conditions in the Laguna.

Question 3.3.2 To what extent does the DO impairment impact the Beneficial Uses? Do dissolved oxygen concentrations reach stressful or lethal levels for salmonids and other aquatic life in the Laguna watershed, at time periods when the fish are likely to be present?

The DO impairment most likely impacts Beneficial Uses related to aquatic life because low DO is observed both in winter and summer months throughout the Laguna. In the Laguna main channel during the summer, minimum DO as low as 0.03 mg/l was observed, and as low as 0.21 mg/l in the winter months in the main channel and 2.29 mg/l in the tributaries. These represent lethal to stressful conditions for most forms of aquatic life.

Key Uncertainties and Data Gaps

The duration and magnitude of these zones and the presence of refuge habitats is unknown. Therefore, more detailed information on when and where the aquatic species may be present is needed. It is also not known to what degree that low dissolved oxygen zones could potentially serve as migration barriers to cold-water fish for access to upper tributaries where DO impairment occurs. Steelhead migration to and from Santa Rosa Creek does not appear to be impacted.

Hypothesis

The current dissolved oxygen conditions within the Laguna represent a serious threat to the viability of several of the Laguna's designated Beneficial Uses.

Question 3.3.3 What is the cause of the DO impairment? What physical, chemical and biological factors control the DO impairment?

As indicated in the previous question, various factors contribute to low DO in the Laguna. Among these, the significant factors include low flow, low gradient of water, channel morphology, high loadings of nutrient and organic carbon, high sediment oxygen demand and an abundance of algae and macrophytes.

Key Uncertainties and Data Gaps

There is uncertainty about the significance of each of the individual risk cofactors listed above in creating low dissolved oxygen conditions.

Hypothesis

It is possible to mitigate the impacts of the various risk cofactors on dissolved oxygen through a series of management actions including reductions in nutrient and organic carbon loading, restoration of riparian habitat, and removal of hydrologic restrictions.

Question 3.3.4 What are the relative contributions of DO consumption due to algae and macrophyte respiration and the decomposition of organic material (e.g. dead algae) in water and sediment?

As indicated in the previous sections, large DO swings indicate the influence of algae and macrophytes respiration; however, the low baseline DO, even in winter months, indicates that there is a large oxygen demand in the lower water column and sediments, possibly due to organic carbon and reduced forms of nitrogen. The relative contribution of DO consumption due to algae or microbes may vary with season. However, prolonged depressed DO observed in summer months indicates a large influence of bacterial activity.

Key Uncertainties and Data Gaps

Sediments and sediment processes within several sections of the Laguna are not well understood. It is not known how much oxygen consumption is due to sediment processes.

Hypothesis

In the Laguna during the summer DO consumption is dominated by algae and macrophytes respiration as well as sediment oxygen demand, and in the winter most of the DO consumption is due to BOD loadings from external sources.

Question 3.3.5 What are the relative contributions of organic carbon originated from terrestrial and aquatic sources to oxygen demand in the Laguna?

It is clear that organic carbon from both the terrestrial sources (e.g. urban/agricultural/forest runoff) and aquatic sources (decay of macrophytes and detritus of algae) contribute to the loading of organic carbon in the Laguna. Organic carbon loads from aquatic sources are possibly more dominant during the summer when primary production is high and are likely to be more bio-available and is more easily decomposed and may contribute to short-term oxygen demand. Such loads may be particularly high following die-back of macrophyte beds. Organic carbon from terrestrial sources is probably more dominant in the winter and not as rapidly decomposed and therefore may be contributing to the long-term prolonged depression. *Ludwigia* continues to be a significant contributor of organic carbon in the Laguna despite progress made by the *Ludwigia* eradication program. Preliminary loading estimates as described in section 3.2 indicate that urban stormwater and agricultural lands contribute to loadings of BOD that could potentially be impacting DO conditions within the Laguna.

Key Uncertainties and Data Gaps

The relative importance of terrestrial and aquatic sources of organic carbon is difficult to determine without further study. High algal density has been observed during 1990 to 1994 (*e.g.*, average of 78.7µg/l of chlorophyll a at the Laguna at Occidental Road – Table 3-16); however, information on current algal levels has not been reviewed by the project team. In addition, background loading of BOD and organic carbon has not been determined. Therefore, the estimates provided in this document must be considered preliminary.

Hypothesis

Within the Laguna organic carbon contributions during the summer and fall are dominated by aquatic sources, while in the winter organic carbon sources are dominated by terrestrial sources.

Question 3.3.6 What are the relative contributions of organic/inorganic nitrogen originated from terrestrial and aquatic sources to oxygen demand in the Laguna.

Nitrogen loads to the Laguna have an important indirect effect on oxygen dynamics by supporting growth of algae and macrophytes. The direct contribution of nitrogenous oxygen demand is less clear. Relatively high organic nitrogen and inorganic nitrogen (ammonia) concentrations were observed in sections of the Laguna. Oxygen demand due to nitrification could be significant. The main terrestrial TKN sources include runoff from dairies and other agricultural activities. Nitrogen sources in water include possible ammonia releases from sediment and organic nitrogen released from decomposition of dead algae and plant tissue. In the nutrient and dissolved oxygen dynamic study (Otis, 2006), TKN in the water column at SEB3 was found to increase with depth (from 1.3 to 6.9 mg/l from surface to bottom), indicating a possible aquatic source. The importance of this question is to determine whether any additional effort should be directed to managing terrestrial sources of nitrogen or rather that aquatic sources that are not easily managed are dominant.

Key Uncertainties and Data Gaps

Without a loading estimate for aquatic sources, the relative contribution is not clear.

Hypothesis

It is most likely that the largest portion of the reduced forms of nitrogen comes from agricultural sources in close proximity to the Laguna and if controlled would significantly reduce the overall nitrogen oxygen demand. Reduced algal and macrophyte abundance will also reduce the aquatic portion of nitrogen oxygen demand.

Question 3.3.7 Does nitrogenous oxygen demand contribute to DO consumption in the water column?

Yes, there is evidence that nitrogenous oxygen demand does contribute to DO consumption in the water column. It is likely that BOD is a more significant demand than nitrogen. As indicated previously high TKN concentrations were observed in sections of the Laguna result in increasing levels of oxygen demand due to oxidation of TKN. TKN concentrations have been measured at 6.9 mg/l in the lower water column at SEB3 on July 21, 1998 (Otis, 2006).

Key Uncertainties and Data Gaps

The extent of nitrogen oxygen demand in locations other than SEB3 has not been assessed and it is uncertain whether other locations exhibit the same profile as SEB3. Additional monitoring is necessary to determine how broadly the conceptual model developed for SEB3 applies within the Laguna.

Hypothesis

While there are indications of nitrogen oxygen demand in the water column, organic carbon imposes a larger oxygen demand within the Laguna.

Question 3.3.8 Are there impoundments that reduce travel time, promote settling, promote stratification, and promote oxygen consumption?

Yes. There are several reaches in the Laguna where the channel is wide and have a reduced flow velocity that contributes to settling, stratification and oxygen demand (Otis, 2006). These factors contribute to the low DO in the bottom layer of water.

Key Uncertainties and Data Gaps

The location and magnitude of these impoundments is uncertain and the overall impact on water quality within the Laguna is also uncertain.

Hypothesis

Eliminating unnatural impoundments (e.g., constrictions due to bridge abutments) would result in improved water quality conditions within the Laguna.

Question 3.3.9 How and where does wind mixing affect DO concentrations in the water column?

It has been proposed that due to the low gradient, high heat, and lack of canopy, wind mixing is one of the few possible mechanisms for reaerating some reaches of the Laguna's depleted water column. However, there is little information upon which to evaluate the overall importance of this mechanism.

Key Uncertainties and Data Gaps

Additional information on DO diurnal monitoring in association with channel morphology and riparian cover is needed to determine whether, when, and where wind mixing contributes significantly to reaeration of the water column. An important question is the extent to which dense macrophyte beds reduce natural reaeration rates.

Hypothesis

Under current conditions wind mixing is inadequate to overcome excess oxygen demand and respiration effects within the Laguna.

Question 3.3.10 What are physical, biological, and chemical characteristics of the photic zone in various reaches of the Laguna?

The photic zone is usually open without riparian vegetation and therefore receives full sunlight. There is not enough data to quantitatively address the question. In photic zones, excess algal growth can occur as indicated by observed large DO swing. In shallow photic zones, macrophytes such as *Ludwigia* may also grow. A detailed survey of *Ludwigia* cover or algae density has not been reviewed by the project team.

Key Uncertainties and Data Gaps

A detailed survey of *Ludwigia* cover or algae density has not been reviewed by the project team.

Hypothesis

Currently the photic zone is dominated in sections by *Ludwigia*. In sections not dominated by *Ludwigia* the water column frequently has algal biomass (measured as chlorophyll a) exceeding 25 µg/, which also impacts Beneficial Uses.

Question 3.3.11 Is the Basin Plan minimum DO objective of 7.0 mg/l achievable at all times and places within the LSR watershed?

Preliminary data analysis based on limited data suggested that the Basin Plan minimum DO objective was not met at any locations within the main Laguna channel. Santa Rosa Creek meets the DO objective in the winter months but does not meet the basin plan objective in the summer months. Some tributaries downstream of waste water discharge points also do not meet the basin plan objective. More systematic continuous DO monitoring is needed to more completely characterize existing conditions within the Laguna. Clearly under existing conditions, the LSR can not achieve the Basin Plan minimum. This may be due to excess inputs of nutrients and organic materials and restricted flow. Given reduced levels of nutrients and organic inputs, and improved flow conditions (low flow channel) DO conditions would be dramatically improved. However, it is not possible at this time to determine whether these improvements will result in pervasive achievement of the Basin Plan minimum DO objective. It is also important to note that legacy sediment quality effects will likely delay improvements in water quality conditions. Low gradient, flow volume and elevation would probably result in marginal DO conditions during the dry season. This question of DO could be reasonably well addressed through the use of dynamic simulation model to determine the implementation strategies that could result in the achievement of the basin plan objective throughout the Laguna. There is uncertainty regarding the feasibility of achieving desired DO conditions under restored conditions during the summer season.

Key Uncertainties and Data Gaps

Because of the unique nature of the Laguna, there is no known reference site with which to assess the question of whether the DO objectives are achievable in the absence of human disturbance. Development of a calibrated model would allow evaluation of the expected DO regime under natural conditions in the Laguna.

Hypothesis

Using a calibrated model a background simulation will present marginal but acceptable DO conditions within a hypothetically un-impacted Laguna.

3.4 Nutrients, macrophytes and algae

Management questions related to nutrients, macrophytes and algae are discussed here, together with the key uncertainties and data gaps that limit these discussions. To the extent possible, working hypotheses are provided for each management question.

Question 3.4.1 Do nutrient (N, P) loadings contribute to excess algal and macrophytes growth in the Laguna? What are other contributing risk cofactors that contribute to excess growth? For N and P, which one is the controlling factor for algal and macrophytes growth? Is either controlling or are both present in sufficient quantity that there is no limiting nutrient? How will reducing N and P loadings result in improvement in water quality conditions? To what levels will the N and P loadings need to be reduced?

This question is a concern in part because nutrient concentrations in the Laguna are well above other water bodies within Ecoregion 6 (which includes the Laguna de Santa Rosa). Mean nitrate concentrations range from 0.52 – 2.96 mg N/l at different sampling locations in the Laguna. The mean nitrate concentration for minimally impacted waterbodies (N=112) within Ecoregion 6 is 0.16 mg/l. The range of nitrate concentrations from this same Ecoregion 6 sample is .05 mg/l to 2.85 mg/l. Mean TP concentrations in the Laguna range from 0.11- 1.22 mg/l. The range within the Ecoregion 6 survey of minimally impacted waters is 0.03 mg/l to 0.30 mg/l. The mean is 0.08 mg/l. In addition this question may have a different outcome depending on whether macrophytes or algae are being considered limited by nutrients.

The project team recently received a technical memorandum dated March 19, 2007 developed by Dennis J. Brown of LSA Associates as a contribution to the City of Santa Rosa IRWP Discharge Relocation Project Draft EIR. The memorandum evaluates factors controlling the colonization and growth of *Ludwigia* sp. within the Laguna de Santa Rosa. The memorandum states that the availability of propagules and habitat conditions are the main controls on *Ludwigia* infestation. The review suggests that nitrogen in the water column may play a role in limiting growth of *Ludwigia* and that phosphorus concentrations in the water column are unlikely to be limiting, as ample P can be obtained from the sediments via the roots. While external inputs of P clearly increase the sediment store it is unlikely to be a limiting factor since P is mobile under anaerobic conditions and the native sediment is likely to contain enough P to support macrophytes growth. These results would suggest that in addition to mitigating the hydrologic and habitat factors contributing to the infestation that any nutrient management strategy would need to address both N and P over the long-term to have a measurable impact in reducing the abundance of *Luwigia*.

In addition to this most recent study there is additional information to consider relative to this key management question. The effect of nutrients on growth of phytoplankton and other plants is typically represented by Michaelis-Menten kinetics, in which $G = Gmax \cdot C/(K+C)$, where G is the growth rate, $Gmax$ is the maximum potential growth rate (absent any other limitations on growth potential), C is the available nutrient concentration, and K

is the half-saturation constant. Growth limited by a nutrient is then G/Gmax = C/(K+C). In this formulation, nutrient limited growth asymptotes towards 1 as *C* becomes large relative to *K*. As summarized in Thomann and Mueller (1987, p. 427): "If a nutrient control program is initiated, but the reduction in input load only reduces the nutrient concentration to a level of about two to three times the Michaelis constant, then there will be no effect on the phytoplankton growth. This is equivalent to the notion of the limiting nutrient. Removing a nutrient that is in excess will not have any effect on growth until lower concentrations are reached." In fact, the statement of "no effect" is a bit misleading, as the Michaelis-Menten formulation is asymptotic, implying that some potential limitation persists at any concentration, but that it becomes exceedingly small as concentrations become much greater than the half-saturation constant.

Determining at what point nutrient limitation becomes "insignificant" depends on the specification of the half-saturation constants, as well as the decision as to what represents a significant effect. Thomann and Mueller cite typical half-saturation constants for phytoplankton growth of 10-20 µg/L for [inorganic] N and 1-5 µg/L for [inorganic] P. Other authors have suggested somewhat different values.

The Michaelis-Menten formulation indicates that when concentration is 4 times the half-saturation constant growth will be 80 percent of the maximum potential rate, implying only a minor limitation. The upper ranges on the Michaelis-Menten half-saturation constants suggest that minimal limitation on phytoplankton growth by nutrients will occur until inorganic N concentrations fall below 80 µg/L or inorganic P concentrations fall below 20 µg/L or less. In contrast, inorganic N concentrations in the Laguna appear to be around 450 µg/L and inorganic P concentrations around 900 µg/L – suggesting that N is likely to limit phytoplankton growth by less than 5 percent and P by less than 1 percent of the maximum potential rate. Of course, algal growth may be limited by other factors, including light, temperature, settling, and grazing.

In a paper in which he reviews the eutrophication status of streams Dodds (2006) states that in an excess of threshold values of total N and total P there are no increases in mean benthic chlorophyll a. Dodds suggests that this indicates that nutrient limitation is overcome when water column nutrient concentrations are great enough. It is possible neither nitrogen nor phosphorus ever becomes limited in the Laguna due to the availability of these nutrients released from the sediments. It would be necessary to further control N and P loadings to begin to address excess algal and macrophyte growth in the Laguna. However, other risk cofactors including shallow water depth, lack of riparian cover, low flow, altered flow regime, and high water temperature also contribute to excess algal and macrophytes growth. A nutrient management strategy will have limited success in controlling excess algal growth without also addressing other risk cofactors.

Listed below are some the key summary points from the Dodds (2006 and 2006a) that relate to this management question:

- There is a relationship between TN/TP with primary production (particularly for benthic, and planktonic algae);
- The relationship to macrophytes is less clear but it is still considered to be a factor for most species;
- When nutrients in the water column reach a high level, nutrient limitation can be overcome;

- Organic carbon input (both allochthonous and autochthonous) can increase heterotrophic activity and lead to net heterotrophic status;
- Nutrients enrichment can stimulate both autotrophic and heterotrophic activity;

Dr. Eugene Welch has commented on this question for the Laguna stating that N/P ratios have little meaning if concentrations for both are high, citing studies that suggest that light will become the limiting factor before nutrients (Saas et al. 1989; and Cooke et al. 2005 – page 93). In general he states that phosphorus control leads to more efficient biomass control.

The project literature review included a reference to an Algal Growth Potential (AGP) assay conducted by the City of Santa Rosa in waters collected from the Laguna de Santa Rosa and presented in their findings in the "1996 City of Santa Rosa EIR" (Wickham, 2000). The AGP results suggested that the Laguna is a nitrogen limited system. Tetra Tech conducted a review of the AGP procedure and prepared the following review:

The City of Santa Rosa (City) examined the Algal Growth Potential (AGP) in waters collected from the Laguna de Santa Rosa and presented their findings in the "1996 City of Santa Rosa EIR" (Wickham, 2000). According to Wickham (2000), the City collected an aliquot of water from a particular station and isolated and held it for 14 days. They monitored algae production and measured nutrient uptake to see which nutrients were depleted first. Their premise being that the limiting nutrient would be depleted before the non-limiting nutrient.

Although the description of the specific procedures used in the City's AGP test as presented in Wickham (2000) are not reported, and, therefore, cannot be commented upon, some general uncertainties about the procedure can be discussed. The following sections provide a discussion about these general uncertainties. An alternate method for evaluating nutrient limitation is provided in Section 9 "Monitoring Recommendations".

1. The test method cited used "raw" water and resident algal species. This procedure incorporates several uncertainities:
    a. Raw water contains not only nutrients and algae, but bacteria, rotifers, zooplankton, and detritus.
    b. Rotifers and zooplankton graze on the algae, making accurate quantification of growth/lack of growth impossible. It also impedes the ability to identify the limiting nutrient(s) because the nutrients are constantly being assimilated by algal growth and released as metabolic by-products.
    c. Raw water samples can contain a mixture of algae species, the health of which is unknown. Unhealthy algae can add bias into the test results.
    d. Detritus can provide a surface upon which nutrients can sorb, thus adding bias into the test results.
2. The City's AGP test method was unable to differentiate between nutrients that were assimilated by the algal cells vs. those assimilated by bacteria or sorbed onto particulate detritus. Since the City's method used a chemical quantification of the

remaining nitrogen and phosphorus, there exists the potential for some methodologically derived uncertainties:

e. If the sample was not filtered through a 0.45 micron sterile filter prior to chemical quantification of nitrogen and phosphorus, the analytical procedure would result in lysing the cells, releasing all of the nutrients back into solution. Thus making it very difficult to quantify which nutrients were assimilated by algae and bacteria or sorbed onto particulate detritus.

f. If the sample was filtered through a 0.45 micron sterile filter, and the filtrant analyzed for nutrients, the results would provide only the amount of nutrients assimilated by whatever was living in the test solution (algae, bacteria, etc.) or sorbed by particulate detritus.

3. There is no indication that the City examined seasonal nutrient limitation. For example, what is limiting during the summer dry months might not be limiting during the wetter winter and spring months.

The management question is linked to the potential impact of organic matter in two ways. First that nutrients are not the only potential stressor resulting from external loading sources; and secondly that the primary impact is the internal production of organic matter that then leads to low dissolved oxygen conditions. For the Laguna, the high organic carbon load suggests that there should be high heterotrophic activity. The role of organic carbon as a stressor upon beneficial uses is likely to be important. A key aspect regarding organic matter is whether the main source of organic carbon is originated from the water column or from terrestrial input.

As defined by Dodds in the 2006 paper, the Laguna has the situation where the autotrophic and heterotrophic state coexist (one may dominate according to season). If the heterotrophic state dominates and the main carbon source is allochthonous, then controlling carbon should help limit heterotrophic activity. However, as nutrients can stimulate primary production (which can provide and internal carbon source) and heterotrophic activity, controlling carbon only without controlling nutrients will still result in heterotrophic activity and high DO demand.

High turbidity in Laguna water may lead one to believe that algal growth is limited. However, as the diurnal cycle illustrated in the DO analysis indicated that in open water there is substantial algal activity. Tetra Tech did obtain and summarize algal data for the period of 1989-1994 (Table 3-16). The values in Table 3-16 must also be evaluated in light of a potentially successful *Ludwigia* removal program. If turbidity is not the dominant light limiting factor the removal of the shading effects of the macrophytes could lead to nuisance levels of algal growth. Monitoring for algal concentrations in *Ludwigia* control reaches should be undertaken to investigate the potential for this possibility. In summary:

- N and P loadings likely contribute to excess algal and macrophytes growth in the Laguna, however other factors must be considered;
- Under current conditions it is unlikely that either N or P are a controlling or limiting factor for algal or macrophytes growth;

- Reducing nutrient loading for the long-term will reduce growth rates of both algae and macrophytes that will lead to improved DO and habitat conditions; and
- It is not clear how much or how long nutrient loading will need to be reduced to see measurable improvement in water quality conditions.

Key Uncertainties and Data Gaps

It is unclear whether nitrogen and phosphorus ever become a limiting nutrient to algal or macrophyte growth in the Laguna. What is the relative contribution of other risk cofactors to excess levels of algae and macrophytes? The assessment of nutrient targets or loading reduction must be done in association with other risk cofactors, which can be best accomplished through the use of a dynamic water quality/watershed simulation model(s).

Hypothesis

A reduction of nitrogen and phosphorus loading to the Laguna in conjunction with the strategy to mitigate risk cofactors will reduce excess algal and macrophyte growth within the Laguna to acceptable levels.

Question 3.4.2 To what extent do the macrophytes (including *Ludwigia* and other nuisance invasive species) and algae growth impact the beneficial uses?

As illustrated in the overview conceptual model (Figure 3-1), macrophytes and algal growth and decay processes significantly impact water quality conditions (DO, pH, etc.) causing impairment to all beneficial uses. The respiration phase of the diurnal cycle results in lower DO that would be harmful to fish and other aquatic life. Decay of macrophytes and algal material consumes oxygen and also results in low DO. The physical density of macrophytes is also likely to impair beneficial uses (migration, recreation, etc.). Unaesthetic odor and slime also impair recreation uses. Macrophytes (specifically *Ludwigia*) provide ideal breeding habitat for mosquitos, which impacts public health. Hypotheses demonstrating impacts of other beneficial uses can be developed using the overview conceptual model in Figure 5-1.

Key Uncertainties and Data Gaps

Tetra Tech (2006) recommended a maximum algal density of less than 10 µg/L chlorophyll a in lakes and reservoirs to support cold water aquatic life uses without impairment and 25 µg/L chlorophyll a to support warm water aquatic life uses without impairment. It is not clear if these lake targets are applicable to the Laguna. It is also not clear what the threshold density for macrophytes should be to ensure that impacts to Beneficial Uses do not occur. No targets have been recommended for macrophyte density at this time.

Hypothesis

Specific targets for macrophytes density and coverage or algal concentrations have not been developed. However, it will require a comprehensive management strategy that includes habitat restoration and nutrient reduction strategies to reduce the impact of nuisance invasive species and algal growth and to restore the beneficial uses to the Laguna de Santa Rosa.

Question 3.4.3 What are the sources of nutrient loadings? What are the relative contributions of the following sources: urban storm water runoff; agricultural storm water runoff; agricultural irrigation return flows; municipal wastewater discharge; sediment flux; atmospheric deposition; and groundwater? For external nutrient loadings, what is the relative contribution from point and various non-point sources? Can we reasonably estimate the amount of nutrient loading from each source? What are the largest sources of nutrient loading (both N and P) in the watershed? Can the identified sources be effectively managed?

Various sources exist in the Laguna contributing to nutrient loadings, including all the sources listed above. Based on preliminary loading estimates, main sources of nutrient loadings vary with season and constituents. During winter, urban storm water runoff, agricultural storm runoff and municipal wastewater discharge are the main sources of nutrients. Phosphorus has a tendency to bind with sediments. Therefore, transport of phosphorus is more associated with sediments, which are mobilized by storm flows. Release of phosphate from anoxic bottom sediments can be a large source of phosphorus during the dry season. As summarized in Section 2.3.4, shallow groundwater may interact with streams and therefore be a potential source of loadings. Currently there is limited information on the connectivity between surface and deep groundwater, but generally deep groundwater may not be a significant source

For nitrate, point source of municipal wastewater discharge remains as a main source. Urban storm water runoff is also a main source. For ammonia, urban storm water runoff and agricultural runoff from dairies are the main sources. For nitrate, both municipal wastewater and urban stormwater runoff are the significant sources. For phosphorus, municipal wastewater discharge and urban storm water runoff are main sources for phosphate. However transport of phosphorus is closely associated with sediments, and therefore non point sources of runoff from various land uses (e.g. agricultural lands, urban) should be a larger source for total phosphorus.

Municipal wastewater discharge remains as one of the main nitrate sources and phosphate. However, runoff from urban storm water and agricultural lands contribute more significantly to ammonia, organic nitrogen, and total phosphorus. For non-point sources, some best management practices (BMPs) such as riparian cover are necessary for reducing loadings to streams.

Key Uncertainties and Data Gaps

The loading estimates we developed are based on assumptions that need to be further evaluated and without detailed model calculations, the estimates are preliminary. The following uncertainties and data gaps must be addressed before a meaningful loading analysis can be completed:

- Ground water discharges need to be better mapped and quantified.
- Estimates of dry and wet atmospheric deposition of ammonia and nitrate need to be further refined.
- Contributions of nutrients from septic tanks through infiltration during wet and dry periods need to be monitored.
- Overall loadings from agricultural operations (e.g. manure application, slurry rates, and irrigation, fertilizer use in vineyards) need to be updated.
- A comprehensive estimate of urban runoff needs to be developed.
- Factors that affect the bioavailability of nutrient loads to algae and macrophytes needs to be further evaluated.
- Loading from internal nutrient cycling and sediment flux needs to be better quantified.

Hypothesis

Atmospheric deposition is likely to be a minor source of nutrients during storm events when compared to other source categories. Groundwater, as shallow infiltration, is an uncertain but likely source of nutrients during storms and from irrigation infiltration; however, it is also a smaller source when compared to surface runoff from agricultural operations, urban stormwater, and point source discharge during winter storms. During the summer dry season, urban incidental runoff, sediment flux and internal cycling in the Laguna could be major sources of nutrients.

Question 3.4.4 Are nutrient loadings greater from external or internal origin? What are the primary nutrient loadings under high flow and under low flow conditions? Are nutrients being released from sediment during low flow, and is it a significant source? To what extent does internal sediment contribute to the loading of nutrients? What management intervention for sediment control would have the most significant effect on nutrient loading?

Even without accurate estimates of internal loading rates it is likely that during the winter months external loads are greater than internal loads. During the dry season internal loading rates could be greater than the external loading rates–but most of the internal load ultimately derives from external sources. External sources during the dry season include: infiltration to base flow from irrigation and septic systems, and urban storm drain discharge from incidental water use. It is unclear during the dry season whether external or internal sources are larger.

Even though they are smaller, summer loads (including cycling of deposited wet season nutrients) may be more important to nuisance growth of algae and macrophytes. That is, nutrients can also accumulate in the sediments that are transported to the Laguna from urban stormwater and from wastewater discharges. Sediment flux and internal nutrient cycling can be significant sources of nutrients during low flow season. As shown in previous studies, sediments in the Laguna have accumulated large pools of nutrients and organic matter in the sediments.

The most effective management intervention for reducing nutrients in the sediment is to reduce overall nutrient loading to the Laguna and allow natural hydrologic processes to either transport the nutrients out of the Laguna or bury them until they are no longer biologically available. The hydrologic transport of nutrients out of the Laguna may take many years. Increasing DO at the sediment-water interface will also reduce cycling into the water column through the formation of insoluble ferric hydroxides. Dredging is likely to be too expensive to be a practical option and could have significant adverse impacts on habitat. Other management strategies should be evaluated regarding their feasibility including reaeration and alum treatments. In addition, limited restoration of low flow stream channels should be considered.

Key Uncertainties and Data Gaps

Internal loading rates are unknown. Loading rates from wet and dry season groundwater sources are also unknown. Are nutrients introduced during high flow events available for uptake by biota?

Hypothesis

Overall nutrient loading to the Laguna exceeds the ecosystem's capacity to assimilate and process these nutrients and maintain the integrity of Beneficial Uses. During the summer sediments are a significant source of nutrients for biological productivity and excess nutrients that have accumulated in the sediments will remain as a significant source for a long period of time.

Question 3.4.5 What impact does irrigation and surface discharge of treated wastewater on agricultural lands have on water quality? Can loading from this source be reduced through enhancement of vegetated buffers? How have groundwater nutrient concentrations been impacted by wastewater irrigation and application programs? To what extent are the Laguna surface waters under the influence of this ground water source?

The irrigation with treated wastewater has the possibility of exceeding nutrient demand of crops (mostly pastures), but should be operated in a manner that agronomic rates are not exceeded. Riparian forest has been found to remove nitrogen more efficiently than pastures. Therefore enhanced vegetated buffers may reduce the potential loading from this source. Previous monitoring data suggest that groundwater from agricultural lands that received irrigation from reclaimed water can have nitrate concentrations greater than 10 mg/L. As suggested in Section 4.3.4, shallow groundwater is likely to influence surface water quality. The magnitude of loading from this potential pathway is unknown. However limited information is available to assess the connectivity between deep groundwater and surface water except in the vicinity of the confluence of Santa Rosa Creek and the Laguna.

Key Uncertainties and Data Gaps

The impact of restored riparian buffer with developing woody species is difficult to predict, but previous studies indicated that the buffer can serve to intercept and trap nutrients before they reach the aquatic ecosystem and serve as a filter for sediment and organic matter. The degree to which this will reduce these loadings will need to be further developed and explored using a dynamic watershed model.

Hypothesis

A restored riparian canopy can benefit water quality conditions though uptake of nutrients and trapping sediment loads being transported to the stream both overland and through infiltration.

Question 3.4.6 To what extent does fish biomass affect internal nutrient cycling?

Internal nutrient cycling in the Laguna transforms nutrients between different forms and different pools. Inorganic nitrogen and phosphate are taken up by algae, macrophytes, bacteria and fungi. Nitrogen and phosphorus (both organic and inorganic) can be leached or excreted from the living biomass or released through decaying from non-living biomass. Particulate forms of nutrients can be settled to bottom sediment and released through decay processes mediated by bacteria. Fish can take up nutrients through consumption of phytoplankton or ingestion of particulate forms of nutrient and excrete nutrients in various forms. As discussed in Section 3.2 internal cycling can be a significant source of nutrients during summer. However, it is unclear how important fish biomass can be relative to the vegetative biomass that includes macrophytes and algae. Certain fish populations (carp) disturb bottom sediments during mating and feeding, thus resuspending nutrient laden sediment into the water column.

Key Uncertainties and Data Gaps

Fish biomass estimates for the Laguna were not available to the project team. The extent to which fish bioturbation contributes to the resuspension of sediments into the water column is not known.

Hypothesis

The Laguna fish population community has shifted to low DO tolerant species such as carp, who through their feeding and mating activities (bioturbation) significantly contribute to internal nutrient loading.

Question 3.4.7 How did the changes in hydrology, sediment delivery, channel morphology and riparian degradation over time contribute to macrophyte growth? Do the nutrient sources for *Ludwigia* growth originate from the sediment or water column or both?

A previous sediment study indicated sediments yields have increased compared to historical conditions,as a result of flashier runoff, increased permeable area, and increased disturbance of soils (PWA, 2004). Channelization also results in more delivery of sediments to the Laguna channel instead of on the alluvial fan. Previous studies suggest that the Laguna main channel has accumulated approximately 1.5 feet of sediments between 1966 and 2002. The accumulated sediments have reduced channel depth. This reduced average depth has increased the area that can be colonized by macrophytes because they are now within the reach of their rooting zone. Enriched nutrients in sediments also provide nutrients for macrophytes growth. It is not clear to what extent the *Ludwigia* infestation has led to the decline of the riparian canopy or rather that the decline of the riparian canopy has contributed to the spread of *Ludwigia*. It is also possible that *Ludwigia* has also impacted the Laguna hydrology by reducing flows due to increased channel roughness.

Nutrient for *Ludwigia* growth can originate from both sediments and water column. The USDA-ARS study of *Ludwigia* growth indicated that soil nutrients are more significantly related to growth in early life stage (highly significant across all response variables; Dr. Brenda Grewell 2007 workshop report to Foundation) and is the primary sources of nutrients during the early stage of development. Water nutrients are also significant for rooting nodes (vegetative reproduction interaction effect). At high water nutrient levels there is more rooting node growth. Elevated nitrogen in the water column can enhance *Ludwigia* growth rates.

Key Uncertainties and Data Gaps

The contribution of factors such as hydrology, sediment delivery, degraded channel morphology, riparian degradation, and excess nutrients to the accelerated growth and spread of *Ludwigia* in the Laguna has not been quantified.

Hypothesis

Ludwigia has benefited from excess sediment delivery to the Laguna's channel and has impacted the Laguna hydrology by reducing flow rates. The *Ludwigia* infestation has impacted riparian cover through over saturation of soils causing sections of riparian forest to be drowned. Elevated nitrogen in the water column is not the sole cause of the *Ludwigia* infestation but exacerbates the problem.

Question 3.4.8 What are the natural factors/processes that contribute to the excess macrophytes and algae growth? To what extent can the system recover given the natural conditions? Are there natural attenuation processes of N and P in the Laguna?

The Laguna historically has been a productive ecosystem that is in some parts lake, wetland, and stream. The low gradient and low elevation characteristics lead to naturally low flow rates and high temperatures. This has made the Laguna more susceptible to accelerated nutrient and sediment loading related to development activities. One common characteristic of wetland ecosystems is the presence of macrophytes. The surrounding clay soils may have resulted in higher than average phosphorous concentrations within the Laguna.

The Laguna retains significant portions of its original natural biological communities. Through proper stewardship a significant portion of the naturally functioning conditions should be able to be restored. Access to tributaries will be critical to restoring facultative use by a cold water aquatic community. No disturbed ecosystem can ever fully recover its original trajectory; however, given adequate commitment large components of lost integrity can be recovered.

Some natural attenuation processes in the Laguna may include nutrient removal by riparian vegetation and wetlands before reaching the streams. Riparian vegetation and wetlands can remove nutrients through uptake and denitrification processes which convert nitrate into gases. However, riparian vegetation and wetlands have decreased (Smith, 1990).

Key Uncertainties and Data Gaps

The Laguna is a unique ecosystem for which no reference condition exists. Historical records indicate a productive ecosystem that supported the designated Beneficial Uses. Ecosystem recovery is difficult to predict.

Hypothesis

The Laguna will remain as a productive ecosystem once nutrient loading and other risk cofactors have been addressed due to natural conditions that define it as a marginally euthrophic wetland/lake/riverine ecosystem. Pervasive low dissolved oxygen episodes will become infrequent to rare. Nutrient concentrations will significantly decline over a period of years.

3.5 Biological diversity

Management questions related to biological diversity are discussed here, together with the key uncertainties and data gaps that limit these discussions. To the extent possible, working hypotheses are provided for each management question.

Question 3.5.1 What are the ecosystem engineers of the Laguna, and what are their 'roles?' What are the highest priority habitat restoration targets for improving water quality? How would enhanced riparian habitat conditions improve water quality and the status of beneficial uses? How does habitat degradation influence beneficial uses, water quality, flooding capacity, water supply?

Riparian zones

Trees in riparian buffer zones can be viewed as "ecosystem engineers," as they fundamentally change ecosystem function. Riparian zones could thus be viewed as 'keystone' communities. Areas where historical riparian vegetation have been lost are sure indicators of habitat loss/degradation, negatively affecting the entire associated aquatic and terrestrial communities. Terrestrial streamside communities are mainly impacted through the loss of cover, foraging and nesting habitat (Pearson and Manuwal 2001). Stream habitat degradation could be in the form of increased run-off and stream bank erosion, lack of shade along stream banks causing increased water temperatures, and loss of fish cover or spawning habitat. Lack of riparian vegetation may also allow adjacent livestock to enter the water, causing bank erosion, degrading the stream bottom through trampling and the introduction of increased nutrients into the stream via direct and indirect input of livestock excrement.

The loss or degradation of vegetation along streams also reduces the effectiveness of riparian buffers to improve water quality through processing and removal of excess anthropogenic nitrogen from surface and ground waters. To maintain maximum buffer effectiveness, buffer integrity should be protected against soil compaction, loss of vegetation, and stream incision (Mayer et al 2006). Restoring degraded riparian zones, and stream channels may improve nitrogen removal capacity of the stream system, making riparian buffers a 'best management practice' (Mayer et al 2006). While there is not one generic riparian corridor width to keep water clean, stabilize banks, protect wildlife, and satisfy human demands, generally the larger the width of vegetation, the better the impact on ecosystem services and biodiversity (Kreitinger & Gardali 2007, Semlitsch and Bodie 2003, Pearson and Manuwal 2001).

Invasive *Ludwigia* sp.

Invasive exotic plants can also act as 'ecosystem engineers,' negatively impacting the ecosystem (Crooks 2002). As exotic invasive plants, such as invasive *Ludwigia* sp., increasingly take hold in native plant communities, they threaten native biodiversity by changing the native vegetation structural diversity, often completely 'taking over,' not only out-competing native plants and establishing an extensive and expanding mono-culture, but in the process permanently changing the habitat structure and function. This process so fundamentally changes the original native ecosystem, causing the local extinction of organisms tightly linked to the original community structure and function (National Invasive Species Council 2001). A large proportion of noxious invasive plants were brought to their new range by humans and initially established in disturbed sites (Mack et al 2000).

Key Uncertainties and Data Gaps

Riparian zones

Extant riparian areas in the Laguna de Santa Rosa have been mapped in the lower watershed via aerial photo interpretation in 2000 (Laguna de Santa Rosa: Resource Atlas and Protection Plan 2000), and modeled in 2006 on a watershed scale in Enhancing and Caring for the Laguna (Vol. II, Plate 2). In order to expand on these baseline efforts, the Laguna de Santa Rosa Foundation is currently engaged in a comprehensive mapping effort of the entire watershed using aerial photography. This effort aims to address current data gaps in the watershed.

Invasive *Ludwigia* sp.

Some of the factors influencing invasive *Ludwigia* sp. growth may include: changes in hydrology of the Laguna, sedimentation and siltation of channels and streams, and nutrient loads in sediment and/or water column. There are several pathways for the capture of nutrients by invasive *Ludwigia* sp. via trimorphic roots: floating nodes on the gas-filled, rhizomatous shoots are able to absorb nutrient from the water column directly, while subsurface roots take up nutrients from the sediment. Studies of the relative contribution of each pathway towards plant vigor have not been completed. Preliminary data from a completely randomized, full factorial growth experiment by USDA/ARS (Dr. Brenda Grewell, pers. comm.) suggest that soil nutrient loadings may be more significant in affecting early invasive *Ludwigia* sp. growth (highly significant across all response variables) than nutrients in the water column. Continuation of this USDA/ARS research program will likely shed more conclusive light on this question in the near future.

At this time the specific relationship between nutrient loadings, habitat factors and invasive *Ludwigia* sp. growth is still unclear, and no conclusive inferences can be drawn from currently available data.

Hypotheses

Relationship of terrestrial and aquatic fauna to riparian habitat loss and fragmentation. Riparian zones provide foraging and nesting habitat for migratory and resident birds and territory and corridors for terrestrial vertebrates and invertebrates. They further provide stream bank structure and reduce water temperature for aquatic fauna and flora. The size and complexity of the riparian vegetation is positively correlated with the amount of terrestrial and aquatic biodiversity.

Relationship of native woodland/wetland/riparian/grassland communities to exotic invasive species. A number of the more aggressive exotic invasive species are ecosystem engineers and so have the potential to permanently alter species composition and structure of native communities. They also modify the ecological processes operating on a site and may lead to local extinction of species and loss of endemics. Spread of exotic plants is often related to disturbance, and invasive animals may be tied to invasive plant communities. Noted in more detail in the invasive *Ludwigia* sp. model description.

Relationship of the absence of herbivores and competitors to invasive Ludwigia sp. *local establishment and spread*. In their new range, most noxious invasive plants are usually released from their native range predators and competitors. This absence of their natural population check allows them to establish and spread more quickly in open suitable habitat.

Question 3.5.2 Can ecological restoration occur to support anadromous and other native fish species? Where are barriers to fish passage? What are current levels of bioaccumulation of toxins in fish? Mercury/heavy metals: where in the watershed were the quarries, mines, gravel mines that are now leaching?

Fish community data of the Laguna de Santa Rosa watershed are at present only available for a small number of its tributaries: Mark West Creek, Santa Rosa Creek, Millington Creek and Copeland Creek. The available data show that a number of introduced fish species occur in the surveyed reaches and that there are areas with vast mats of invasive *Ludwigia* sp. that could potentially impair fish passage.

Key Uncertainties and Data Gaps

While anecdotal reports exist of juvenile Steelhead in Copeland creek, several key uncertainties exists in 1) how well adults leave and reach these upper watershed spawning and rearing grounds, as they have to swim through the more seriously impaired (e.g.: low dissolved oxygen, high temperature) sections of the lower watershed in order to reach either the Russian River on their way to the ocean, or when returning to their spawning grounds in the upper watershed; leading to 2) how abundant and demographically healthy Steelhead and other anadromous fish populations are within the entire watershed; and to 3) whether there are structural impairments (e.g. culverts, extensive mats of invasive *Ludwigia* sp., etc.) preventing fish movement into certain upper watershed reaches. Fish community composition in both WARM and COLD habitat types, coupled with a better understanding of the components of the aquatic faunal food web and potential impacts to native fauna from introduced fish species are critical to assess past and future anthropogenic, and impending climate change impacts on the ecosystem.

Further, the level of pollutant bioaccumulation in high-level consumers (e.g., predatory fish and birds) is a water quality key uncertainty. Currently, fish bioassays are conducted by surveying only one species (Rainbow trout–not native to the watershed) within the City of Santa Rosa storm water monitoring program. This program could be expanded and improved by incorporating other reaches and species that tolerate different levels of contaminants, and so allow for a more comprehensive coverage, and a higher confidence level in assessing the water as non-toxic to more than just one species. This would also be beneficial in determining the source of toxicity. Fish bio-assays address levels of known contaminants but should potentially be extended to yet unregulated pollutants, such as endocrine disruptors, pharmaceuticals and other toxic substances in the future.

Hypotheses

Relationship of aquatic fauna to elevated summertime temperatures. Salmonids and other cold water fish require cool water for reproduction success. Increased temperatures are negatively correlated with the amount of dissolved oxygen in the water column, since the solubility of oxygen is affected by temperature and by the partial pressure of oxygen over the water. The solubility of oxygen is so greater in colder water than in warm water. Increased water temperatures thus negatively affect respiration of aquatic fauna.

Relationship of floodplain aquatic community distribution to increased seasonal stream flow velocities. Increased seasonal stream velocities cause a spatial shift in sediment deposition zones, in turn causing a shift in aquatic community distribution within the floodplain at a frequency rate that exceeds natural levels. Increased stream velocity also negatively affects availability of foraging and breeding habitat for aquatic fauna causing a decrease in species diversity and abundance.

Relationship of aquatic fauna to landslides and sediment erosion. Excessive sediment erosion negatively affects aquatic fauna, in particular endangered Salmonid habitat, through potential barriers to fish passage and high turbidity in the water column, the former preventing passage and the latter inhibiting successful spawning and rearing of juvenile fish.

*Relationship of aquatic fauna to mercury a*nd other pollutants. The presence of high levels of toxic pollutants in the water column negatively affects the health of the aquatic fauna. Bioaccumulation is the build up of poisons in the body of an organism. If pollution levels are sustained over time bio-magnification occurs within the food web causing an increase in the concentration of toxins as they pass through successive levels of the food web, particularly affecting top-level predators.

*Relationship of fauna and flora to the introduction of path*ogens. In line with exotic invasive species, the spread of pathogens throughout the system will negatively impact the health of wildlife, which can alter native community composition and structure.

*Relationship of human and wildlife health to unregulated s*ynthetic hormonally active agents. Hormonally active agents have been found in surface waters worldwide and may cause adverse health effects in humans and wildlife and thereby contribute to environmental degradation. Treated wastewater and livestock feedlots may act as source of such compounds in the Laguna watershed.

Question 3.5.3 What are the early biotic indicators of impaired ecosystem function? What are the current levels of habitat complexity & biodiversity in the Laguna watershed?

Benthic macroinvertebrates, amphibians, and periphyton are some of early biotic indicators of impaired ecosystem function (see section 5 on indicators). Habitat complexity and biodiversity in the Laguna watershed have been degraded and reduced, respectively, however neither has been directly quantified to date (Honton and Sears 2006).

Key Uncertainties and Data Gaps

With the exception of six creek reaches within the Santa Rosa urban boundary, benthic (macroinvertebrate) community data are missing for the majority of creek and stream habitats in the Laguna de Santa Rosa watershed. Given that current available data indicate very poor biological condition of these urban reaches, the level of biological conditions in the rest of the wadeable streams in the watershed is a key uncertainty. Adding permanent monitoring sites in the upper and lower parts of the watershed to the on-going data from the Santa Rosa urban creeks, will outline, water quality and habitat conditions on a watershed scale. This will aid in determining areas within the entire watershed where water quality is impacted by either point or non-point sources, and will provide more comprehensive causal connections between the upper and lower reaches. In cases where specific indicator species have not yet been defined, comparisons of biotic functional groups may be an appropriate way to assess stream health in comparison to reference conditions.

Current monitoring programs in the Laguna de Santa Rosa watershed do not include amphibians, except for California Tiger Salamanders *(Ambystoma californiense)*, that breed in vernal pools on the Santa Rosa plain (D. Cook, pers. comm.). The reduced numbers of endangered California red-legged frogs *(Rana aurora draytonii)* and Foothill yellow-legged frogs *(Rana boylii),* species of special concern, in the watershed signify that habitat loss and deterioration are potential causes for their decline. Populations of these frogs are not monitored regularly, but data on these species are periodically entered into the California Natural Diversity Database. Amphibians can serve as early indicators for water quality impairments for Laguna de Santa Rosa waterways, and the distribution, species composition and abundance of amphibians in the watershed are critical uncertainties.

There are no periphyton monitoring programs in the Laguna de Santa Rosa watershed. Periphyton surveys could serve to get a better understanding of lower watershed processes, in the slow flowing- lake-like areas of the Laguna de Santa Rosa. The aquatic species composition and abundance of the flooplain reaches represent key uncertainties that would allow a better evaluation of water quality on ecosystem processes. The objectives of a rapid bioassessment protocol for periphyton could include, but are not limited to, assessment of biomass (chlorophyl a or ash-free dry mass), species, composition and biological condition of periphyton assemblages. The strength of biological assessments is optimized by using algal data in association with macroinvertebrate and fish data (USEPA 2006).

Hypothesis

Relationship of biological indicators to impaired ecosystem function. Biological indicators are characteristics or processes that serve to assess the condition of different areas in the watershed with respect to one or more criteria.

Question 3.5.4 How does wetland diversity and habitat loss and fragmentation affect biodiversity?

The Laguna de Santa Rosa floodplain represents important breeding and foraging habitat for migratory and wetland birds along the Pacific Flyway. Water birds feed in a variety of foraging habitats and the needs for individual species can be quite specific (Kushlan et al 2002). In order to restore a biologically rich bird fauna in the Laguna de Santa Rosa it is important to have a variety of aquatic habitats in the region, many of which are degraded to varying degrees and represent opportunities for restoration, that can serve the needs of many different bird species. Birds are excellent indicators of ecosystem health, and if bird diversity will decrease, it likely indicates an overall decrease in faunal and floral diversity.

In winter 2004/05 and summer 2005, PRBO Conservation Science completed a one-time point count survey of bird distribution, breeding status, abundance, richness, and diversity along the Laguna de Santa Rosa floodplain, between Todd Road to the south, and just to the north of Occidental Road. The study was designed to inform the Sonoma County Agricultural Preservation and Open Space District of potential negative impacts on birds from a proposed trail system for this area. This study represents a very valuable baseline dataset, but as was outline in the study's final report (PRBO 2005), a one-time survey is not sufficient to determine natural fluctuations of all parameters measured from those caused by trail construction or use or other anthropogenic actions, such as impaired water quality. The Laguna Foundation is currently continuing this program in the short-term and is developing ways to continue the effort in the long-term.

Key Uncertainties and Data Gaps

No specific Laguna watershed bird survey exists at this time (B. Burridge, pers com.). Standardized long-term surveys are needed along the lower reaches of the watershed in order to assess how impaired water quality affects 1) the role of the floodplain as an important stopover habitat for migratory birds along the Pacific Flyway, 2) regional waterfowl population dynamics, and 3) wetland and riparian bird breeding success. Once baseline data are established changes in hydrologic factors, sedimentation, turbidity, and pollutants can be identified as extreme departures from normal data distributions in long-term abundance, breeding, distribution, richness, and diversity datasets.

Waterfowl and wading birds are also highly suitable for inclusion in bioassay studies, due to their top rank as consumer in the aquatic food web. Toxic substances can bio-accumulate in bird tissue and affect their health or their reproductive success. The levels of toxic substances in wetland birds represents a key uncertainty.

Hypothesis

Relationship of terrestrial and aquatic fauna to wetland habitat loss and fragmentation. The decline of wetland habitat is directly correlated with the loss of associated species diversity, including both resident and migratory species. Wetland loss along the Laguna floodplain directly affects birds along the Pacific Flyway migratory route.

The diversity of birds is positively correlated with habitat and faunal diversity. Bird diversity indicates the functional health of their associated faunal and floral communities.

Question 3.5.5 How will global climate change affect the Laguna ecosystem function in the short-and long-term?

Global climate change is predicted to affect rainfall periods and storm/flood frequencies and magnitudes. This may have a measurable impact on sediment transport, temperature and inundation regimes that will likely negatively affect biodiversity.

Key Uncertainties and Data Gaps

How the Laguna de Santa Rosa watershed will be affected by impending climate change remains a key uncertainty. Storm frequency and strength may increase, causing an increase in flooding frequency and levels. Temperature fluctuations may become more extreme. Mediterranean climate summers may change from dry and hot to wetter and colder, over time bringing with it potentially severe changes in the floral and faunal components of the ecosystem. Some periods may also get dryer and hotter, increasing the fire danger. Current levels and dynamics of habitat complexity and biodiversity of the watershed are still largely unknown, and so a multitude of scales need to be investigated. Therefore a holistic, multi-scale approach to long-term management of the resources in the watershed is imperative.

Hypotheses

Relationship of native grassland species richness to summer rainfall. The typically long summer droughts of the Mediterranean climate in California severely constrain plant growth during this period, supporting drought adapted grassland communities. Consistent long-term summer inundation within the Laguna floodplain negatively impacts these native grassland ecosystems, causing reduced plant and invertebrate richness over time. Species typically favored by summertime inundation include annual grasses and non-nitrogen fixing forbs, while nitrogen-fixing forbs may initially increase, but then return to lower levels (Suttle et. al. 2007).

*Relationship of biodiversity to multi-decadal bui*ld up of fuel loads. High intensity catastrophic fires will negatively impact the native natural communities through a shift in community types, favoring exotic species, and will so induce native biodiversity loss.

Relationship of temperature to invasive Ludwigia sp. persistence and spread. Ideal growing conditions for invasive *Ludwigia* sp. represent warm temperatures (above freezing point), while extended periods in conditions below freezing will inhibit its growth. Its aquatic habitat may effectively buffer extremely low air temperature conditions and so prevent massive dye-offs during the winter months.

3.6 Invasive *Ludwigia* sp.

Management questions related to invasive *Ludwigia* are discussed here, together with the key uncertainties and data gaps that limit these discussions. To the extent possible, working hypotheses are provided for each management question.

Question 3.6.1 What are the natural factors/processes that contribute to excess macrophyte growth? How did the changes in hydrology, sediment delivery, channel morphology and riparian degradation over time contribute to invasive *Ludwigia* sp. growth? To what extent does the growth of invasive *Ludwigia* sp. impact the beneficial uses?

Macrophytes are emergent, submergent, or floating aquatic plants that grow in or near water. Macrophytes provide cover for fish and substrate for aquatic invertebrates and are so beneficial to lakes. They produce oxygen, which assists with overall lake functioning, and provide food for some fish and other wildlife. Crowder and Painter (1991) indicate that a lack of macrophytes in a system where they are expected to occur may suggest a reduced population of sport and forage fish and waterfowl. In addition, the absence of macrophytes may also indicate water quality problems as a result of excessive turbidity, herbicides, or salinization. In contrast, an overabundance of macrophytes can result from high nutrient levels and may interfere with lake processing, recreational activities (e.g., swimming, fishing, and boating), and detract from the aesthetic appeal of the system (USEPA 2006).

Key Uncertainties and Data Gaps

The relative contributions of historic changes in hydrology and hydraulics affecting channel depth and shape, and nutrient levels in both the water column as well as accumulated levels in the sediment on invasive *Ludwigia* sp. growth and spread remain key uncertainties at this time. USDA/ARS research is underway to address the ecology, physiology, and growth dynamics of this invasive. The literature on macrophyte growth shows that in artificial stream experiments macrophyte *(Potamogeton pectinatus,* a rooted pondweed) biomass was enhanced by the addition of phosphorous, and unaffected by addition of nitrogen (Carr and Chambers 1998). *Ludwigia* species have been used in constructed wetlands due to their ability to tolerate nutrients enriched waters. Greenway (1997) showed that *Ludwigia peploides* had the highest tissue nutrient concentrations (both P and N) of eight macrophytes, with P and N concentrations double that of the other macrophytes under natural and experimental conditions. This indicates that *Ludwigia* species are extremely tolerant to high nutrient conditions and, in this case floating leaves are able to extract a large amount of nutrients from the water.

The extent to which invasive *Ludwigia* sp. changes the aquatic chemistry and food web-community in invaded areas, and how directly or indirectly it promotes mosquito growth are key uncertainties. While the Marin/Sonoma Mosquito and Vector Control District shows an overall reduction of adult mosquitoes at sites where invasive *Ludwigia* sp. populations have been reduced (Marin Sonoma Mosquito and Vector Abatement District unpublished data), more comprehensive studies directed at the aquatic larval lifestage of mosquitoes and on potential aquatic food web impacts are needed.

Another aquatic plant of note is the native mosquito fern *(Azolla filiculoides)*. While not a macrophyte, it also forms dense mats in stagnant water such as lakes and ponds, and has been observed in the Laguna de Santa Rosa (C. Sloop pers. obs.) and in the upper watershed at Fairfield Osborne Preserve: (http://www.sonoma.edu/Org/Preserve/species_lists/plants_at_fop.pdf). It can impact water quality directly through input of nitrogen, since this tiny floating aquatic water fern has a symbiotic relationship with a nitroxen-fixing microscopic filamentous blue-green alga or cyanobacterium *(Anabaena azollae)*. A major invasive in South Africa, *Azolla filiculoides,* has severely affected the biodiversity of aquatic ecosystems and had implications for all aspects of water utilization (Gratwicke and Marshall 2001). In South Africa these effects were also severe in the agricultural sector, where the weed increased siltation of dams and rivers, reduced the quality of water for agricultural and domestic use, clogged irrigation canals and pumps, and caused drowning of livestock that were unable to differentiate between pasture land and a weed covered dam (Hill 1997). The effect of nitrogen input by mosquito fern on Laguna de Santa Rosa water quality and its effect on the aquatic biodiversity are key uncertainties.

Areas with high levels of sedimentation (accrued over the past decades, having absorbed a large amount of available phosphorous and nitrogen), represent prime habitat for invasive *Ludwigia* sp. This is not only because these areas represent shallow conditions ideal for invasive *Ludwigia* sp. to take root, but also due to the potential availability of nutrients that are taken up through plant roots in the sediment. Enriched sediments can accelerate the growth rate of macrophytes (Carr and Chambers 1998), and it is therefore likely that all factors including habitat formation from sedimentation, altered hydrology, channel modifications, and nutrient enrichment have played a role in the infestation All factors will need to be addressed in any effective control program. Ongoing research will determine the best strategy for each factor within the Laguna.

The relative contributions of historic changes in hydrology and hydraulics affecting channel depth and shape, and nutrient levels in both the water column as well as accumulated levels in the sediment on invasive *Ludwigia* sp. growth and spread remain key uncertainties at this time.

Hypotheses

Relationship of altered stream hydrology and hydraulics to invasive Ludwigia sp. *introduction and establishment*. The introduction and establishment of exotic invasive species is facilitated by anthropogenic habitat disturbance. Altered flow regimes, causing more stagnant conditions and decreased water depth due to sediment build-up represent ideal macrophyte growing conditions: the roots have increased anchoring space (not just along the shore), and low-energy flow prevents wash-out during most of the year. This means that under these conditions large dense mats can form that completely cover vast areas of previously open water.

Relationship of periodic high-energy flow in invasive Ludwigia sp. *invaded areas to its recurrent spread to and establishment at new sites downstream*. Severe winter storm events drastically increase water velocity through areas where invasive *Ludwigia* sp. occurs. High-energy flow causes invasive *Ludwigia* sp. shoots to break off and get carried downstream, where they eventually settle out alongshore and re-establish, increasing the geographic range of the invasion.

Relationship of invasive Ludwigia sp. *invasion to anadromous fish passage*. Extensive mats of invasive *Ludwigia* sp. can grow several feet thick, consisting of thin and thick (0.1 to 1.5 inch diameter) floating rhizomes that are intertwined with each other and large leaves. Fish passage can only occur below these mats. In areas where channels are shallow, invasive *Ludwigia* sp. may also root directly in the bottom sediment, making passage of large salmonids impossible.

Relationship of invasive Ludwigia sp. *invasion to native aquatic food web community.* Extensive mats of invasive *Ludwigia* sp. shade the water column and reduce the availability of open water habitat. While increasing the amount of cover, *Ludwigia* sp. floating mats cause open water habitat to be reduced or lost, resulting in a potential shift in the native food web community from limnetic to littoral marsh.

Relationship of invasive Ludwigia sp. *mats to availability of dissolved oxyg*en. While macrophytes generally fix oxygen within the water column, extensive mats prevent surface influx, and massive decomposition of *Ludwigia* sp. vegetation in turn takes up oxygen through bacterial decomposition.

Relationship of invasive Ludwigia sp. *to sediment deposition*. The roots and rhizomes of extensive mats of invasive *Ludwigia* sp. inhibit the movement of suspended particles in the water column increasing the potential for local deposition of sediment.

Relationship of invasive Ludwigia sp. *to loss of structural habitat diversity. Ludwigia* has the potential to grow into low diversity monoculture-like mats. These floating mats eliminate the historic open-water habitat that was previously there.

Question 3.6.2 Do the nutrient sources for macrophytes and algal growth originate from the sediment or water column or both?

Some of the factors influencing invasive *Ludwigia* sp. growth may include: changes in hydrology of the Laguna, sedimentation and siltation of channels and streams, and nutrient loads in sediment and/or water column. There are several pathways for the capture of nutrients by invasive *Ludwigia* sp. via trimorphic roots: floating nodes on the gas-filled, rhizomatous shoots are able to absorb nutrient from the water column directly, while subsurface roots take up nutrients from the sediment. Studies of the relative contribution of each pathway towards plant vigor have not been completed. Preliminary data from a completely randomized, full factorial growth experiment by USDA/ARS (Dr. Brenda Grewell, pers. comm.) suggest that soil nutrient loadings may be more significant in affecting early invasive *Ludwigia* sp. growth (highly significant across all response variables) than nutrients in the water column. Continuation of this USDA/ARS research program will likely shed more conclusive light on this question in the near future.

Key Uncertainties and Data Gaps

At this time the specific relationship between nutrient loadings, habitat factors and invasive *Ludwigia* sp. and other macrophyte growth is still unclear, and no conclusive inferences can be drawn from currently available data. Correlations between water-column nutrient concentrations and invasive *Ludwigia* sp. vigor that do not account for the contribution from sediment-bound phosphorus may not be tracking the true signal. It is therefore premature to determine habitat as a more important factor over that of nutrient loadings, since these are closely inter-connected, and long-term sediment nutrient loadings may play a more important role in invasive *Ludwigia* sp. growth as currently understood. Please refer to the water quality section of this report for more in depth discussion on this topic.

Hypotheses

Relationship of nutrient levels to invasive Ludwigia sp. *persistence and spread*. Rapid and extensive expansion of invasive *Ludwigia* sp. populations are fueled by the high availability of nutrients in the water and sediment. Invasive *Ludwigia* sp. can tolerate and thrive on extremely high levels of available nitrogen.

Relationship of aquatic flora (algae, macrophytes) and fauna to increased nutrients (nitrates & phosphates). Aquatic plants and algae need sunlight, water, carbon dioxide, and nutrients-including phosphorous, nitrogen, and potassium to grow. Increased levels of available nutrients will generally increase aquatic plant growth. Excessive growth of algae or macrophytes can lead in turn to large diel (24-hour) swings in pH and dissolved oxygen concentrations. Excessively low dissolved oxygen concentrations and excessively low or high pH levels can reduce the diversity of animal life in a stream by stressing the physiological systems of most organisms and reducing reproduction.

Relationship of aquatic fauna to run-off pollutants (pesticides, oils, heavy metals, etc.). The presence of high levels of toxic pollutants in the water column negatively affects the health of the aquatic fauna. Bioaccumulation is the build up of poisons in the body of an organism. If pollution levels are sustained over time bio-magnification occurs within the food web causing an increase in the concentration of toxins as they pass through successive levels of the food web, particularly affecting top-level predators.

Question 3.6.3 To what extent does invasive *Ludwigia* sp. and other aquatic flora promote mosquitoes (vectors of West Nile virus)?

Invasive *Ludwigia* potentially contributes to a public health threat as it creates protective habitat for mosquito species that can carry West Nile virus (WNV), which reached Sonoma County in 2004. Dense invasive *Ludwigia* sp. mats sharply inhibit current mosquito control efforts by inhibiting larvicide applications; and several *Ludwigia*-infested areas have been observed to produce mosquito populations more than 100 times greater than normally considered acceptable (Marin/Sonoma Mosquito and Vector Control District, unpublished data). The Marin/Sonoma Mosquito and Vector Control District (MSMVCD) expended more than $80,000 for 2003-04 alone for mosquito control in *Ludwigia* areas, diverting resources and energy from other parts of the County. If larvicide cannot be properly applied, operators must use pyrethrin-based adulticides, which are less effective overall and tend to have greater negative impacts on fish. In addition, the stagnant eutrophic conditions associated with invasive *Ludwigia* sp. appear to favor 'foul-water' mosquito species that are superior vectors for West Nile virus (in the genus *Culex*).

Key Uncertainties and Data Gaps

After year two years of the *Ludwigia* control program there has been a notable reduction in adult mosquitoes captured near invasive *Ludwigia* sp. infested areas (Marin/Sonoma Mosquito and Vector Control District, unpublished data) in 2006. While adult mosquito traps can indicate the relative abundance and types of mosquito species in a general area, they fail to give detailed information on the larval origin of these mosquitoes. Comparative studies aimed at the aquatic larval stage of mosquitoes within and outside of the invasive *Ludwigia* sp. mats are needed to ascertain a more direct relationship of mosquito abundance and invasive *Ludwigia* sp.

Hypotheses

Relationship of invasive Ludwigia sp. *invasion to mosquito abundance*. Extensive mats of invasive *Ludwigia* sp. prevent application of mosquito control agents to the invaded water body via surface application. Therefore mosquito abatement efficacy is reduced by invasive *Ludwigia* sp. biomass, resulting in localized mosquito population growth.