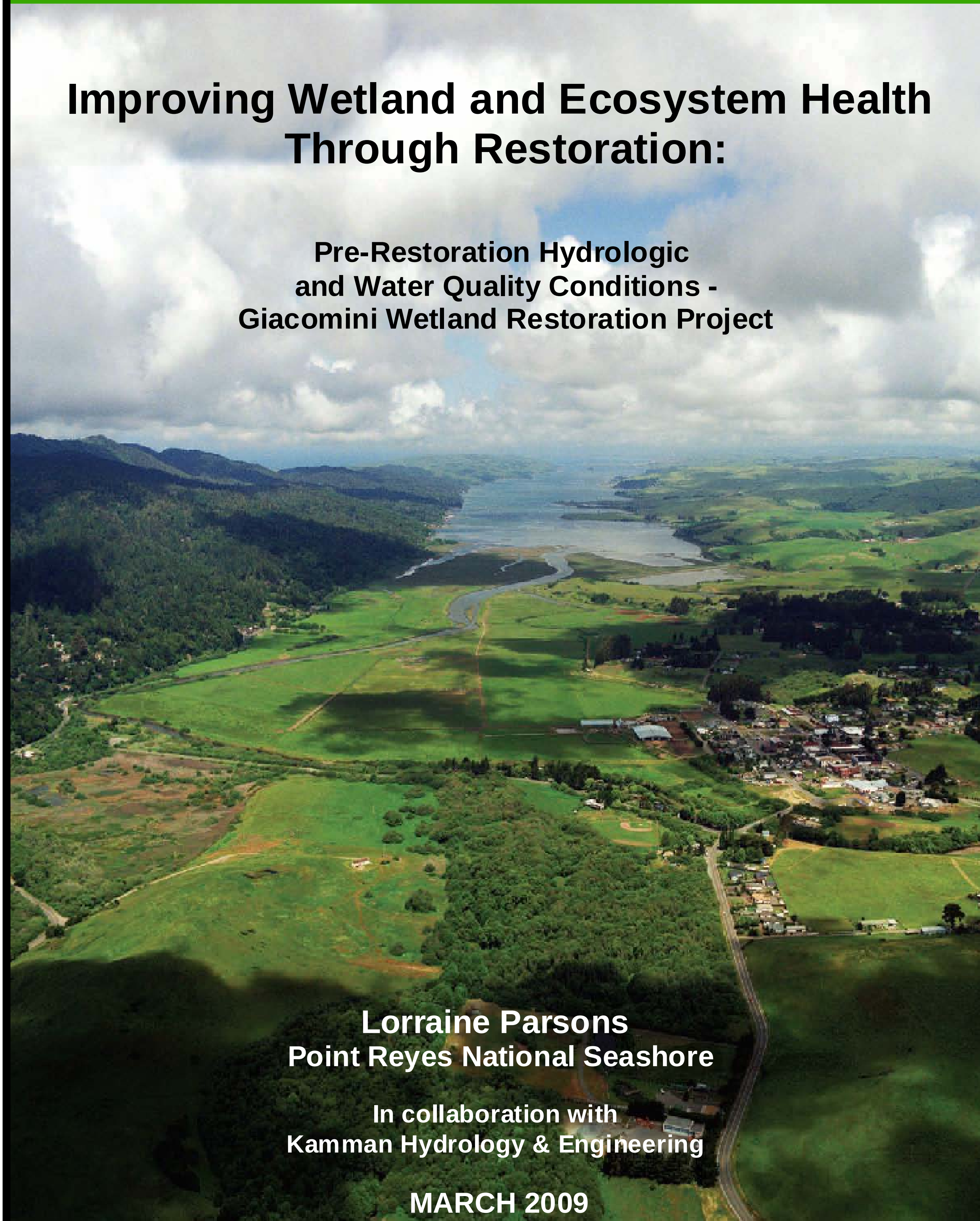
National Park Service
U.S. Department of the Interior

Point Reyes National Seashore
Golden Gate National Recreation Area
Marin County, CA



Improving Wetland and Ecosystem Health Through Restoration:

Pre-Restoration Hydrologic and Water Quality Conditions - Giacomini Wetland Restoration Project

Lorraine Parsons
Point Reyes National Seashore

In collaboration with
Kamman Hydrology & Engineering

MARCH 2009

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Pre-restoration Hydrologic and Water Quality Conditions – Giacomini Wetland Restoration Project

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MARCH 2009

Executive Summary

The National Park Service (Park Service) has implemented an approximately 550-acre wetland restoration project in the southern end of Tomales Bay in Marin County, California (Figure 1). Rather than try to recreate historic conditions, the Park Service focused on restoring natural hydrologic tidal and freshwater processes, thereby promoting restoration of hydrologic and ecological functions. Natural hydrologic processes are the cornerstone of many hydrologic and ecological functions and economic "services" associated with wetlands such as floodwater retention, flood energy dissipation, water quality improvement, and wildlife habitat that benefit both wildlife and humans. Perhaps, one of the most important functions that wetlands can play -- particularly in Tomales Bay -- is water quality improvement. While it is generally perceived as pristine, this rural coastal watershed still suffers from negative anthropogenic influences such as agriculture, home and road development, leaking septic systems, mercury mining, landfills, and oil spills. During the last few decades, poor water quality in the Bay has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak.

As an integral component of the restoration project, the Park Service is implementing a comprehensive long-term monitoring program to assess whether restoration is successful. The 20-year monitoring program will include assessment of both the Project Area and nearby reference wetlands both prior to restoration and after restoration is implemented. As part of this program, the Park Service conducted from winter 2002 to fall 2006 monthly to quarterly systematic sampling of water quality field parameters, nutrients (nitrate, nitrites, total ammonia, total dissolved phosphates), chlorophyll a/phaeophytin, and pathogen indicators (total and fecal coliform) within the Giacomini Ranch, Olema Marsh, and selected reference sites. Continuous or synoptic monitoring of hydrologic variables such as surface water and groundwater levels and general water quality parameters were conducted at key locations as part of baseline surveys by the park's contract hydrologists, Kamman Hydrology & Engineering (San Rafael, Calif.), and park staff.

This document attempts to synthesize the myriad amount of information produced by past studies on Tomales Bay and some of its larger subwatersheds with the hydraulic, hydrodynamic, and water quality information from the Giacomini Wetland Restoration Project to develop an integrated understanding of water and sediment processes and resource conditions in this vital estuarine transition zone prior to restoration. An integrated analysis of pre-restoration processes and conditions in Tomales Bay, the Project Area, and Reference Areas is presented in the main body of this report. The Summary and Conclusions section synthesizes these results to draw some key conclusions, discusses how processes and conditions might change with restoration, and makes recommendations regarding the future direction of the water quality monitoring program component.

To facilitate analysis of restoration progress, the Long-Term Monitoring Program relies on a modified BACI ("Before-After, Control-Impact") sampling framework. The program divides the Study Area into the Project Area (PA) or Impact Area (Giacomini Ranch and Olema Marsh) and Reference (REF) or Control Areas (natural tidal marshes in Tomales Bay and adjacent watersheds). In addition, for some analyses, sampling locations on the upstream perimeter of the Project Area were evaluated separately as Upstream Areas (US) to more clearly differentiate the effect of the Project Area on internal water quality and downstream loading conditions. Within these Major Study Areas, subsampling units or sub-groups were also broken out that included the differently managed pastures or areas in the Giacomini Ranch (East and West Pastures and the leveed Tomasini Creek), Olema Marsh, and the individual reference wetlands (Undiked Marsh, Walker Creek Marsh, and Limantour Marsh).

General Water Quality Conditions Good in Project Area, with Exception of Dissolved Oxygen

The Project Area lies in the Estuarine Transition Zone, the dynamic interface between freshwater and saltwater influences. For this reason, salinity regimes and patterns are understandably dynamic both spatially and temporally. To some degree, the Reference Areas also occur within this transition zone, but the magnitude of effects is seemingly dampened by either a smaller watershed size (e.g., Walker Creek Marsh and Limantour Marsh) or distance downstream from the mouth (e.g., Undiked Marsh). This difference between the Project Area and the Reference Areas has only been exacerbated by the system of levees, roads, and culverts that have kept tides out or minimized their influence and impounded freshwater in the Project Area. Much of this freshwater comes from the copious amount of small freshwater drainages and emergent groundwater flow from the Point Reyes Mesa and Inverness Ridge, as well as the larger creeks such as Lagunitas Creek, Olema Creek, Bear Valley Creek, Fish Hatchery Creek, and Tomasini Creek.

Because of these freshwater influences, salinities and temperatures differed significantly between the Project Area and other Study Areas. Salinity averaged 6.9 ppt in the Project Area, 22.0 ppt in Reference Areas, and 0.6 ppt in Upstream Areas, which receive less or no tidal influence and have strong perennial or seasonal freshwater influences. Temperatures were also lower in the Project Area (median=15.1 degrees Centigrade) than in Reference Areas (median=17.3 degrees Centigrade), although not lower than those in Upstream Areas (median=12.7 degrees Centigrade). While diking of the Giacomini Ranch and the culvert-levee road system at Olema Marsh resulted in longer residency time for waters – and more time for sunlight to drive up water temperature – the substantial freshwater influences from both creek and emergent groundwater flow appeared to moderate the effect of these management impacts on water temperature. Reference Areas exceeded the lethal limit for salmonids of 25 degrees Centigrade (Moyle 2002) approximately 6.7 of the time, and another 17.8 percent exceeded 22 degrees Centigrade, the suboptimal limit for salmonids (Moyle 2002). Comparatively, in the Project Area, temperatures exceeded the lethal limit during only 5 percent of the sampling periods and exceeded the suboptimal limit during approximately 15 percent of the sampling periods.

While Reference Areas were chosen as representative of potential future conditions in the Project Area, salinity and temperatures within the Project Area will probably never totally converge with that of the Reference Areas due to its position within the freshwater-saltwater interface zone, although both spatial and temporal pattern of salinities and temperatures are expected to change with restoration. The influence of freshwater can even be seen in pH conditions. While pH might be expected to be lower in the freshwater-dominated Project Area compared to the more marine-influenced Reference Areas – pH of ocean waters is typically somewhat alkaline -- pH did not vary significantly between the Project Area and the other Study Areas prior to restoration (range=7.60 to 7.63 in Upstream Areas). Most creeks feeding into the Project Area actually had fairly high pHs, as well (range = 7.7 – 8.1) regardless of differences in geologic substrate between the granitic Inverness Ridge and the Point Reyes Mesa coastal marine terrace and surrounding Franciscan Formation hills, which are separated by the San Andreas Fault that created this tectonic estuary. Muted tidal influence in the West Pasture and Tomasini Creek and high primary productivity during some sampling events also boosted pH. Lower pH waters (~5.9 – 6.6) occurred only in areas where more extensive influence from groundwater occurs.

While diking did not negatively impact salinities, temperature, or pH of waters within the unrestored Project Area, this major impact and other agricultural land management practices did appear to affect oxygen concentrations within drainage ditch and creek waters, causing hypoxic or even anoxic conditions. Most of the extremely low oxygen concentrations occurred in the East Pasture drainage ditches, where frequent ditching increased oxygen demand by filling ditch waters with vegetation material that was consumed by oxygen-dependent bacteria. This management practice, coupled with the relatively infrequent exchange or subsidy of ditch waters except during the winter or when irrigation was performed, typically kept oxygen levels below 5 mg/L and often below 2 mg/L. Oxygen levels in the East Pasture averaged 4.98 mg/L, with median levels actually slightly lower (4.56 mg/L). These same factors – copious amount of organic matter and infrequent exchange between the impounded marsh and Lagunitas Creek -- also contributed to consistently low levels of oxygen in Olema Marsh, although levels were not as low as the East Pasture (mean = 5.83 mg/L). Median oxygen concentrations in other Project Area subsampling areas or sub-groups – excluding upstream sampling sites -- ranged from 8.77 mg/L in Lagunitas Creek to 7.78 mg/L for Tomasini Creek, with the less heavily managed West Pasture having slightly higher levels (9.00 mg/L). In the Project Area, oxygen concentrations fell below the Basin Plan standard during 25 percent of the sampling periods, with most of these exceedances occurred in the East Pasture. In contrast, only approximately 8 percent of the oxygen concentrations recorded in reference marshes fell below 5 mg/L, the Basin Plan standard.

Nitrates Predominant Nutrient Source, with Levels Higher in Intensively Managed Areas

The relatively well oxygenated conditions present in most of the Study Areas except the East Pasture may have contributed to the dominance of nitrates as the primary source of nutrients. In contrast to ammonia and phosphates, nitrates were only rarely not detected, even at relatively high commercial laboratory detection limits. Results from the LMER/BRIE study conducted a decade earlier – which were, at least for Bay samples, generally much lower in magnitude than ours – also showed nitrates to represent the predominant source of nutrients. In our study, average nitrate concentrations did differ between Major Study Area groups, although median concentrations within the Project Area (0.83 mg/L) were actually not considered significantly different from those in the Reference Areas (0.7 mg/L).

The Project Area mean was substantially influenced by consistently high values in the more heavily managed East Pasture, which supported two active dairy herds, as well as being more actively managed in terms of irrigation, manure spreading, haying, land leveling, and other actions. Within the Project Area (excluding upstream sampling sites), estimated nitrate concentrations averaged 7.25 mg/L for the East Pasture and then dropped to below 1.1 mg/L for the other sub-groups. While nitrate concentrations were lower in less heavily managed portions of the Project Area, these areas were still subject to nitrate inputs from passive agricultural management of the West Pasture (e.g., grazing of dry or less active dairy herds), dairy use of Lagunitas Creek both inside and directly upstream of the Project Area, loading from upstream portions of Lagunitas, Tomasini, and Fish Hatchery Creeks, non-point source run-off and stormwater flow from the town of Point Reyes Station, and potential influence of leaking septic systems in groundwater that flows along the perimeter of the Giacomini Ranch and Olema Marsh.

The similarity in nitrate concentrations between the Project Area and Reference Areas and even among the different Reference Areas – all of which occur in different watersheds or subwatersheds -- suggests that nitrogen and other nutrients are strongly controlled by internal as well as external factors. Indeed, these factors at times appear to override the differences in concentrations and loading that would be expected from the three Reference Areas given the very substantial difference in the degree and type of agricultural and residential development in the respective subwatersheds. While concentrations of nitrates were highest in winter and fall sampling events in the Project Area, there were occasionally spikes or pulses in spring or summer that were unrelated to increases in streamflow with storm events or run-off. Some of the pulses in nitrates during non-flood periods may result from inorganic nutrients being regenerated “internally” from breakdown of organic matter within marshes (Chambers et al. 1994b).

Most of the ammonia pulses in the Project Area occurred in waters with lower oxygen (or pH) levels and appeared more related to cattle grazing and other management practices such as ditch maintenance than with timing of storm inflows or run-off. Cattle grazing provided a source of ammonia that would be maintained in low oxygen waters, while ditch maintenance promoted hypoxic conditions by increasing organic matter available for mineral decomposition and creating a surge in biological oxygen demand. These conditions favored retention of nitrogen as ammonia over nitrates. Within the Project Area (excluding upstream sites), estimated ammonia concentrations in the East Pasture averaged 2.61 mg/L, which differed significantly from that estimated for the West Pasture (0.45 mg/L) and Tomasini Creek (0.20 mg/L). Ammonia pulses in Reference Areas more likely resulted from decreases in oxygen levels in tidal creek waters due to high primary productivity and subsequent respiration or an increase in water residency time than point-source loading, while sporadic pulses in creeks such as Lagunitas and Walker Creek probably related more to point-source loading or an immediately proximal source of ammonia than low oxygen waters.

Phosphates, too, appeared to be driven more by biochemical processes than upstream loading, at least in most of the Project Area. While concentrations of phosphates were sometimes high during storm events – as was observed in Walker Creek and Lagunitas Creek -- they also showed peaks during spring and fall. These spring and fall peaks probably resulted from recirculation of phosphates from sediments into overlying waters when the upper sediment and bottom water layers became anoxic due to low oxygen levels at the soil-water interface, which can occur when plankton respiration rates increase substantially.

Phosphate concentrations were highest in the Project Area and, specifically, in the East Pasture due to not only the proximity of sources such as cattle and septic-influenced groundwater, but also due to agricultural management regimes that caused oxygen levels within ditch waters to frequently be low. Phosphates averaged an estimated 0.99 mg/L in the Project Area compared to 0.23 mg/L for Reference Areas and 0.12 mg/L for Upstream Areas. In the East Pasture, concentrations averaged an estimated 2.40 mg/L, which was significantly higher than the means for the rest of the Project Area (excluding upstream sampling sites), which ranged from 0.15 mg/L (West Pasture) to 0.24 mg/L (Olema Marsh).

Low oxygen levels also probably accounted for the higher estimated average phosphate concentrations for Olema Marsh and for the higher estimated average concentration and loading rates during the summer for many of the Reference Areas such as Limantour and Walker Creek marshes. Phosphate levels within Reference Areas would also be influenced by the greater relative proximity of these systems to the ocean, where phosphorous is naturally high (Mitsch and Gosselink 2000, Day et al. 1989).

Pathogens A Major Issue in Project -- and Reference -- Areas

In general, pathogens represent one of the major water quality issues facing Tomales Bay. While seemingly pristine, the Bay and its surrounding watershed generate a considerable volume of pathogen indicator bacteria, total and fecal coliform, because of the large amount of land in agricultural use, leaking septic systems in the many rural residential communities perched on the Bay's edge, and other factors such as bilge discharge from boats. With Giacomini Ranch supporting a considerable number of dairy cattle during its operation, the Project Area was certainly located in an area where it could have had maximum impact on downstream water quality.

The Project Area did have substantially higher estimated median concentrations of fecal coliforms (1,600.9 mpn/100 ml) than the Reference Areas (72.0 mpn/100 ml) and, seemingly, Upstream Areas (637.1 mpn/100 ml), although differences were not statistically significant. Not surprisingly, the heavily managed East Pasture had significantly higher estimated geometric means or medians (6,298.8 mpn/100 ml) than most of the other sub-sampling areas, with the possible exception, from a statistical standpoint, of Olema Marsh (1,821.4 mpn/100 ml). Estimated geometric means or medians for all other subsampling areas (excluding upstream sampling sites) ranged between 356.9 mpn/100 ml for downstream Lagunitas Creek to 1,131.7 mpn/100 ml for the West Pasture.

In terms of compliance with Basin Plan or TMDL standards, more than 95 percent of all samples collected from the Project Area – this time, including upstream sites – exceeded objectives for shellfish harvesting and municipal water supply of 14 and 20 mpn/100 ml respectively. Approximately 78 percent exceeded contact water recreation standards of 200 mpn/100 ml, and 36-47 percent of the values actually were higher than 2,000 to 4,000 mpn/100 ml, the standards for non-contact water recreation. Lagunitas Creek exceeded the TMDL standard of 200 mpn/100 ml during 72 percent of the sampling events and the 90th percentile standard of 400 mpn/100 ml 58 percent of the time, with the overall geometric mean and 90th percentile estimated at 584.6 mpn/100 ml and 6,146.8 mpn/100 ml, respectively. The TMDL load-based allocation of 95 mpn/100 ml set for Green Bridge location on Lagunitas Creek was never met during the study period. In comparison, only 34 percent of Reference Area samples exceeded contact water recreation standards, and less than 12 percent exceeded non-contact water recreation standards.

Despite Higher Concentrations, Loading Rates in Project Area Lower Than Either Reference or Upstream Areas

Despite high concentrations in the Project Area, loading rates for the Giacomini Ranch and Olema Marsh were usually lower or only slightly higher than Reference Areas. This trend reversal resulted from the fact that the East Pasture – where concentrations were highest – essentially contributed nothing to downstream loading, because it was diked. The only potential for loading from the East Pasture came during moderate to large storm events when floodwaters overtop the levees or when the Giacominis occasionally pumped ditch waters into Lagunitas Creek. However, even if the East Pasture had been operated as a muted tidal unit, the volume of water and, subsequently, loading that these ditches and sloughs could have contributed to downstream flow would have been relatively insignificant (between 0.1 and 1.15 mg/s for nitrate loading), based on rates estimated using average discharge for similarly sized creeks in the adjacent Undiked Marsh: with diking of Lagunitas and Tomasini Creeks, the East Pasture had no source watersheds to increase flow and loading volumes.

Loading rates were generally highest in Upstream Areas, which included sampling locations on the upstream perimeter of the Project Area on Lagunitas, Tomasini, Bear Valley, and Fish Hatchery Creeks. There were some exceptions. For example, for fecal coliform, estimated loading rates for the Project Area (mean=249,389 mpn/s) were lower than Upstream Areas (mean=3.86 million mpn/s), but higher than Reference Areas (mean= 60,094.1 mpn/s). Conversely, Reference Areas had the highest loading rates for phosphates (0.15 mg/s), with rates for the Project Area (0.03 mg/s) and Upstream Areas (0.06 mg/s) much lower, which, as discussed earlier, may relate to the more substantial marine influence in these areas.

As with concentrations, estimated median loading rates were considerably smaller than mean loading rates, showing the influence of pulses during the winter or wet season sampling events. One of the clear findings from our study is the close relationship between rainfall, run-off, streamflow, and loading. While these relationships were not always distinct enough to be linear, with some exceptions, most of the high loading events occurred during winter or wet-season sampling events, with the highest values usually occurring during storm events. The importance of storm events to downstream loading is evident in the disparity between mean (10.11 mg/s) and median (0.66 mg/s) instantaneous loading rates for nitrates on Lagunitas Creek: During an April 2006 storm, rates reached as high as an estimated 220 mg/s. Research on other agricultural watersheds has also documented the highest export of nutrients and pathogens in stormflow, with levels generally higher in the wet season than the dry season (Vanni et al. 2001, Lewis and Atwill 2007). Ironically, storms are usually the least sampled due to planning and logistical difficulties.

Some Pollutant Trapping Occurred Despite Being Diked

Because of being extensively leveed, the Project Area was not expected to provide much in the way of downstream reduction in either concentrations or loading of nutrients or pathogens. In general, floodplain systems are most effective at removing particulate forms of nutrients and other pollutants, because emergent vegetation "traps" the sediment or organic matter and removes it from water sheetflowing across the floodplain or marsh surface. Pollutants can also be trapped within creek channels and bays by physical forces related to fluvial and estuarine sediment transport and circulation processes. Sediment laden with nutrients, organic matter, and pollutants are likely to deposit in areas where the creek gradient flattens or velocities decrease sharply.

Downstream reductions in pollutants were evaluated for two parameters – nitrates and fecal coliform. Several of the sampling locations are strategically arranged with sites at the upstream boundary of the Project Area and either at the downstream boundary or midway through the Project Area. Fecal coliform concentrations and loading showed no statistically significant pattern of downstream reductions for any of the Project Area creeks, although high variability in the data may have masked differences. Both the estimated median concentrations and loading rates did appear lower at the downstream perimeter of Lagunitas Creek, with median concentrations being 955.3 mpn/100 ml at the Green Bridge and 356.9 mpn/100 ml near the Giacomini Ranch North Levee and median loading rates being 12,430.6 mpn/s at the Green Bridge and 2,533.1 mpn/s at the North Levee. Median pathogen concentrations and/or loading rates actually increased downstream in some areas, including Fish Hatchery Creek and Bear Valley Creek. This suggests that there are some additional inputs to this marsh system other than the upper portions of the Bear Valley Creek watershed, such as septic-influenced surface water and groundwater flowing from the adjacent developed portion of Inverness Ridge into the west end of the marsh or wildlife use.

Despite the fact that soluble nutrients such as nitrates are the least effectively trapped pollutants by floodplain systems, nitrates did show some downstream reductions for many of the creeks, including Fish Hatchery Creek, Tomasini Creek, and Bear Valley Creek. As with pathogens, no statistically significant trend of lower nitrates was apparent for Lagunitas Creek, although noisiness in the data may have again precluded detecting differences, as both the arithmetic mean and median loading rates were seemingly lower at the downstream site (4.0 mg/s and 0.65 mg/s) than at the upstream site (14.5 mg/s and 1.47 mg/s). Nitrate on Fish Hatchery Creek may have resulted from change in creek gradient as creek flows from the steep slopes of the Inverness Ridge drop abruptly onto the broad, low-gradient flooplains in the West Pasture. Fish Hatchery Creek was not leveed directly, but contained within the Lagunitas Creek levees. Trapping also appeared to occur on Bear Valley Creek and Tomasini Creek. For Tomasini Creek, most of the reduction in nitrate concentrations and mean (if not median) loading rates probably occurred due to the change in creek gradient and flow velocity and trapping of materials within the creek itself, not on the relatively narrow floodplains. With its defined inlet and outlet, Olema Marsh, in some ways, resembles a constructed treatment marsh, where long residence times often result in accelerated trapping of nitrates.

Primary Production – Too Much of A Good Thing

As with nutrients, there can be too much of a good thing with both organic matter (DOC and POC) and algae. Systems where algae grows uncontrollably due to high nutrient influx, warm temperatures, and long water residency times often become eutrophic, causing wide swings in oxygen levels that can negatively affected and even kill fish. In addition, changes in pH associated with excessive oxygen production by phytoplankton can also trigger shifts in the chemistry of waters, helping to lead to the formation of unionized ammonia, which increases when both temperatures and pH increase. Unionized ammonia is toxic to aquatic organisms.

As with many of the other parameters, the Project Area had substantially higher levels of DOC (med. = 4.2 mg/L) than either the Reference (med.= 2.9 mg/L) or Upstream (med.= 3.1 mg/L) Areas. Similarly, chlorophyll concentrations were also higher in the Project Area (med.= 3.0 mg/L) than in Upstream Areas (1.8 mg/L), but were similar to those in Reference Areas (2.8 mg/L). Within the Project Area itself (e.g., not including upstream sampling locations), the East Pasture had the highest DOC and chlorophyll a concentrations. Median DOC concentrations were 14.5 mg/L, with medians for other areas ranging from 4.3 mg/L for the West Pasture to 2.5 mg/L for Lagunitas Creek. For chlorophyll a, medians were estimated at 9.8 mg/L for the East Pasture, with medians for the other areas ranging from 3.3 mg/L for the West Pasture to 0.06 mg/L for Tomasini Creek.

Somewhat surprisingly, both DOC and chlorophyll a did not exhibit any clear seasonal or temporal patterns. In the East Pasture, pulses of DOC occurred throughout the year due to intensive agricultural management and activities such as ditching. There were fewer pulses in other Project Area sub-groups with those that did occur typically distributed throughout the year, although many took place during winter or wet season sampling events. For chlorophyll a, concentrations in the Giacomini Ranch and Olema Marsh were typically highest in the summer and fall, with occasional peaks in spring. While winds in Tomales Bay might generally dampen phytoplankton productivity in the Bay itself, the levees protected drainage ditches from the churning effects of the wind and allowed warm temperatures and solar radiation to increase primary production. Also, despite the drop in flows, there was probably no nutrient limitation on production during either the summer or fall in the Project Area. Interestingly, both DOC and chlorophyll a levels were relatively low in Olema Marsh, which would have been expected to have high rates of both due to abundant plant decomposition, long water residence times, and lack of hydrologic connectivity within different portions of the marsh leading to more stagnant pools.

The lack of a clear temporal pattern extended to Reference Areas, with, for example, Limantour Marsh having the highest DOC values in the winter/wet season and spring sampling events while the Undiked Marsh had the highest values almost exclusively in fall. Upstream land use and management such as reservoir releases, agriculture, and residential-related practices may affect the volume and timing of both DOC and nutrient import from upstream sources, essentially decoupling primary production cycles from some of the traditional seasonal patterns expected.

Where Do Monitoring Efforts Go From Here?

Ultimately, monitoring of water quality and other hydrological variables will become part of a larger evaluation of the success achieved in restoring the Giacomini Ranch and Olema Marsh. Based on evaluation of the preliminary data, predicted changes with restoration, and results from some of the progress criteria analyses proposed in the Long-Term Monitoring Program Framework: Part I (Parsons 2004), it appears that some water quality monitoring variables might be more capable of discerning change between pre-restoration and restored conditions and the direction of the evolutionary restoration trajectory (i.e., are restored wetlands becoming more like reference marshes?) than others. For example, the pattern of salinities between the Project and Reference Areas may never totally converge, because the Project Area receives more direct, abundant, and perennial freshwater inputs than Reference Areas. In general, however, most of the parameters sampled appear important to retain in the monitoring program, although not necessarily perhaps in the progress criteria. Some factors such as salinity may not seemingly not represent a good indicator for evaluating improvement in conditions within the Project Area and convergence of conditions with those observed in Reference Areas, but may ultimately be important as harbingers of potential future changes in the system from direct and indirect effects of climate change, including changes in pH, water level, extent of high tides, and salinity.

Monitoring of water quality changes with restoration could be improved through increasing frequency and spatial coverage of sampling during storm events, assessing particulate as well as dissolved nutrients, and better assessing nutrients such as total ammonia and total dissolved phosphates through use of analytical techniques with lower laboratory detection limits. In addition, for future analyses, some of the Reference Areas or sampling locations within these marshes may need to be reevaluated due to restoration activities occurring upstream, with effects from restoration potentially rendering some of these areas ineffective as “controls.” While monitoring is focused on assessing change resulting from restoration, the program will also need to take into account more global changes resulting from climate change, which ultimately may have a significant effect on both Project Area and Reference Area systems.

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I would like to thank the many, many people who have slogged through the mud, waded through channels, lugged equipment, logged countless hours entering and validating data, and, lastly, spent innumerable hours helping with production of this report: Amelia Ryan, Leslie Allen, Sarah Minnick, Leslie Adler-Ivanbrook, Chelsea Donovan, and a number of other intrepid souls. Many thanks to my family, as well, who endured my many long hours trying to finally finish this report. Also, Greg and Rachel Kamman have invested a tremendous amount of time and energy into this project, and the information that they have compiled provides a framework without which we could not really interpret our water quality results. They deserve special kudos for all their hard work. Projects such as this one tend to inspire people, including myself, and I thank all those who have helped make this incredible project -- and this report -- a reality.

Table of Contents

List of Figures

List of Tables

Introduction

The National Park Service (Park Service) has implemented an approximately 550-acre wetland restoration project in the southern end of Tomales Bay in Marin County, California (Figure 1). The Project Area historically supported a vast complex of subtidal and intertidal waters and wetlands, but these wetlands were diked between the late 1800s and early 1940s for a dairy operation and construction of a road. Rather than try to recreate what was present historically, the Park Service is focusing on restoring natural hydrologic tidal and freshwater processes, thereby promoting restoration of hydrologic and ecological functions. Natural hydrologic processes are the cornerstone of many hydrologic and ecological functions and economic "services" associated with wetlands such as floodwater retention, flood energy dissipation, water quality improvement, and wildlife habitat that benefit both wildlife and humans. These hydrologic and ecological functions are particularly important in Tomales Bay. While it is generally perceived as pristine, this rural coastal watershed still suffers from negative anthropogenic influences such as agriculture, home and road development, leaking septic systems, mercury mining, landfills, and oil spills.

As an integral component of the restoration project, the Park Service is implementing a comprehensive long-term monitoring program to assess whether restoration is successful. The proposed 20-year monitoring program will include assessment of both the Project Area and nearby reference wetlands both prior to restoration and after restoration is implemented. Similar to many other restoration projects, our monitoring program will rely on a modified BACI sampling approach (Stewart-Oaten et al. 1986, Underwood 1991). "BACI" refers to monitoring of an "impact" (I) area both "before" (B) and "after" (A) an activity is implemented, with concurrent monitoring of "control" (C) areas. This framework will enable us to better determine whether restoration has increased functionality of the restored Project Area relative to conditions present in the Project Area prior to restoration and brought it closer to conditions in natural undiked marshes or reference wetlands.

The Park Service anticipates that restoration will either reintroduce wetland processes and functions that were lost through diking or enhance functions that are already present due to the fact that the pastures are largely already "wetland." The monitoring program will enable the Park Service to evaluate how successful removing, modifying, or minimizing infrastructure and agricultural practices have been in reintroducing or enhancing wetland processes and functions. In addition, it will address the success of the Project in achieving Critical Resource Objectives, which are processes and functions or components of processes and functions that the Park Service has prioritized for restoration such as water quality, floodplains, marsh/transitions, riparian, high marsh/upland ecotone, shallow shorebird habitat, and anadromous species. The objective of establishing processes and functions in the restored Project Area similar to those occurring in reference wetlands also meets one of the requirements imposed by the California Coastal Commission (CCC) in its mitigation agreement with California Department of Transportation and the Park Service.

Perhaps, one of the most important functions that wetlands can provide in Tomales Bay is water quality improvement. During the last few decades, poor water quality in the Bay has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak. In 1994, Tomales Bay was listed as threatened under the state's Shellfish Protection Act. Mercury mining during the late 1960s-1970s eventually resulted in deposition of mercury-contaminated sediment into Tomales Bay. Because of mercury problems, fish consumption advisories were established in 2000 and reissued in 2004 for Bay species such as jacksmelt (*Atherinopsis californiensis*), California halibut (*Paralichthys californicus*), and leopard shark

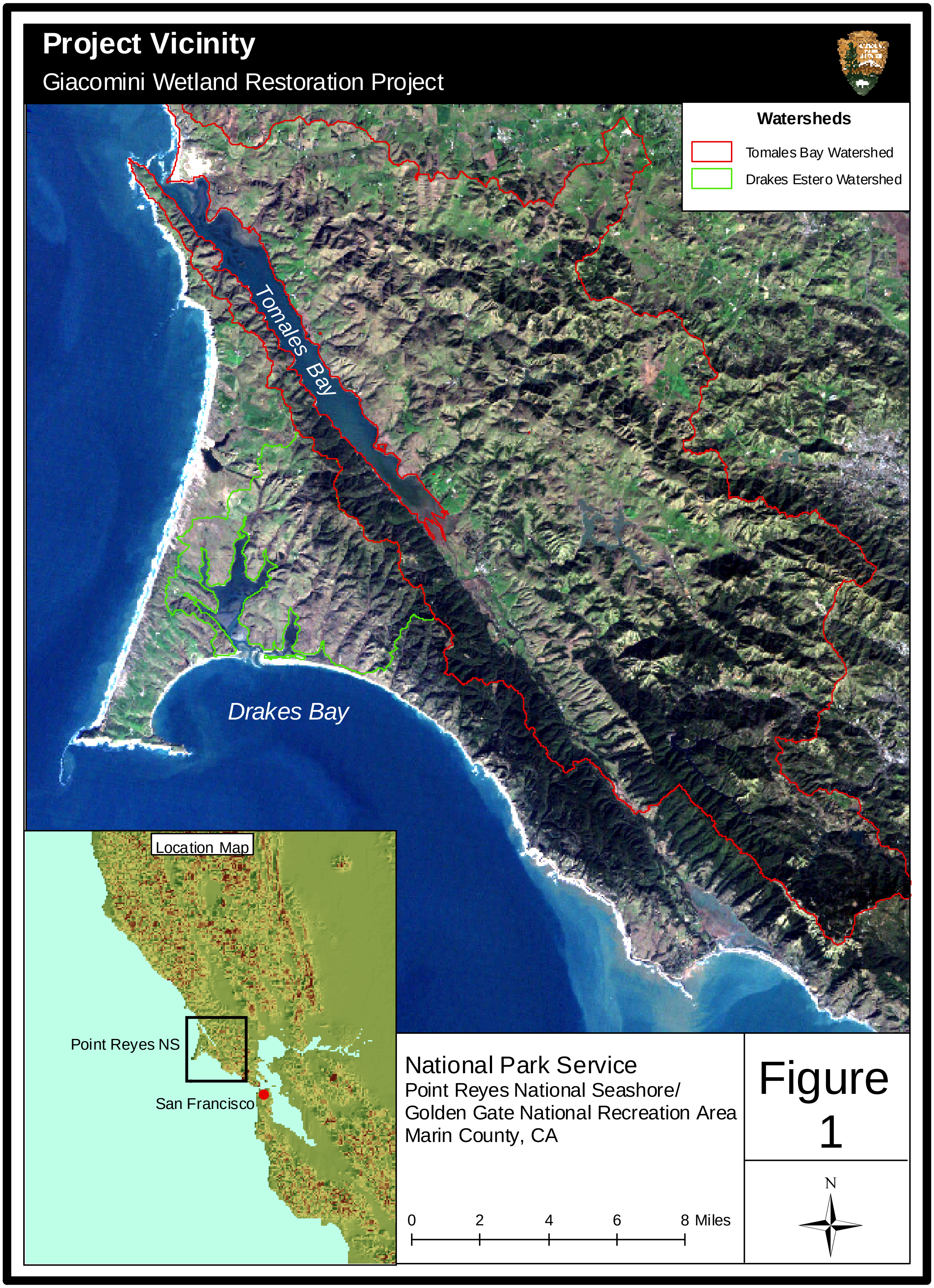

Project Vicinity
Giacomini Wetland Restoration Project
Watersheds
Tomales Bay Watershed
Drakes Estero Watershed
Tomales Bay
Drakes Bay
Location Map
Point Reyes NS
San Francisco
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0
2
4
6
8 Miles
N

Figure 1

(*Triakis semifasciata*; Brodberg 2004).

The failure of Tomales Bay to consistently meet water quality standards for designated beneficial uses such as oyster mariculture, public recreation, and wildlife needs prompted the Regional Water Quality Control Board (RWQCB) to designate it as impaired under Section 303(d) of the Clean Water Act. These water quality problems have galvanized public and private efforts to improve water quality through both source reduction and restoration. The Park Service is actively working with community and local government groups on a number of projects related to water quality, the largest of which is the Giacomini Wetland Restoration Project. The Park Service believes that reestablishing the hydrologic connection between the Bay and this historic salt marsh could play a vital role in improving water quality not only within the Project Area, but within Tomales Bay by retaining and/or transforming sediment, nutrients, and pathogens in floodwaters. Two-thirds of the Bay's freshwater inflow comes from the Lagunitas and Olema Creeks, which flow through the Project Area (Fischer et al. 1996). The Lagunitas Creek and Olema Creek watersheds often carry high loads of nutrients, sediments, and pathogens because of adjacent residential and agricultural land uses.

The importance of this issue to Tomales Bay led the Park Service to initiate hydraulic and water quality monitoring components of the Long-Term Monitoring Program well before most of the other monitoring program components. Water quality monitoring was initiated in February 2002 prior to formal development of the Long-Term Monitoring Program. Since 2002, the Park Service has conducted monthly to quarterly systematic sampling of water quality field parameters, nutrients (nitrate, nitrites, total ammonia, total dissolved phosphates), chlorophyll a/phaeophytin, and pathogen indicators (total and fecal coliform) within the Giacomini Ranch, Olema Marsh, and selected reference sites. Starting in 2003, monitoring of water levels in Project Area creeks and groundwater was conducted, along with more intense monitoring of salinity and other water quality parameters at specific locations. Most of the hydrologic monitoring other than water quality monitoring was conducted by the project's hydrologists, Kamman Hydrology & Engineering (San Rafael, Calif.), along with, to a lesser extent, the Park Service.

The Park Service anticipated that this monitoring information, combined with information from hydraulic and hydrodynamic computer modeling, would prove invaluable to assessing baseline conditions and designing restoration alternatives, as well as analyzing potential benefits and impacts from restoration. In addition, it provides a clearer picture of the relationship of the Project Area, which represents one of the largest estuarine transition zones in Tomales Bay, to upstream and downstream portions of the watershed, which have been studied in more detail historically.

This document attempts to integrate information from past studies on other portions of the Tomales Bay watershed with the hydraulic, hydrodynamic, and water quality information collected or generated by this project to paint a clearer picture of existing or pre-restoration water and sediment processes and resource conditions in this vital transition zone between the upper watershed and the Bay. It summarizes and analyzes results from the first four years of pre-restoration hydraulic and water quality monitoring, including directed intense monitoring efforts focused on evaluating particular hydraulic, water quality, and salinity issues. These analyses not only define existing or baseline conditions within the Project Area, but compare existing conditions between unrestored and reference wetlands to identify relevant differences between these systems.

Hydraulic and water quality monitoring will be continued in future years as part of the Long-Term Monitoring Program for the proposed project. Ultimately, information from the water quality and other monitoring components will enable the Park Service to measure the success of its efforts in restoring or improving hydrologic and ecological processes and functions and, thereby, help the Park Service determine whether the Project Purpose and Objectives have been achieved. It will also help Park Service managers recognize when adaptive management or remedial measures might be necessary to improve the success of restoration efforts. Lastly, we believe that lessons learned from this restoration project through will prove invaluable to managers of other future wetland restoration projects.

Relevant Regulations and Policies

Increasing concern about polluted waters in the 1960s led to a number of federal and state efforts to improve water quality, some of which led to increasing protection for wetlands, which were recognized for their important role in improving water quality.

The most well-known legislation protecting the nation's waters is the Federal Water Pollution Control Act (Clean Water Act) and subsequent amendments of 1977 (33 USC §1251 et seq.). The Clean Water Act provides for the restoration and maintenance of the physical, chemical, and biological integrity of the nation's waters, primarily through three sections – Section 404, Section 401, and Section 303(d). Section 404 (33 U.S.C. 1344) of the Act prohibits the discharge of fill material into navigable waters, tributaries to navigable waters, and special aquatic sites of the United States, including wetlands, except as permitted under separate regulations by the U.S. Army Corps of Engineers (the Corps) and U.S. Environmental Protection Agency. Under Section 401 (33 U.S.C. 1341), states and tribes can review and approve, condition, or deny all Federal permits or licenses that might result in a discharge to state or tribal waters, including wetlands. In California, authority for Section 401 has been delegated to the State Water Resources Control Board (SWRCB), which shares its authority with nine regional boards (see Porter-Cologne Act below).

The Clean Water Act was actually predated by California's Porter-Cologne Water Quality Act of 1969 (California Water Code, Division 7, §13000), the principal California law governing water quality control in California. The Porter-Cologne Act applies broadly to all State waters, including surface waters, wetlands, and ground water; it covers waste discharges to land as well as to surface and groundwater, and applies to both point and non-point sources of pollution. SWRCB is the lead agency for enforcement and provides for establishment of waste discharge requirements for discharge to the state's surface and groundwater resources. SWRCB shares authority for implementation of the Clean Water Act and the Porter-Cologne Act with regional water boards. Each RWQCB governs one of the nine hydrologic regions into which California is divided, adopting regional water quality control plans (basin plans) for their respective regions. Waste discharge requirements for San Francisco Bay are outlined in the *Water Quality Control Plan for the San Francisco Bay Basin* (Basin Plan; 1995). Water quality control plans designate beneficial uses of water for specific water bodies, establish narrative or numerical water quality objectives to protect those uses, and provide a program to implement the objectives.

For Lagunitas Creek, the primary creek within the Project that bisects the Giacomini Ranch into the so-called East and West Pastures, beneficial uses include contact and non-contact recreation, oyster production, municipal and domestic water supply, agricultural supply, cold freshwater habitat, fish migration, preservation of rare and endangered species, recreation, fish, spawning, and wildlife habitat. For certain water quality objectives such as total and fecal coliform, specific numeric criteria have been developed for different beneficial use types. A list of the most relevant water quality objectives is provided in Table 1. These numeric criteria often specify a maximum or minimum or one-time "not to exceed" concentration or range of values, but also include so-called measures of central tendency such as average or median concentrations (the central or middle value) over specified periods of time.

Should water bodies violate water quality objectives for its beneficial uses, the state is authorized under Section 303(d) of the Clean Water Act to declare these areas as "impaired" or unable to perform designated beneficial uses by specified contaminants. Both Lagunitas Creek and Tomales Bay have been declared impaired under Section 303(d) for excessive sedimentation and high levels of nutrients and pathogens. Tomales Bay has also been listed for mercury. In recent years, the RWQCB has been changing its primary focus from regulating point source discharges

TABLE 9. SELECTED WATER QUALITY OBJECTIVES UNDER THE SAN FRANCISCO BASIN PLAN AND USEPA

BACTERIA[a]	**Beneficial Use or Habitat/Location**	**Fecal Coliform (MPN/100ml)**	**Total Coliform (MPN/100ml)**
Basin Plan	Water Contact Recreation	• Geometric mean<200 • 90th Percentile <400	• Median < 240 No sample > 10,000
	Shellfish Harvesting[b]	• Median < 14 • 90th Percentile <43	• Median < 70 • 90th Percentile <230[c]
	Non-contact Water Recreation[d]	• Mean < 2000 • 90th percentile < 4000	
	Municipal Supply/ Surface[e]	• Geometric mean < 20	• Geometric mean < 100
Tomales Bay Pathogen TMDL	Tomales Bay	• Median < 14 • 90th percentile < 43	
	Lagunitas Creek, Olema Creek, and Walker Creek	• Log mean <200 • 90th Percentile <400	
TMDL Load Allocation	*Lagunitas Creek at Green Bridge*	• Log mean < 95	
DISSOLVED OXYGEN	**Habitat/Location**	**Numerical Min. Objective**	**Numerical Median Objective**
	Tidal Waters *Bay* *Delta*	5.0 mg/l Minimum 7.0 mg/L minimum	
	Non-Tidal Waters *Cold* *Warm*	7.0 mg/L minimum 5.0 mg/L minimum	Median D.O. for any three consecutive months not < 80 percent.
PH	**Habitat/Location**	**Acceptable Range**	**Numerical Change Objectives**
	All	6.5-8.5	Controllable water quality factors not cause changes > 0.5 units in ambient pH.
SALINITY	**Habitat/Location**	**Narrative Objective/Numerical Change Objectives**	
	All	Controllable water quality factors not increase the total dissolved solids or salinity of waters so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat.	
SEDIMENT	All	• Suspended sediment load and suspended sediment discharge rate not be altered in such a manner to cause nuisance or adversely affect beneficial uses. • Controllable water quality factors not cause a detrimental increase in concentrations of toxic pollutants in sediments or aquatic life.	
TEMPERATURE	Inland Waters – Cold and Warm Habitats	• Natural receiving water temperature not altered unless demonstrated that alteration does not adversely affect uses. • The temperature of any cold or warm freshwater habitat not > 5°F above natural temperature.	
TURBIDITY	All	Waters free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases relatable to waste discharge not > 10 percent in areas where natural turbidity is > 50 NTU.	
NITRATES	*USEPA*	Human Consumption	• 10 mg/L
	Estuaries (NOAA/USEPA	Max Aquatic Diversity	• 1 mg/L
		Mod Aquatic Diversity	• 0.1 mg/L
NITRITES	USEPA		• 1.0 mg/L
	RWQCB	Aquatic Organisms Toxicity	• 0.5 mg/L
PHOSPHATES	*Estuaries (NOAA/USEPA*	Max Aquatic Diversity	• 0.1 mg/L
		Mod Aquatic Diversity	• 0.01 mg/L
UNIONIZED AMMONIA	**Habitat/Location**	**Numerical Objectives**	
	All	Annual Median ≤ 0.025	
	Central Bay/Delta	Maximum ≤ 0.16 mg/L	
	Lower Bay	Maximum ≤ 0.4 mg/L	

Notes:
a. Based on a minimum of five consecutive samples equally spaced over a 30-day period.
b. Source: National Shellfish Sanitation Program.
c. Based on a five-tube decimal dilution test or 300 MPN/100 ml when a three-tube decimal dilution test is used.
d. Source: Report of the Committee on Water Quality Criteria, National Technical Advisory Committee, 1968.
e. Source: DOHS recommendation.

Table Source: RWQCB 1995a

only to managing point and non-point source pollutant loads within entire systems or waterbodies through setting Total Maximum Daily Load (TMDL) standards. The RWQCB has finalized the Tomales Bay Pathogen Total Maximum Daily Load (TMDL) standard and is in the process of developing sediment TMDLs for Tomales Bay, Lagunitas Creek, and Walker Creek (RWQCB 2007).

Salinity is typically not a regulated parameter of water "quality," but within certain regions, salinity can be a concern. Discharge of agricultural waters and run-off can increase concentrations of agricultural "salts" (i.e., conductivity or conductance) within downstream water bodies, which can affect aquatic biota. Conversely, increases in duration and volume of freshwater inflow from releases of treated wastewater can change salinity dynamics within estuaries, converting saltwater wetlands to freshwater ones. Large acreages of wetlands within south San Francisco Bay have shifted from being saltwater wetlands to brackish or even freshwater ones because of large volumes of year-round treated wastewater release. The RWQCB has attempted to stop this trend by requiring many sewage treatment plants to store treated or re-use wastewater during the summer to ensure that salinity dynamics of the estuary do not continue to be altered. In the 1995 Basin Plan, the RWQCB states that, "controllable water quality factors shall not increase the total dissolved solids or salinity of waters of the state so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat."

In regulated rivers or streams, streamflow or discharge rate is typically governed through mandated releases from upstream dams and issuance of appropriative and riparian water rights that restrict the amount of water that can be pumped or diverted from rivers and creeks. In Lagunitas Creek, which has several dams in the upstream portion of the watershed, instream flow is now regulated by the State Water Resources Control Board (SWRCB) through Decision 95-17, which has mandated minimum creek base flow at Samuel P. Taylor State park gage during the summer from storage reservoir releases of 8 cfs during normal rainfall years and 6 cfs during dry years. In November, minimum flow requirements increase to 20 and range between 16 to 25 cfs between November and April 30.

Marin County also promotes restoration and enhancement of watersheds and natural stream channel function (including protection and enhancement of fish habitat) in its draft update of the Countywide Plan (2005). In the Coastal Zone, the Local Coastal Program (LCP) also includes policies regarding stream alterations, including protection of stream channels from impoundments, diversions, channelizations, or other substantial alterations, as well as protection of at least 100 feet on either side of creeks as "buffers" to increase wildlife habitat quality and water quality benefits (Marin County Comprehensive Planning Department 1981). The Point Reyes Station Community Plan (Marin County Community Development Agency 2001) further supports preservation of streams and streamside environments in their natural conditions, including protection of existing riparian habitat or "buffers" and removal of invasive plant species, and protection of Lagunitas Creek, specifically its water quality, coho salmon and steelhead populations, and other aquatic life in its policies.

The National Park Service Management Policies (2006) support practices that "re-establish natural functions and processes in human-disturbed components of natural systems in parks unless otherwise directed by Congress…..Impacts to natural systems resulting from human disturbances include ......changes to hydrologic patterns and sediment transport; the acceleration of erosion and sedimentation; and the disruption of natural processes. The Service will seek to return human-disturbed areas to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated"(NPS 2006, Section 4.1.5). The Management Policies also call for parks to "protect, preserve, and restore the natural resources and functions of floodplains (NPS 2006, Section 4.6.4)," which includes benefits such as floodwater storage.

The Park Service Management Policies (2006) support federal and state efforts to either preserve or improve the quantity and quality of park waters. Parks are required to "determine the quality of park surface and ground water resources and avoid, whenever possible, the pollution of park waters by human activities occurring within and outside of parks" (Section 4.6.3; NPS 2006). Furthermore, parks are mandated to "take all necessary actions to maintain or restore the quality of surface waters and groundwaters consistent with the Clean Water Act and all other applicable federal, state, and local laws and regulations" (Section 4.6.3; NPS 2006). Marin County regulates activities that substantially degrade surface or groundwater quality through CEQA review, as well as through grading and stormwater permits. It has established several-water related policies, including reduction of pathogen, sediment, and nutrient (WR-2.2), avoidance of erosion and sedimentation (WR-2.3), and protection of watersheds and aquifer recharge (WR-1.1; Marin County Community Development Agency 2005). The Point Reyes Station Community Plan (Marin County Community Development Agency 2001) identifies protection of Lagunitas Creek, including its water quality, as an objective.

Materials and Methods

Monitoring Program Framework

Similar to many other restoration projects, our monitoring program relies on a modified BACI sampling approach (Stewart-Oaten et al. 1986, Underwood 1991). "BACI" refers to monitoring of an "impact" (I) area both "before" (B) and "after" (A) an activity is implemented, with concurrent monitoring of "control" (C) areas. Based on this sampling design, we are evaluating the Project Area before and after restoration is implemented and using three (3) reference wetlands to better discern the effects of the restoration "impact" relative to natural variability. The Park Service is focusing monitoring efforts on those hydrologic and ecological processes and functions that are expected to be either improved or reintroduced through restoration. These key processes and functions will be assessed either by directly measuring some variable or realized component of function (e.g., wildlife density for wildlife habitat) or by using indicators that relate to the capacity or opportunity for a function to occur (e.g., measuring floodplain width rather than total water storage for floodwater retention). In instances where assessing function is too difficult, specifically food chain support, we will focus on functional potential and establishment of optimal ecological or water quality conditions similar to those present in reference wetlands.

Monitoring of these variables and indicators incorporate both field- and office-based components, such as mapping, field surveys, sample collection and analysis, and aerial image and map interpretation using Geographic Information System (GIS) software. Intra-annual and inter-annual monitoring frequency varies depending on the variable or indicator, with some assessed several times annually, and others, only once. Overall, inter-annual monitoring is scheduled annually prior to restoration and at Years 1, 2, 3, 4, 5, 7, 10, 15, and 20 after restoration is implemented. The scale of monitoring efforts is dramatically reduced by the fact that most variables and indicators are incorporated into more than one process, function, or condition.

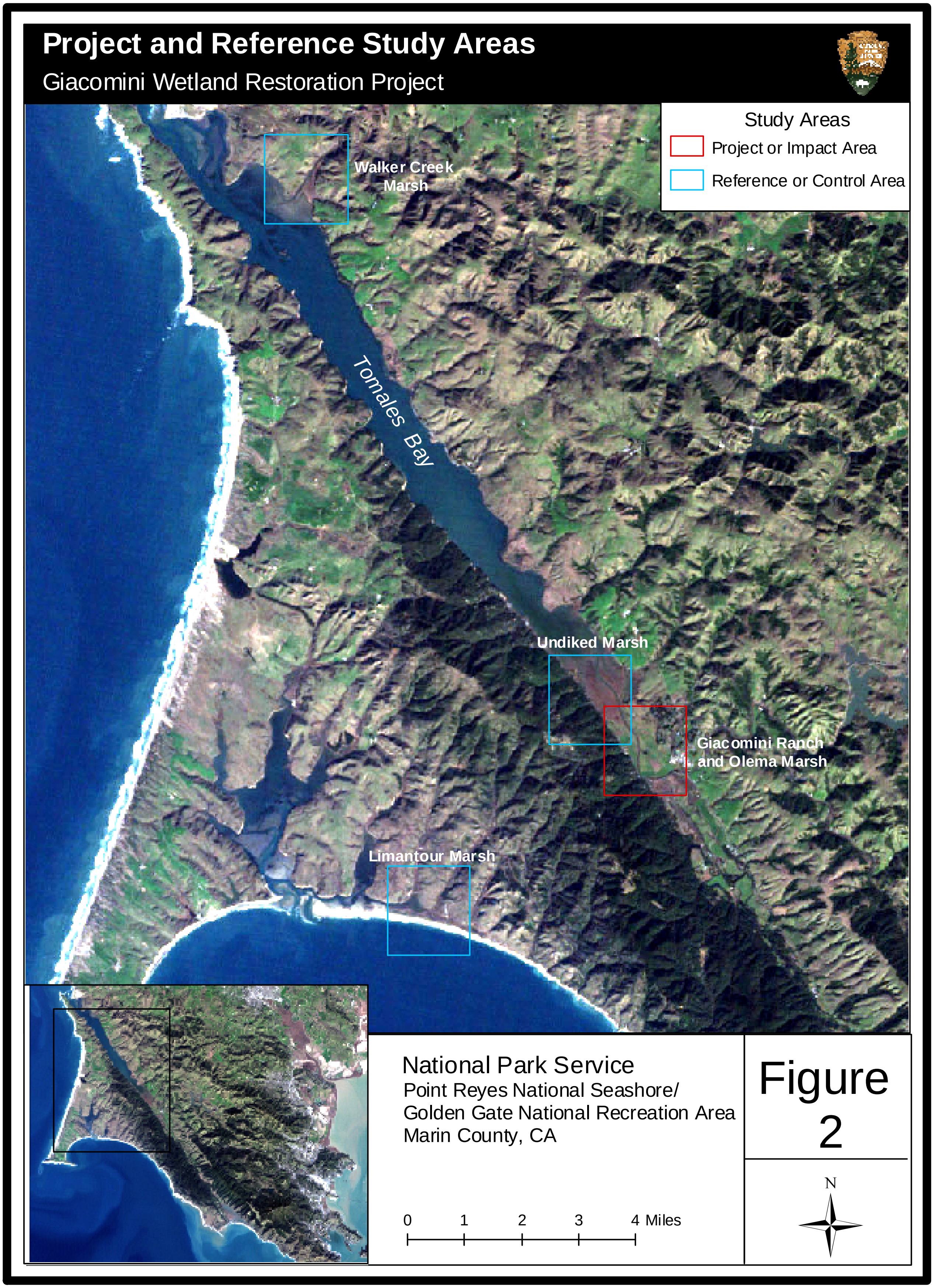
The Park Service will use overall numerical "scores" obtained from summing variables and indicators for each process, function, or condition to assess the Project's progress toward reaching its Purpose, Goals, and Objectives through use of Performance Goals. Through statistical analysis of the data, the Park Service will assess whether key hydrologic and ecological processes, functions, and conditions of the restored Project Area 1) exceed those of the Project Area prior to restoration and 2) begin to approach, over time, those of nearby reference marshes, given the potential for some natural range of variation in functionality, even among unimpacted wetlands.

This report summarizes pre-restoration monitoring results for several of the parameters incorporated into the monitoring program, specifically hydrology and water quality within the Study Areas, including the Project or "Impact" Area and the Reference or "Control" Areas. The information in this report will serve as the cornerstone for analyzing changes now that the Project Area has been restored.

Study Area Location and General Description

The Study Areas are located in the Tomales Bay and Drakes Estero watersheds, which are located directly north of San Francisco Bay in Marin County along the outer central California coast (Figure 1).

The Project Area is located at the head – or southernmost portion -- of Tomales Bay between the towns of Point Reyes Station and Inverness Park (Figure 2). The Project Area incorporates the Giacomini Ranch and Olema Marsh. The Giacomini Ranch was an operating dairy ranch between 1946 and 2007 and closed after being bought by the Park Service in 2000 for wetlands



Project and Reference Study Areas
Giacomini Wetland Restoration Project
Study Areas
Project or Impact Area
Reference or Control Area
Walker Creek Marsh
Tomales Bay
Undiked Marsh
Giacomini Ranch and Olema Marsh
Limantour Marsh
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0 1 2 3 4 Miles
Figure 2
N

restoration. The Giacomini Ranch is located in the north district of Golden Gate National Recreation Area (GGNRA), which is managed by Point Reyes National Seashore (Seashore). Even after purchase, the dairy continued to operate under a Reservation of Use Agreement for several years. In 2007 and 2008, the Park Service conducted an extensive restoration to remove agricultural infrastructure and conditions and reestablish natural hydrologic and ecological processes and functions.

The Giacomini Ranch portion of the Project Area lies at the confluence of Lagunitas, Olema, and Bear Valley Creeks with Tomales Bay. Lagunitas Creek flows in a northerly direction from the upper portions of its watershed in the Coast Range mountains through largely local- and state-owned lands to the headwaters of Tomales Bay where it curves to the west for a short distance before reaching the 90-degree bend at “White House Pool” and resuming its northward course. Lagunitas Creek bisects the Giacomini Ranch into two pastures – the East and West Pastures (Figure 2).

Cows in East Pasture of Giacomini Ranch

The 200-acre West Pasture is bordered by the town of Inverness Park and Sir Francis Drake Boulevard (Figure 2), which is the only road connecting the town of Inverness and the rest of the Point Reyes Peninsula to other areas within west Marin and the county. While most of the businesses and homes occur on the west side of Sir Francis Drake Boulevard at the base or along the steep hillsides of the Inverness Ridge, several private residences have been built on the east side of Sir Francis Drake Boulevard directly adjacent to the pastures. The 350-acre East Pasture is bordered by the town of Point Reyes Station and the outlying residential community north of the town on the Point Reyes Mesa (Figure 3). The town is located on a mesa or coastal terrace, with all of the homes and businesses are elevated anywhere from 30- to 100 feet above the East Pasture.

South of the Giacomini Ranch is the Levee Road area, a section of Sir Francis Drake Boulevard that was built through construction of a levee during the late 1800s (Figures 2 and 4). The northeastern half of Levee Road is residential, with more than 15 homes directly adjacent to Lagunitas Creek and across the creek from the East Pasture. The southwestern half of Levee Road borders Olema Marsh, a 63-acre marsh jointly owned by the Seashore and Audubon Canyon Ranch that is also part of the Project Area (Figures 2-4). Bear Valley Creek currently flows on the eastern perimeter of the marsh through culverts underneath Levee Road to its confluence with Lagunitas Creek near the location of the old summer dam. The marsh is bordered on the west and south by Bear Valley Road, which is also culverted to allow passage of flows from the upstream end of Bear Valley Creek into the marsh.

Undiked Marsh

The Reference Areas are located in several different areas. North of the Giacomini Ranch is undiked marshland owned by the CSLC (Figure 2). Several hundred acres of marsh formed between 1860 and 1950 extend outward into the southern portion of Tomales Bay before reaching largely unvegetated subtidal and intertidal lands. This area represents one of the Reference Area marshes, the Undiked Marsh (Figures 2-3). The other Reference Areas are Walker Creek Marsh and Limantour Marsh (Figure 2). Walker Creek Marsh is also located in Tomales Bay at its northern end toward the outlet to the Pacific Ocean. This marsh occurs at the mouth of Walker Creek, which drains into Tomales

Bay approximately 10.6 miles northeast of the Project Area. The marsh is owned and managed by Audubon Canyon Ranch. Limantour Marsh is in an entirely different watershed on the other side of the Point Reyes Peninsulal in between Golden Gate (the outlet of San Francisco Bay) and Tomales Bay. Limantour Marsh lies at the eastern terminus of Drakes-Limantour Estero in the Wilderness portion of the Seashore.

Because both the Undiked Marsh and Limantour Marsh may be affected by upstream restoration efforts, the use of these marshes as Reference Areas may need to be re-evaluated in the future. In anticipation of future impacts, most of the sampling sites for the Undiked Marsh were moved north to reduce the potential for at least direct changes resulting from restoration of the adjacent Giacomini Ranch.

Hydraulic and Hydrodynamic Monitoring and Computer Modeling Component

Most of the hydrologic monitoring was performed by the Seashore's hydrologic consultants, Kamman Hydrology & Engineering (KHE, San Rafael, Calif.). This information was subsequently used to characterize the existing hydraulic and hydrodynamic conditions in the Project Area. As part of baseline surveys, water levels were monitored in a number of creeks and drainages at various locations within these systems using water level loggers that were surveyed in to establish absolute elevation (NAVD88). Monitoring locations included upper and lower Lagunitas Creek, Tomasini Creek, Fish Hatchery Creek, upper and lower Bear Valley Creek, and Olema Creek (Appendix B1). Wells were typically installed in stilling wells, which were attached to T-posts in the center of the channel. Some of the water level loggers used recorded temperature and conductivity or conductance. In addition, the Park Service collaborated with KHE and installed some continuous water quality monitoring equipment at select locations, including Tomasini Creek, upper portions of Lagunitas Creek, and the West Pasture Freshwater Marsh (Appendix D1).

Groundwater wells were also installed by both the Park Service and KHE in the West and East Pastures (Appendix C1). These wells were monitored by Park Service staff on a monthly basis between 2002 and 2006. Depth measurements involved lowering a measuring tape with attached pen flashlight until the reflection of water was observed and then noting the depth to water from the top of the casing: the height of the casing above the ground was then measured on three (3) sides of the well. When salinity was incorporated, wells were bailed prior to measurement and allowed to recharge before measuring salinity with a YSI 85 (Yellow Springs, OH) handheld monitoring instrument. During installation of KHE wells, KHE conducted borings in soils to characterize characteristics and stratigraphy within Project Area soils. These investigations were augmented by boring of soils in other portions of the Project area, as well (KHE 2006a).

Some of the analysis for documenting baseline or pre-restoration conditions required construction of a hydrodynamic model (MIKE 11, Danish Hydrologic Institute/DHI) that provided more detailed estimates of tidal exchange, flooding frequencies, stream power, salinity structure, and other factors. MIKE11 is a depth-averaged one-dimensional (1D) unsteady flow model (KHE 2006a). MIKE11 permits links to be established between floodplain areas and computational nodes of the main channel network, which represents a pseudo 2D approach to computing both mass and momentum exchange across the floodplain (KHE 2006a). Flood recurrence was modeled using extreme flooding conditions, combining both high flood flows and extreme tides (6.0 feet) such as occurred during the 1982 flood (KHE 2006a). Salinity modeling in MIKE11 averages salinities both vertically and laterally and does not take into account stratified flow, which is known to occur in the Project Area (KHE 2006a). More information on monitoring and modeling conducted by KHE can be obtained from *Hydrologic Feasibility Assessment Report: Giacomini Wetland Restoration Project* (KHE 2006a).

Water Quality Monitoring Component

Water quality sampling assesses basic parameters of water quality, as well as carbon, nutrient, and pathogen concentrations. As discussed earlier, this portion of the Long-Term Monitoring Program is somewhat distinct in that the Park Service initiated water sampling in February 2002, before the Long-Term Monitoring Program was formally developed.

In developing the water sampling component, we referred to the Regional Monitoring Program (RMP) developed by SFEI. It focuses on evaluating water and sediment quality issues within the San Francisco Bay and lower Sacramento Delta regions, as well as assessing issues of bioaccumulation, atmospheric deposition, and other relevant contaminant issues. In addition, we referenced recent recommendations made by the Park Service Marine/Estuarine Required Parameter Working Group (Irwin 2002) on variables that should be incorporated into estuarine monitoring programs.

Water quality sampling is primarily divided into assessment of field parameters and collection of water samples for laboratory analysis through field sampling, although other special monitoring efforts, some of which employ continuously recording water quality monitoring instruments, have sometimes been conducted.

Field Sampling

Field Parameters

As noted above, water quality sampling was initiated in February 2002. For two years, field parameters were assessed on a monthly basis, while collection of water samples for laboratory analysis occurred on a quarterly basis. In January 2004, we reassessed the need for monthly monitoring and decided that we could reduce sampling efforts to quarterly monitoring in January, April, July, and October without losing information. Initially, monitoring was conducted both during neap and spring tide series, and efforts were usually made to time monitoring of tidally influenced sampling sites with the moderate or high tides for that day. In 2004, however, we moved to time the exact week of monitoring within the general time frame (e.g., late January, late April, etc.) with a neap tide series, and, during that week, monitoring of tidally influenced stations is timed to the maximum extent possible with low or ebb tides. Tidal stage influences numerous factors, including salinity, temperature, dissolved oxygen (D.O.), pH, and/or concentration of nutrients, pathogens, and sediments, while time of day affects temperature, D.O., and potentially pH. For logistical reasons, sampling sites have been usually monitored at around the same time of day (e.g., morning, noon, early, and late afternoon) during each sampling event, which may minimize our ability to detect diurnal variation in certain variables.

Water quality field parameters are described in detail in Table 2. Depending on total water depth, parameters are assessed either 1) just at the surface (top 10 cm) or 2) at the surface and on the bottom: surface and bottom measurements are taken when the total water depth exceeds 25 cm. Because of logistical constraints, sampling on some of the larger creeks is conducted in nearshore waters (within 1-2 m) of the creek banks of larger creeks within the Study Area using a pole, therefore, measurements are not necessarily reflective of conditions in the center of these creeks. Some of the creeks appear to be vertically stratified during certain times of the year due to the different densities of freshwater and saline tidal flows. To enable determining instantaneous loading rates, stream flow measurements are taken at each sampling site with a Marsh-McBirney, Inc. Flo-Mate Portable 2000 (Frederick, Maryland), and water depth is measured. Also, tidal stage (if relevant), time, and weather are recorded.

TABLE 2. Description of measurement, units, and monitoring frequency for water variables and indicators

Variable or Indicator	Description of Measurement and Units	Frequency	Units
Field Parameters	Assessment of "quality" of resident waters and thereby potential for use by invertebrates, nekton, and other wildlife species, as well as maintenance of characteristic vegetation community.	• Monthly to Quarterly Pre-Proj; • Quarterly Post-Proj Yrs 1-5, 7, and 10 • Quarterly every 5 years thereafter.	• pH • Temp(deg C°) • Salinity (ppt) • D.O. (mg/L) • D.O. (%) • Conductivity and Specific Conductance (uS or mS) • Turbidity (ntu)
pH	Measurement using Oakton pHTestr 2 (Oakton Instruments, Vernon Hills, Ill).		
Temperature, Salinity, Dissolved oxygen, Conductivity, Specific Conductance	Measurement using YSI 85 (YSI Inc., Yellow Springs, Ohio) system.		
Turbidity/Clarity	Measurement using 2100P Portable Turbidimeter (Hach Co., Portland, Oregon) or other comparable instrument.		
Nutrient, Carbon, and Pathogen, Parameters	Assessment of "quality" of resident waters and thereby potential for use by invertebrates, nekton, and other wildlife species, as well as maintenance of characteristic vegetation community.	• Quarterly Pre-Proj; • Quarterly Post-Proj Yrs 1-5, 7, and 10 • Quarterly every 5 years thereafter.	• Nutrients (mg/L) • DOC (mg/cL) • Coliform (mpn/100ml) • Chla (mg/m^3) • Current (m/s)
Nitrates, Nitrites, Total Ammonia, Total Dissolved Phosphates, Total and Fecal Coliform (or E Coli), Chlorophyll a, Dissolved Organic Carbon (DOC).	Collection of grab sample from nearshore surface waters. Sample kept at 4° C until pick-up by or delivery to laboratory.		
Flow	Measurement using Marsh-McBirney, Inc. Flo-Mate Portable 2000 (Frederick, Maryland).		

Most of the measurements described are discrete measurements or samples. For variables such as D.O. and salinity, continuous recording instruments provide a more valid picture of oxygen and salinity conditions within sampling sites. Because of the expense of these instruments, they cannot be deployed at all sampling sites, but, in areas where discrete measurements or other factors suggest possible D.O. issues, we deployed continuous recording instruments (Hydrolab Minisonde, Hach Environmental, Loveland, CO) for periods ranging from several weeks up to several months. (Appendix D1) Continuous recording instruments were used in the Freshwater Marsh in the West Pasture during the late winter-early spring 2004 to determine salinity patterns following collapse and replacement of the Fish Hatchery Creek tidegate in fall 2003 (Appendix D6). Continuous recording instruments were also deployed into Tomasini Creek in late summer-fall 2004 to determine salinities and patterns of salinity in this creek, which supports the federally endangered brackish water fish species, tidewater goby (*Eucyclogobius newberryi*; Appendix D5).

In fall 2005, these same instruments were placed in Lagunitas Creek near the U.S. Coast Guard North Marin Water District (NMWD) municipal groundwater wells to determine salinities and patterns of salinity during spring tides or high tide events when salinity intrusion events into wells typically occur (Appendices D2-D4). Salinity profiles in Lagunitas Creek were also constructed for modeling needs from a one-day sampling event in October 2003 in which depth-integrated sampling was conducted during high tide, low freshwater flow conditions at 1-m depth intervals from the northern boundary of the Giacomini Ranch to the U.S. Coast Guard facility (Allen 2003; Appendix E).

Sampling of field parameters has been conducted at 35 sampling sites in the Project Area and 16 sampling sites in the three (3) reference wetlands (Appendices A1-A4). Monitoring of four (4) creek and tidal channel sampling sites within both the Walker Creek and Limantour Study Areas began in April 2002. We added eight (8) creek, tidal channel, and pond sampling sites in the undiked Lagunitas Creek Study Area in April 2003. Prior to restoration, the East Pasture Study Area had 14 sampling sites within water ways that include Tomasini Creek, duck ponds, flooded mud flats, and drainage ditches and/or remnant sloughs that are currently used for storing irrigation waters: the number and location of sites has been adjusted since restoration to take advantage of changed conditons. The West Pasture Study Area has 14 sampling sites in Fish Hatchery Creek, small drainages, remnant sloughs, seep areas, and ponds. There are another five (5) sampling sites in the portion of Lagunitas Creek between the East and West Pasture Study Areas. Two (2) sampling sites were added in Olema Marsh in 2004. Sampling sites were chosen to be spatially representative of the Study Area, with the exact sampling locations chosen haphazardly.

Nutrient, Carbon, and Pathogen Parameters

Quarterly sampling of nutrients and pathogen and productivity indicators occurs in January, April, July, and October and is intended to correspond to seasonal changes in water resource conditions. Water sampling is conducted simultaneously with monthly monitoring of field parameters during those months. Because of costs associated with laboratory analyses, nutrient, carbon, and pathogen samples are only assessed for some of the water sampling sites in the Project Area: these sampling locations were selected on the basis being spatially representative. Grab samples of surface waters (top 10 cm) have been collected at five (5) sampling sites in the West Pasture Study Area; five (5) in the East Pasture Study Area; two (2) in Lagunitas Creek; two (2) in Olema Marsh, and three (3) to four (4) in each of the three (3) reference wetland Study Areas. Again, because of logistical constraints, grab samples are typically collected from the nearshore waters (1-2 m) of the creek banks of larger creeks within the Study Areas. A recent study, however, by Lewis and Atwill (2007) on Lagunitas Creek and several other northern California subwatersheds showed that, at least for pathogen sampling, samples collected from the nearshore did not differ noticeably in concentration from those collected in the center of the channel.

Laboratory analyses incorporated the following parameters: nutrients such as nitrates, nitrites, total ammonia, and total dissolved phosphates; pathogen indicators such as total and fecal coliform; and carbon/productivity indicators such as chlorophyll a, phaeophytin (phytoplankton degradation product), and dissolved organic carbon (DOC; Table 2). All water samples are immediately placed within a cooler and kept at an average temperature of 4 degrees Centigrade. Water samples are delivered to the laboratory on the same day that sampling is conducted. Laboratory analyses have primarily been conducted by Analytical Sciences, Inc. (Petaluma, Calif.). Ion chromatography was used to assess nitrates (EPA 300). Total phosphorous was assessed through inductively coupled Plasma-Atomic Spectrometry (EPA 200.7), and total dissolved phosphates were analyzed using the ascorbic acid method (SM 4500 P E). Total ammonia was determined through the phenate method (SM 4500-NH3 F). Some of the other parameters were assessed as follows: dissolved organic carbon (SM 5310 C) and chlorophyll a (SM 10200 H). It is important to note that all of these parameters are reported as ions (NO_3^- and PO_4^-) and not as elements of these ions (NO_3 as "N" or PO_4 as "P").

Nutrient and pathogen concentrations were converted to instantaneous loading rates for those sampling dates where flow measurements and estimates of water depth and channel width were available.

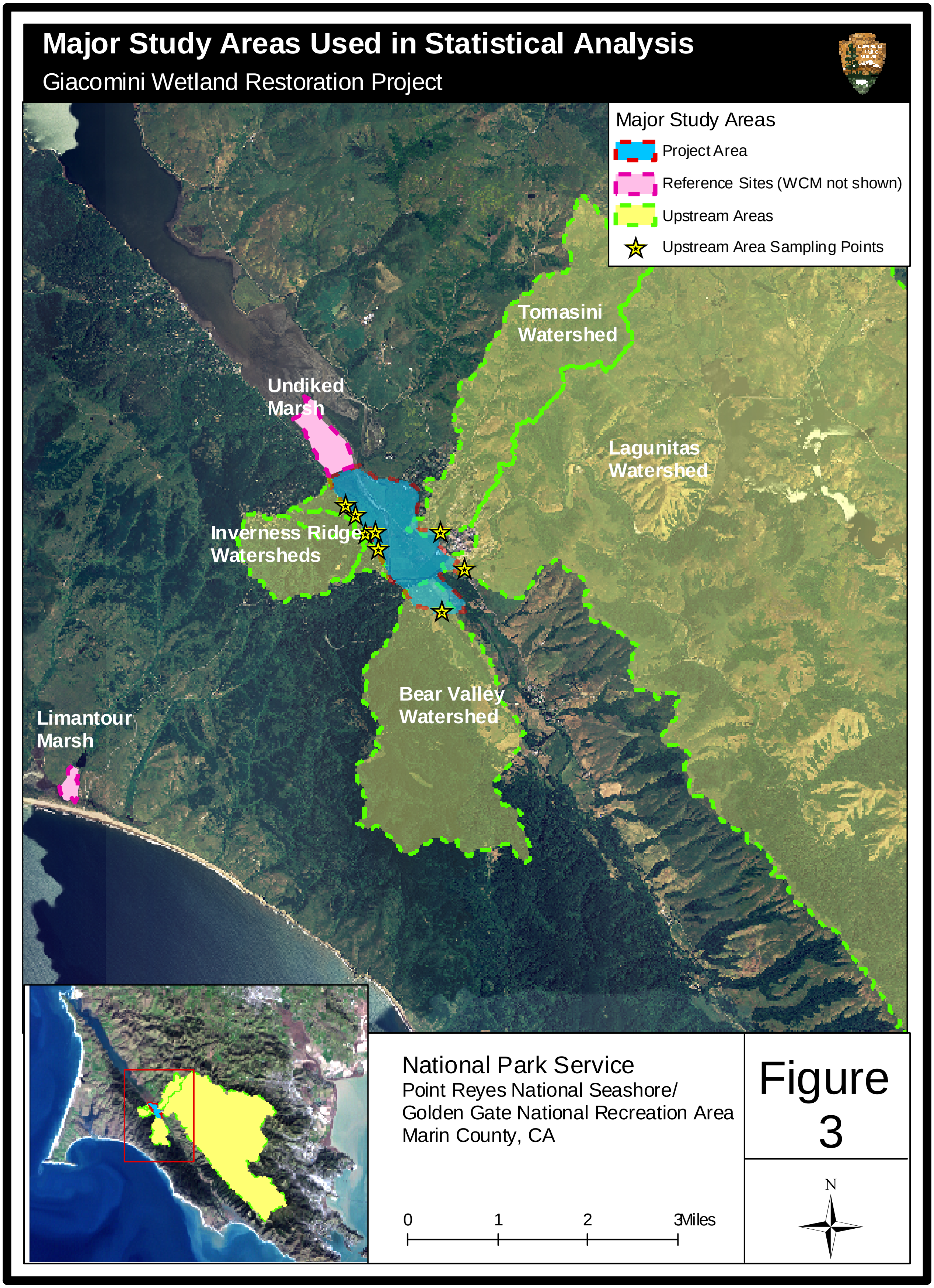
Data Analysis

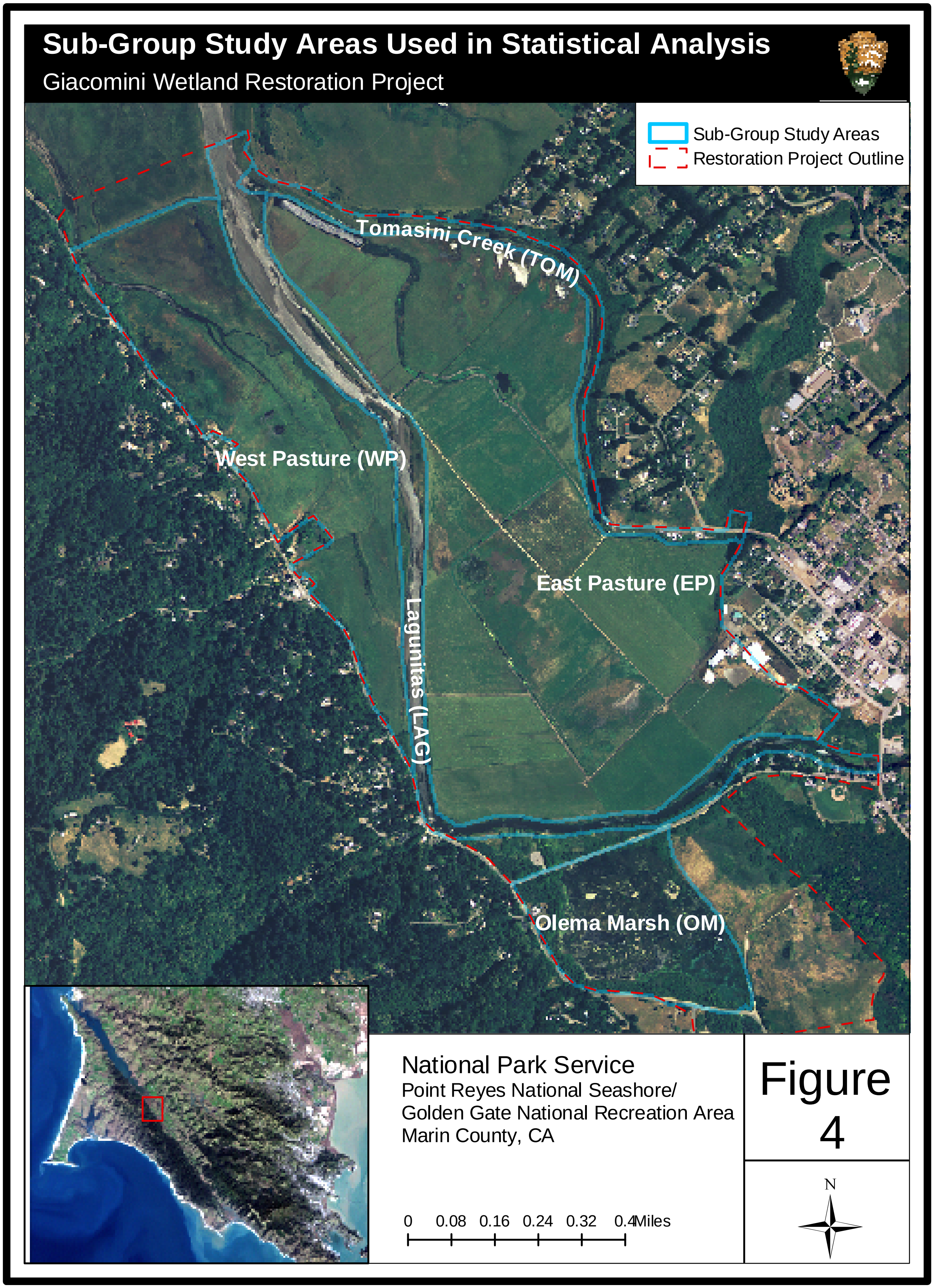
Grouping of Data

To analyze data, data were grouped into three separate types of groupings. The first grouping corresponded somewhat with the BACI approach in that it separates out Project or "Impact" Area (PA) sampling sites from Reference or "Control" Area sampling sites (REF; Figure 3). In addition, a third Major Study Area Group was also incorporated: Upstream Areas (US) or sampling sites on the perimeter of the Project Area that would not be expected to have been influenced by land management practices within the Project Area itself (Figure 3). These sites represent the conditions of waters flowing into the Project Area from surrounding subwatersheds and included locations on upper Tomasini Creek, Fish Hatchery Creek, Lagunitas Creek, Bear Valley Creek, and a few small drainages and emergent groundwater areas in the West Pasture (Figure 3).

Within these Major Study Area groups were sub-groups or somewhat distinct hydrologic units that may have been managed different or were hydrologically separated from other areas even if they were immediately adjacent. For the Project Area, these sub-groups included the East Pasture (EP), the West Pasture (WP), Tomasini Creek (TOM), Lagunitas Creek (LAG), and Olema Marsh (OM; Figure 4). The East and West Pastures are separated by Lagunitas Creek, which was separated from these pastures by levees. Tomasini Creek was separated from the East Pasture by a levee. The boundaries for these areas were the Green Bridge or Highway 1 and the Giacomini Ranch North Levee for Lagunitas Creek; Mesa Road and the flashboard dam structure outlet for Tomasini Creek, Sir Francis Drake Boulevard and the former Giacomini Ranch North Levee for Fish Hatchery Creek; and Bear Valley Road and Levee Road for Olema Marsh. Reference Areas were separated into three sub-groups: Undiked Marsh (UM), Walker Creek Marsh (WCM), and Limantour Marsh (LIM; Figure 2).

The last grouping involved characterizing each of the Project Area sub-groups either with or without upstream sampling sites to provide a more distinct characterization of the hydrologic unit as a whole as well as conditions strictly within the Project Area portion of the sub-group. Most of the detailed description in the text and tables focus on the Project Area sub-groups with upstream sampling sites incorporated, while the comparison sections focus analysis strictly on the Project Area portion of the sub-group.


Major Study Areas Used in Statistical Analysis
Giacomini Wetland Restoration Project
Major Study Areas
Project Area
Reference Sites (WCM not shown)
Upstream Areas
Upstream Area Sampling Points
Tomasini Watershed
Undiked Marsh
Lagunitas Watershed
Inverness Ridge Watersheds
Bear Valley Watershed
Limantour Marsh
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0
1
2
3 Miles
Figure 3
N


Sub-Group Study Areas Used in Statistical Analysis
Giacomini Wetland Restoration Project
Sub-Group Study Areas
Restoration Project Outline
Tomasini Creek (TOM)
West Pasture (WP)
East Pasture (EP)
Lagunitas (LAG)
Olema Marsh (OM)
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0 0.08 0.16 0.24 0.32 0.4 Miles
Figure
4
N

Summary Statistics

To characterize existing or baseline conditions, summary statistical measures such as arithmetic means, geometric means, medians, standard deviations, standard error, and other relevant parameters such 5^{th} and 95^{th} percentiles were used to evaluate water quality data collected between February 2002 and April 2006.

While conductivity and specific conductance data were collected, data analysis relies on transformations by the instruments of conductance data into estimates of salinity in parts per thousand (ppt), which has more utility in estuarine and salt marsh monitoring fields. Also, while percent saturation and concentration data were both collected for dissolved oxygen (DO), analyses focus on concentration data, because that has the most comparability to Basin Plan standards (RWQCB 1995, Table 1). Also, because total coliform data are less specific in terms of indicating potential pathogen levels, this information was also excluded from analysis, along with, for the time being, phaeophytin, a chlorophyll degradation product.

Most of the field parameter data fell within instrument detection limits.   For these parameters, either Excel or a statistical package such as Minitab (State College, PA) or Systat (Chicago, IL) were used to generate summary statistics for these sites. Dissolved oxygen occasionally exceeded instrument detection standards (>20 mg/L), but, because these exceedances were extremely infrequent (<1 percent of the sample values), substitution was used for analysis purposes, replacing the ">20" with the number "20."

Substition can be employed if the number of non-detects or "censored" data is relatively low (<15 percent of the data; Helsel, 2006, *pers comm*.). However, when the number of non-detects exceeds 15 percent of the data, more sophisticated analytical techniques should be used that take advantage of the information provided even in a value that does not exceed method detection limits (MDL; Helsel 2005). Most of the nutrient, pathogen, and chlorophyll a data showed varying proportions of non-detect data, with some of the most problematic in terms of high numbers of non-detect values being the total ammonia and total dissolved phosphates data. These parameters, along with nitrates and chlorophyll a, are primarily left-censored: that is, most of the non-detect values come from samples falling below the MDL However, fecal coliform often manifests as arbitrarily censored data in that samples fall either below or above the MDL for the particular dilution selected for multitube analysis.

For parameters that had moderate to large number of values that fell either below or above the reporting limit, summary statistics were calculated using statistical methodologies commonly employed in other fields such as the medical and biotechnology industries that fit a distribution to observed values using Maximum Likelihood Estimates (MLE) or other parametric or non-parametric equivalents and then extrapolate a collection of values above and below the reporting limit for use in estimations (Helsel 2005). Depending on the number of data (n) and the number of non-detects, different survival/reliability analysis techniques were employed to derive summary statistics, including MLE, Kaplan-Meier (KM), and Robust Order on Statistics (ROS) based on recommendations by Helsel (2005). These techniques were performed using both packaged and macros developed specifically for the Minitab program.

Most of these techniques perform better for data with single or limited MDLs or that have been censored only at a few values. Multiple MDLs can result from changes in laboratories, analytical approach, matrix interference from salts, or other issues. Because of these issues, the highest non-detect values (3- 15 mg/L) for total dissolved phosphates were removed to improve estimation capability by these techniques. Otherwise, all detect and non-data were incorporated into these analyses.

Comparison between Unrestored Project Area and Reference Areas

Differences in the means, geometric means, or medians of the Project Area (PA) prior to restoration and Reference Areas (REF) were assessed for most of the parameters assessed. In addition, these areas were compared with summary values for Upstream Areas (US). For non-censored data, standard statistical techniques were employed that involved use of either standard parametric (e.g., ANOVA, t-test) or non-parametric (e.g., Kruskal-Wallis, Sign Test) techniques depending on whether assumptions for use of parametric statistics (e.g., homogeneity of variance, normal distribution) were met. Statistical packages used to analyze data included Minitab, Systat, and Excel. When appropriate, differences between groups were assessed post-hoc using either a multiple comparison or contrast procedure (e.g., Bonferroni or Tukey).

For censored data, a similar approach was employed using survival/reliability statistical techniques. For data that met parametric assumptions under normal or lognormal distributions, MLE was used to assess differences in Major Study Area groups. Kruskal-Wallis or Wilcoxon Box Score tests were used for data that did not meet parametric assumptions. These procedures were performed using packaged tools or macros written specifically for Minitab. When appropriate, differences between groups were assessed post-hoc using multiple comparisons with control of the overall experiment-wise error rate through reduction of the alpha employed to determine significance of results.

In addition to these comparisons, the unrestored Project Area was also compared with Reference Areas in terms of the percentage of values that fell within the range of variability observed in Reference Areas. This approach was defined in the original Framework Plan (Parsons 2005). We have defined the normal range as the range of values incorporating 95 percent of the population of reference values (Kilgour et al. 1998) or the 5th and 95th percentile of values in Reference Areas. In certain cases, only the upper part of the range (95th percentile) was used, because the lower part of the range would not be of ecological interest or importance. While ranges are not as frequently tested as means, there are some methods available for analysis, including use of summary statistics, box and whisker plots, and others (Irwin 2002, Thompson 1938, Kilgour et al. 1998). Because these procedures are currently not readily available, they were not employed as part of the pre-restoration analysis, but may be incorporated later.

In addition to evaluating the overlap in the range of variability between the Project Area and Reference Areas, we also assessed whether 50 percent of the values measured in the unrestored Project Area ranked above the lowest 16.7 percent of the values recorded in reference wetlands. The latter standard is similar to that established by Short et al. (2000) for the Great Bay Estuary project. As described in the Framework Plan (Parsons 2005), progress criteria for this project required that data from the “impact” site fall not only within the distribution of values for each indicator from the reference wetlands, but rank above the lowest 16.7 percent of those values (± 1 SD). The “1 SD” measure was selected, because it is the statistical standard of variability that is independent of sample size and yet directly related to the coefficient of variation (Short et al. 2000).

Comparison between Major Study Area Sub-Groups

The analyses between Major Study Area sub-groups were exactly identical to those described for the Major Study Area Groups above. Again, as discussed earlier, statistical comparisons between Project Area Sub-Groups in the Comparison sub-sections of each section of this document dealt specifically with all sites except upstream sampling sites. Those are only discussed in the sub-sections discussing results from individual areas.

Graphing of Water Quality Data

In addition to summary statistics, graphing of the most relevant field and nutrient parameters was performed using boxplots to show differences in summary water quality data between Major Study Area groups (PA, REF, and US) and select Study Area sub-groups (PA and REF). The sub-group graphs incorporate upstream sampling sites for Project Area sub-groups.

Evaluation of Variability in Assessed Parameters in Reference Areas

Lastly, comparison of the "Impact" or Project Area site with reference wetlands is intended to involve assessing key indicators or variables representative of processes, functions, and conditions. The definition of "key" for the purposes of this project is still being developed and will rely, to some degree, on results from analysis of pre-restoration data. In comparing impact and control sites, Short et al. (2000) advocated using only variables with a low coefficient of variation among all reference sites for inclusion in project-related progress criteria based on his experience with a mitigation project in Maine's Great Bay Estuary. For example, key variables might include densities of benthic invertebrates if the range of variation in densities among all reference sites was low, even if high spatial or temporal differences occurred within respective sites. Irwin (2002), however, cautioned that variability may not be the only or the most important factor in choosing variables or indicators: some metrics with low variability may not be responsive to impacts or central to the question at hand. Should we elect to follow Short's suggestion, key variables and indicators would be selected using the coefficient of variation (CV; standard deviation divided by the mean), with those having a CV exceeding 0.2 discarded. In this report, we conduct some preliminary analysis of this criteria for selecting key indicators and variables by assessing the biological relevance of indicators and variables displaying low and high variability.

Comparisons with LMER/BRIE data

Between 1985 and 1996, an extensive amount of data was collected on water quality parameters in Tomales Bay and, for slightly shorter periods (1987-1994), some of the larger subwatersheds such as Lagunitas and Walker Creeks. This data was placed on the LMER/BRIE website in Excel spreadsheet format (Smith and Hollibaugh 1997b). Because sampling was eventually conducted on multiple consecutive days (1-3 days) per sampling event approximately every two months, there is potential for temporal autocorrelation between values from consecutive sampling days. For the purposes of comparing data from this period with our data, data from the multiple consecutive sampling dates were averaged, and, then, data from the entire sampling period was averaged overall. Most of the nutrient data comes in units of *u*g/L. These data were converted to mg/L using molecular weights of the respective ions. Again, it should be noted that data in this report is expressed as ions (NO3- and PO4-) and not as elements of these ions (NO3- as N or PO4- as P).

Precipitation During Study Period and Correlations with Nutrients and Pathogens

Between 2002 and 2006, rainfall totals were generally at or above average for the coastal Marin area based on rainfall records. For use in analyzing laboratory parameter data, rainfall totals in the week (~5 days) prior to sampling events (except summer sampling events) were calculated, as well as cumulative rainfall totals for the Water Year to date (October – September; Table 3).

Precipitation data were not only used for general assessment, but also incorporated into regression/correlation analyses performed for certain nutrients and pathogen data to look at relationships between rainfall, streamflow, and concentrations and loading of pollutants. Because they involved censored data, these regression/correlation analyses were performed using survival/reliability statistical techniques that involved use of MLE estimates and associated Likelihood R analogs to the coefficient of determination (R^2) or the proportion of variability in the data accounted for by the proposed regression model.

TABLE 3. Precipitation Totals During Wet Season Sampling Events

	5 Days Prior to Event (in)	Cumulative for WY to date (in)
WY 2002		
2/27/02	0.03	16.65
4/24/02	0	21.1
WY 2003		
10/30/02	0	0
2/05/03	0.01	24.39
4/30/03	0.73	34.23
WY 2004		
10/30/03	0	0
1/29/04	0.93	20.05
4/30/04	0	31.03
5/06/04	0	31.03
WY 2005		
10/28/04	1.79	4.97
1/27/05	1.23	21.12
2/17/05	1.46	23.25
4/28/05	0.46	37.55
WY 2006		
11/03/05	0.24	1.32
11/08/05	0.93	2.25
2/09/06	0	33.81
4/12/06	3.83	54.73
4/27/06	0.02	55.59

Hydraulic Processes and Conditions in the Watershed and Project Area

The Project Area and the watershed in which it is located represent a mixture of tidal, freshwater creek or fluvial, and groundwater hydrologic sources (Figure 5). The zone of influence for each of these hydrologic influences shows considerable overlap within the Project Area, making it a very hydrologically dynamic and complex system. A more detailed description of each of these sources follows below.

The functionality of wetlands is integrally tied to the presence of hydrologic sources such as tides, fluvial or creek flow, and groundwater. The importance of hydrology not only relates to it being a source of water for wetlands, but to its properties and the work accomplished by water when it moves either through bi-directional flow of tides or the uni-directional flow of creeks and groundwater.

Tidal Surface Water

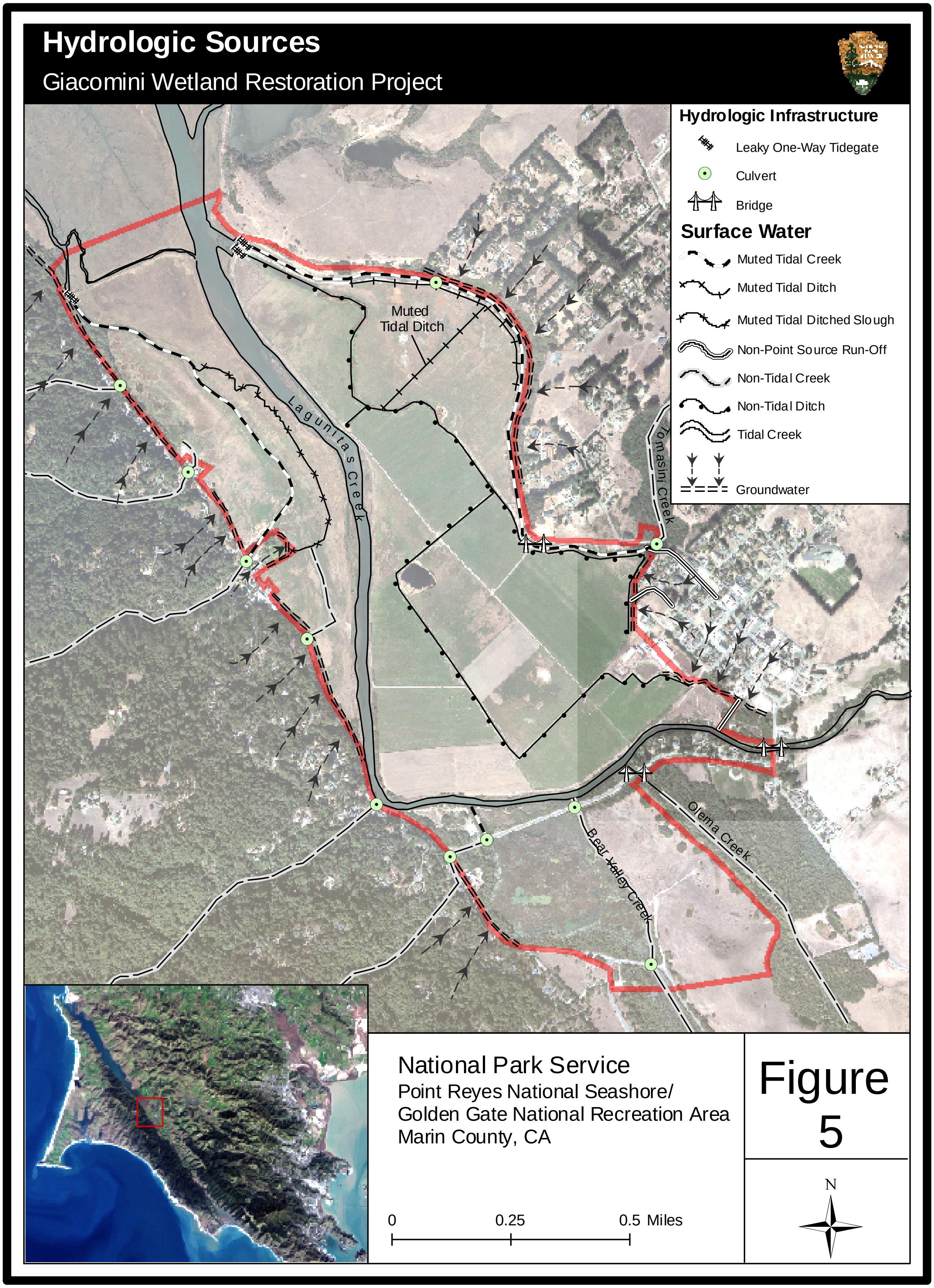
Tomales Bay

Tides represent a source of energy to estuaries that provides oxygen, sediment movement, and, to some degree, nutrients. Tomales Bay is a 10.8 square-mile shallow, tectonically caused (drowned fault valley) Mediterranean-type coastal estuary (Hollibaugh et al. 1988).

Tomales Bay has formed within the long, linear, submerged “rift” valley that has developed along the northwest-trending San Andreas Fault zone that defines the active tectonic boundary between the northwestward-moving Pacific plate and the continental North American plate. This movement of the Pacific and Continental Plates has produced striking differences in the geologic nature of the lands on the west and east sides of Tomales Bay. The eastern portion of the Tomales Bay watershed is dominated by the Franciscan formation (U.S. Soil Conservation Service 1985). West of Tomales Bay on the steeply sloped Inverness Ridge – and within most of the Seashore – granitic rock such as quartz-diorite and granodiorite dominate, forming the backbone of the Point Reyes Peninsula (USSCS 1985; Figure 6).

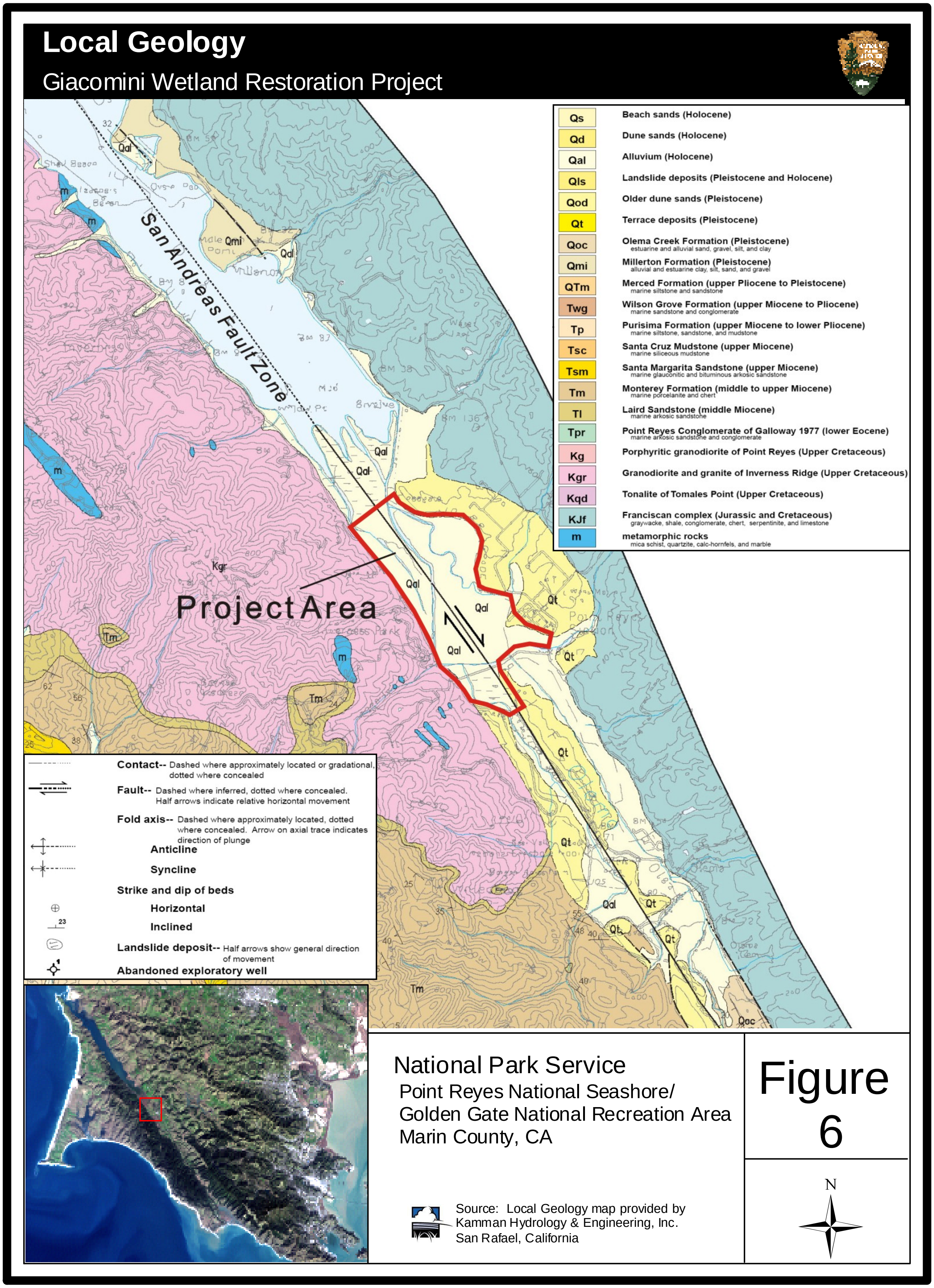
Tomales Bay looking from the ocean south towards the Project Area. Photo: Courtesy of Robert Campbell Aerial Photography.

The Bay was formed 15,000 to 5,000 years ago when it was inundated by rising sea levels from thawed ice at the close of the last ice age (Wahrhaftig and Wagner 1972). Through the millennia, tectonic uplift or subsidence associated with plate movement, combined with other influences such as glacial retreat, has shaped the northern California coastline, with oceanic influence alternately retreating or advancing into the valley. At one point, what is now known as the Pacific Ocean probably extended at least as far as Point Reyes Station and probably even further inland into the Olema Valley. These episodes are evident in the low-elevation coastal marine terraces that run along the eastern perimeter of Tomales Bay between the Bay and the Franciscan Complex hills. Currently, Tomales Bay is approximately 12 miles long and less than one mile wide (RWQCB 2001). The average depth of the bay is less than 20 feet (California Department of Health Services (DHS 1996; TBWC 2002). The Bay is believed to



Hydrologic Sources
Giacomini Wetland Restoration Project
Hydrologic Infrastructure
Leaky One-Way Tidegate
Culvert
Bridge
Surface Water
Muted Tidal Creek
Muted Tidal Ditch
Muted Tidal Ditched Slough
Non-Point Source Run-Off
Non-Tidal Creek
Non-Tidal Ditch
Tidal Creek
Groundwater
Muted Tidal Ditch
Lagunitas Creek
Tomasini Creek
Olema Creek
Bear Valley Creek
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0
0.25
0.5 Miles
N

Figure 5


Local Geology
Giacomini Wetland Restoration Project
San Andreas Fault Zone
Project Area
Qs Beach sands (Holocene)
Qd Dune sands (Holocene)
Qal Alluvium (Holocene)
Qls Landslide deposits (Pleistocene and Holocene)
Qod Older dune sands (Pleistocene)
Qt Terrace deposits (Pleistocene)
Qoc Olema Creek Formation (Pleistocene) estuarine and alluvial sand, gravel, silt, and clay
Qmi Millerton Formation (Pleistocene) alluvial and estuarine clay, silt, sand, and gravel
QTm Merced Formation (upper Pliocene to Pleistocene) marine siltstone and sandstone
Twg Wilson Grove Formation (upper Miocene to Pliocene) marine sandstone and conglomerate
Tp Purisima Formation (upper Miocene to lower Pliocene) marine siltstone, sandstone, and mudstone
Tsc Santa Cruz Mudstone (upper Miocene) marine siliceous mudstone
Tsm Santa Margarita Sandstone (upper Miocene) marine glauconitic and bituminous arkosic sandstone
Tm Monterey Formation (middle to upper Miocene) marine porcelanite and chert
Tl Laird Sandstone (middle Miocene) marine arkosic sandstone
Tpr Point Reyes Conglomerate of Galloway 1977 (lower Eocene) marine arkosic sandstone and conglomerate
Kg Porphyritic granodiorite of Point Reyes (Upper Cretaceous)
Kgr Granodiorite and granite of Inverness Ridge (Upper Cretaceous)
Kqd Tonalite of Tomales Point (Upper Cretaceous)
KJf Franciscan complex (Jurassic and Cretaceous) graywacke, shale, conglomerate, chert, serpentinite, and limestone
m metamorphic rocks mica schist, quartzite, calc-hornfels, and marble
Contact-- Dashed where approximately located or gradational, dotted where concealed
Fault-- Dashed where inferred, dotted where concealed. Half arrows indicate relative horizontal movement
Fold axis-- Dashed where approximately located, dotted where concealed. Arrow on axial trace indicates direction of plunge
Anticline
Syncline
Strike and dip of beds
Horizontal
Inclined
Landslide deposit-- Half arrows show general direction of movement
Abandoned exploratory well
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
Source: Local Geology map provided by
Kamman Hydrology & Engineering, Inc.
San Rafael, California
Figure 6
N

be much shallower than it once was due to rapid sedimentation.

Tomales Bay is a microtidal estuary, which means that the differences between high and low tide are not as pronounced as in other regions of the world such as Alaska's Bay of Fundy, although mesotidal-type tides occur during extreme spring tides in the winter (Harcourt-Baldwin 2003). Within Tomales Bay, the average annual maximum tidal swing is 8.2 feet, with a difference between mean high and mean low tide of about 3.61 feet (KHE 2006a). Tides in Tomales Bay are mixed semi-diurnal, resulting in a daily tidal regime with two flood or "high water" tides and two neap or "low water" tides of varying height or magnitude (KHE 2006a). Relative to the Pacific Ocean, tides are attenuated somewhat in Tomales Bay, with the height of the high tide being generally 0.6 feet less than that at the Golden Gate (KHE 2006a). Tidal prism -- or the volume of water that is exchanged during the typical half-day tide cycle -- has currently been estimated at 990.4 million cubic feet in Tomales Bay, compared to 1.8 billion cubic feet for south San Francisco Bay (CH2M Hill 1990; Watson et al. 1998) and 70.6 billion cubic feet for the entirety of the San Francisco Bay (Barnard et. al. 2006).

Project Area - Lagunitas Creek and Undiked Marsh

Relative to the mouth of Tomales Bay, there is only attenuation of tidal range in the southern or innermost portions of this long, narrow estuary. The closest NOAA tide gauge to the Project Area is the former gauge at Inverness, which was operated from 1960-1978. Tidal datums for this gauge are shown in Table 4.

TABLE 4. Tidal Datums for NOAA Tide Gauge, Tomales Bay at Inverness Tidal Epoch: 1960-78

	MLLW Datum (feet)	NAVD88 Datum (feet)
MHHW	5.34	5.83
MHW	4.64	5.13
MTL	2.76	3.25
NGVD29	2.15	2.64
MLW	0.88	1.37
MLLW	0.00	0.49

A comparison of water levels between the nearest NOAA tidal gauging station in Tomales Bay, Inverness Park , and the portion of Lagunitas Creek within the Project Area indicate that, while the stream gradient is relatively flat through the Project Area, the lower range of tidal amplitude becomes progressively more truncated as distance from Tomales Bay increases (KHE 2006a; Appendices B2, B11).

In terms of the upper end of the tidal range, there is somewhat conflicting information. Based on results from the White House Pool reach, there would appear to be only a very small truncation of high tides or the upper part of the tidal range, with high water levels in the portion of Lagunitas Creek within the Project Area relatively similar to those predicted at Inverness (KHE 2006a). However, in summer 2008, high tides in the reach downstream of White House Pool exceeded predicted Inverness tidal elevations by as much as 0.2 to 0.8 feet (M. Cederborg, Hanford ARC, *pers. comm.*). In this case, tides were actually amplified substantially relative to predicted conditions, potentially due to winds that were stronger than normal in this part of the estuary: this reach is oriented north-south and would receive the full brunt of increased winds. In general, then, MLW and MLLW elevations for the portion of Lagunitas Creek in the Project Area are considerably higher than those of the predicted tides at Inverness, with high tide datums either equivalent or slightly higher depending on the creek reach.

Typically, at MHW, tidal waters would begin to flood onto marshplains. Downstream of the Giacomini Ranch, tidal waters from Lagunitas Creek (and the undiked portion of Fish Hatchery Creek) overflow frequently onto the undiked marshlands owned by the State Lands Commission. However, in the reach of Lagunitas Creek within the Project Area, the Giacomini Ranch levees

Tomales Bay, looking north, with Project Area in foreground. Courtesy: Robert Campbell Aerial Photography

preclude tidal inundation of its historic marshplains. In addition, past deposition of fill in the Green Bridge County Park and White House Pool County Park have also largely eliminated the potential for tidal influence at higher tides in these historic marsh areas. A list of infrastructure and management practices that negatively affect both tidal and fluvial or freshwater hydrologic processes can be found in Table 5. Between Tomales Bay and White House Pool, Lagunitas Creek is wide and relatively uniform in shallowness, although deeper portions of the channel or thalwegs do occur.

Upstream of the the Green Bridge, Lagunitas Creek is primarily a fluvial system, although it is influenced by tides (Appendices B3, D2, D3.2-3.4, 4.1). Tidal influence has been reputed to extend a mile upstream of the Green Bridge. At the Downey Well located downstream of the USGS stream gage station, tides influence water level, but do not appear to affect salinities, even during low-flow summer months (Appendix D3.1-3.4). This area constitutes a freshwater tidal portion of the system.

Project Area - Giacomini Ranch

Tomasini Creek

Tomasini Creek is the primary tributary adjacent to the East Pasture of the Giacomini Ranch (Figure 5). As with Fish Hatchery Creek, the tidegate and flashboard dam structure on Tomasini Creek at its outlet to Lagunitas Creek at the north levee has been less than effective in eliminating tidal exchange due to lack of maintenance (Table 5). The gate-dam structure truncates low tides or controls the extent of drainage during low tides to approximately 2.0-feet NAVD88, at least 1- to 2 feet above the deepest portions of the channel (KHE 2006a, Appendices B4-B6).

However, similar to Lagunitas Creek, there has still been substantial tidal exchange over the upper portion of the tidal range, with only minor reduction of the peak flood-tide water levels of less than 0.5-feet (KHE 2006a, Appendices B4-B6). Peak high tides within the diked portion of the former Tomasini Creek channel reach 7 feet NAVD88 (KHE 2006a, Appendices B4-B6). On some of these high tides, waters from the former Tomasini Creek channel flood into the East Pasture through a culvert in the Tomasini Creek berm into a borrow ditch that runs along the berm's western side (L. Parsons, NPS, *pers. obs*.). Monitoring of water levels near the Giacomini Hunt Lodge in 2004 showed tidally driven fluctuations in water level when

Flashboard dam and tidegate structure on former Tomasini Creek channel

TABLE 5. HYDROLOGIC INFRASTRUCTURE AND MANAGEMENT PRACTICES IMPACTING IMPEDIMENT SURFACE FRESHWATER HYDROLOGIC PROCESSES IN THE PROJECT AREA AND UPSTREAM PORTIONS OF THE WATERSHED

Note: For larger creeks, only impediments on mainstem or central portions of creek are listed. Impediments are listed from upstream to downstream. Multiple similar impediments in the same area of watershed are sometimes denoted by total number of impediments in parentheses, for example (2).

Creek		Project Area: Hydrologic Infrastructure/ Management Impediment: Approximate Location		Upper Watershed: Hydrologic Infrastructure/ Management Impediment: Approximate Location
Mainstem Lagunitas Creek	1.	*Bridge*: Green Bridge at State Route 1	1.	*Dams*: Lagunitas, Phoenix, Alpine, Kent, Nicasio (5)
	2.	*Levees*: Past Fill Placement on Green Bridge County Park, Levee Road, East Pasture Levee and Creek Bank Fill, Past Fill Placement on White House Pool County Park, West Pasture Levee (5)	2.	*Levees*: Sir Francis Drake Blvd and Historic Railroad Grade (2)
	3.	*Management*: Giacomini Cattle Crossing	3.	*Floodplain Development*: Samuel P. Taylor State Park
	4.	*Management*: Infrequent Discharge of Ditch Water to Creek	4.	*Levee*: Platform Bridge Road
	5.	*Management*: Levee Maintenance – East Pasture	5.	*Bridges*: SFD at Platform and Pt. Reyes-Petaluma Road (2)
	6.	*Management*: Levee Maintenance – West Pasture	6.	*Floodplain Development*: Sand Processing Plant
			7.	*Water Diversion*: Gallagher, Downey Well, and Coast Guard Wells (4)
			8.	*Water Diversion*: Genazzi Ranch
			9.	*Management*: Cattle in creek at Genazzi Ranch
Mainstem Bear Valley Creek	1.	*Culverts*: Bear Valley Road, Levee Road, Former west outlet – Bear Valley Creek, Silver Hills drainage (4)	1.	*Levees*: Bear Valley Trail, Bear Valley Road (see Project Area), Limantour Road, Past Fill Placement on west side of creek (4)
	2.	*Levees*: Bear Valley Road, Olema Marsh parking, Past Fill Placement in north portion of Olema Marsh near Levee Road, Levee Road, Past Fill Placement in White House Pool County Park (5)	2.	*Culverts*: Bear Valley Trail, Rift Zone Trail, Vendanta Ranch, Red Barn Road, Visitor Center's Road (5)
	3.	*Management*: Dredge former west outlet at Bear Valley Creek	3.	*Water Diversion*: NMWD right, but no use
	4.	*Bridge*: Footbridge in White House Pool County Park	4.	*Floodplain Development*: Seashore Headquarters Complex
	5.	*Floodplain Development*: WHP park	5.	*Creek Realignment*: Maintenance Yard
			6.	*Floodplain Development*: Maintenance Yard
			7.	*Management*: Dredged below Maintenance Yard
Tomasini Creek	1.	*Water Diversions*: at north end near outlet to Tomales Bay	1.	*Water Diversion*s (2)
	2.	*Culvert*: Mesa Road	2.	*Culvert*: Road crossing on tributary (3)
	3.	*Levees*: Mesa Road, Tomasini Creek berm, Past Fill Placement on North Side at RR Grade	3.	*Levee*: Ranch Road
	4.	*Bridge*: at Hunt Lodge	4.	*Dams*: West Marin Landfill Ponds (2), Livestock ponds (2)
	5.	*Management*: Levee Maintenance	5.	*Culvert*: State Route 1 crossing
	6.	*Tidegate/Culvert*: at East Pasture North Levee		
Fish Hatchery Creek	1.	*Culvert*: Sir Francis Drake	1.	*Water Right Diversions* (3)
	2.	*Floodplain Development*: Private Residence	2.	*Culverts*: Vallejo Avenue road crossings of mainstem and tributary (5)
	3.	*Management*: Dredging downstream of SFD	3.	*Levee*: Vallejo Avenue
	4.	*Water Diversion*: Giacomini Ranch	4.	*Floodplain Development*: Homes (3)
	5.	*Management*: Maintain Creek Crossing	5.	*Bridge*: Driveway crossing of mainstem creek
	6.	*Tidegate*/*Culvert*: at West Pasture North Levee	6.	*Floodplain Development*: Commercial and residential development near Sir Francis Drake Boulevard (15)
	7.	*Management*: Cattle in creek	7.	
1906 Drainage	1.	*Culvert*: San Francis Drake	1.	*Culvert*: Private Road Crossing
	2.	*Realigned Channel*: Private Residence	2.	*Levee*: Private Road
	3.	*Floodplain Development*: Private Residences (2)	3.	*Floodplain Development*: Private residences (2)
	4.	*Culvert*: into West Pasture	4.	*Realigned Channel*: Ditched on north side of Sir Francis Drake
	5.	*Realigned Channel*: West Pasture		
	6.	*Management*: Dredging downstream of residence		
	7.	*Floodplain Development*: Dredge spoil disposal area		
	8.	*Management*: Cattle in creek		

high tide water levels exceed the base level of 4.5-feet NAVD88 (KHE 2006a, Appendix B5-B6).

Fish Hatchery Creek

Fish Hatchery Creek is the primary tributary within the West Pasture of the Giacomini Ranch (Figure 5). The Giacominis installed a one-way tidegate in the West Pasture North Levee near Sir Francis Drake Boulevard, however, at some point, this gate began to malfunction and allow some tidal waters into the pasture (Table 5). Muted tidal flushing in the West Pasture resulted in reduced tidal prism, with prism prior to restoration estimated at 8.1 acre-feet at MHW based on hydrologic modeling (KHE 2006a).

Beyond the Giacomini Ranch, Fish Hatchery Creek continues to run along the western perimeter of Tomales Bay until it reaches the Bay itself, bordered by the so-called Undiked Marsh owned by State Lands Commission to the east. As with Lagunitas Creek, gravel bars within the undiked portion of Fish Hatchery Creek also appear to act as small "weirs," controlling the lower tidal range in the southern sections of the creek (KHE 2006a). Just downstream of the Giacomini Ranch, low tides are controlled at approximately 3.0-feet NAVD88 by these bars (KHE 2006a).

Former tidegate on Fish Hatchery Creek showing inflow during incoming tide

The tidegates on Fish Hatchery Creek in the West Pasture reduced amplitude of both the low and high tides (KHE 2006a; Appendices B7-B8). The lowest water levels measured just inside the West Pasture in Fish Hatchery Creek were 3.25 feet NAVD88 (KHE 2006a). This attenuation continued as the stream gradient increased, with the lowest water levels measured on a tributary to Fish Hatchery Creek, the West Pasture Old Slough, at 4.0 feet NAVD88 midway through the West Pasture (KHE 2006a). The tidegates also truncated the upper portion of the tidal range, which peaked at approximately 5.25 feet NAVD88 (KHE 2006a, Appendices B7-B8). The upper portion of the tidal range typically was not reached unless tides in undiked areas exceeded 6.25 to 6.5 feet NAVD88 (KHE 2006a).

In 2003, the tidegates on Fish Hatchery collapsed and began to erode the levee. During this period, the malfunctioning appeared to allow more even tidal exchange than occurred previously, including into large portions of the West Pasture Freshwater Marsh (See more detailed discussion under *Circulation Patterns and Salinity in the Watershed and Project Area- Project Area – West Pasture and Freshwater Marsh*). After the tidegates were replaced in the fall of 2003, tidal exchange decreased again (KHE 2006a).

Drainage Ditches and Internal Sloughs

Tidal influence within the West and East Pastures was significantly minimized through diking and tidegates (Table 5). However, leakiness of the Fish Hatchery Creek tidegate enabled at least irregular tidal surface overbank flooding of the northern portion of the West Pasture and the northern and central portions of the West Pasture freshwater marsh, as well as depressional features in the central portion of the pasture that appeared to be remnant tidal channels.

West Pasture: In the West Pasture, saltwater not only flowed south up established channels such as the diked portion of Fish Hatchery Creek and the West Pasture Old Slough, but, during the highest tides, overbank flooded into marsh and pasture areas, particularly at the northern, lowest ends of the West Pasture. During these high tide events, saltwater also flowed into a large freshwater marsh at the northern end of the West Pasture. Based on water level data collected within the marsh, tidal influence appeared to occur in the marsh when tides in the diked area equal or exceed 5.25 feet NAVD88, the maximum tidal range currently permitted by the modified tidegate at the North Levee (KHE 2006a; Appendices B7-B8). As noted earlier, these tidal events were relatively infrequent and probably only occurred when salinities in undiked areas exceeded 6.25 to 6.5 feet NAVD88 (KHE 2006a). These extreme high tides occur sporadically throughout the year, but are highest between December and March, when high water levels from high tides are often compounded by high volumes of freshwater flow from rainfall.

East Pasture: The leakiness of the Tomasini Creek tidegate also created some tidal influence within the diked pasture, albeit more indirectly. On some high tides, waters from Tomasini Creek flooded into the East Pasture through a culvert in the Tomasini Creek berm into a borrow ditch that runs along the berm's western side (NPS staff, *pers. obs*.): these waters often overspilled onto the pasture and created essentially a sparsely vegetated, saline flat that was commonly used during the winter and spring by shorebirds and waterfowl (Shallow Shorebird Area). Some of these waters flowed into the pasture's drainage ditch system, which was typically used for storing freshwater for irrigating the pastures during the summer. Otherwise, as with the southern portions of the West Pasture, direct tidal influence may have been limited to large storm events that occur during extreme high tides (e.g., 1982 and 2006) that caused overbank flooding of levees into the pastures. Because of the difficulty in estimating waters that enter the East Pasture from Tomasini Creek episodically through this culvert, the very limited tidal prism that does exist currently could not be accurately estimated.

Limited areas of both the East and West Pasture that immediately border Lagunitas Creek also appeared to have some very indirect tidal influence through hydraulic connectivity of the pastures' groundwater table with the rise and fall of tides in Lagunitas Creek (See *Groundwater-Project Area-East Pasture* for more detailed discussion).

Project Area - Olema Marsh and Bear Valley Creek

Olema Marsh once represented an integrated tidal marsh complex with the Giacomini Ranch (Figure 8). Tidal influence was believed to extend as far upstream on Bear Valley Creek as the park's administrative headquarters during extreme tide conditions. Construction of the levee across the mouth of Olema Marsh in 1892 for construction of Sir Francis Drake Boulevard or Levee Road hydrologically disconnected the marsh from the Giacomini Ranch (Table 5).

While the flow path of Bear Valley Creek through marsh has not remained constant in the intervening years, currently, the box culvert on the downstream end at Levee Road just before the creek's confluence with Lagunitas Creek acts as a grade control structure that reduces the range of tidal exchange into the marsh (KHE 2006a; Figure 5; Table 5). The culvert invert limits tidal exchange to those exceeding 4.5-feet NAVD88 (KHE 2006a). As with many of the other creeks, the culvert does not appear to attenuate or only minimally attenuates the upper portion of the tidal range (KHE 2006a). While the range of tides remains similar, breaching of a small portion of a berm that constrains outflow from these culverts in 2008 may introduce or increase tidal influence within the marsh itself: previously, this berm effectively limited tidal influence to the small section of channel directly flowing into the channel (see *Fluvial Surface Water and Fresh Water – Project Area – Bear Valley Creek* for more discussion).

Olema Marsh looking from eastern edge near Bear Valley Creek towards Inverness Ridge

Prior to the 1998 flood, Bear Valley Creek apparently flowed out of a culvert underneath Levee Road that is on the western perimeter of Olema Marsh near the White House Pool County Park (Figure 5). Currently, this channel is disconnected from the marsh through a build-up of sediment between the marsh and the western culvert, and the culvert now only contains flows from the Silver Hills drainage, which has been redirected into a ditch on the south side of Levee Road. Because sediment deposition within the culvert has raised the elevation of its "bottom," tidal influence in the Silver Hills drainage channel would be limited to some of the highest high tide events, exceeding 6.9 ft NAVD88 (~ 7 ft MLLW; G. Kamman, KHE, *pers. comm.*).

Reference Areas

Walker Creek

As with Giacomini Ranch and the undiked marsh to the north, Walker Creek Marsh is also a deltaic land feature formed at the mouth of Walker Creek into Tomales Bay. Most of this marsh is not diked and, therefore, is fully tidal, although a large alluvial levee that parallels Walker Creek does preclude tidal overflow from the creek onto the marshplain except for high tide events. However, the marsh is influenced by the full range of low and high tides through a series of small and large tidal channels that extend from the Bay into the interior of the marsh. There are a few diked areas along the marsh's southern perimeter that receive either slightly muted or no tidal influence. These areas were leveed off by construction of the berm for the railroad that once ran along the eastern perimeter of Tomales Bay.

Historically, tidal influence extended upstream as far as the town of Tomales on Keys Creek (Prunuske Chatham 2001). The only map of Tomales Bay between 1856 and 1916 to show any indication of delta formation at the mouth of Walker Creek is an 1863 U.S. Coast Guard survey map that denotes measurements of depth in the bay. On this map, the mouth of Walker Creek appears to be subtidal, but its bottom waters are shallower by 2 to 20 feet than the waters in the bay itself (Livingston 1989 *in* Prunuske Chatham 2001). Either the delta was not fully formed during this period, or that level of detail was omitted from most maps because it was not of interest to the surveyors. The earliest depictions of vegetated marsh and mud flats located for this report appear on the 1921 U.S. Coast Guard survey map. The extent of the delta depicted in a 1952 USGS map closely resembles the appearance of the delta in current aerial photos. This suggests a rapid rate of marsh development similar to that of the Project Area, caused by a pulse in sedimentation down the Walker Creek watershed in the early 1900s.

Limantour Marsh

While Walker Creek Marsh and the Project Area/Undiked Marsh were relatively young marshes, Limantour Marsh is even younger. Limantour Marsh occurs at the distal end of the Limantour Estero system. Tides reach the marsh through Limantour Estero, which shares its mouth to the Pacific Ocean with Drake's Estero, by moving along the landward edge of a large sandspit that separates Limantour Estero from the Pacific Ocean. During 1860, the area where the marsh is currently located was once largely subtidal and intertidal mudflat area, with a smaller amount of fringing marsh and marsh flats that were apparently created from alluvium deposited episodically by Muddy Hollow Creek (Northwest Hydraulic Consultants 2004). This condition persisted into the 1950s. Aerial photographs of the marsh from 1952 reveal "braided, fan-like formations, with little or no vegetative cover" (Northwest Hydraulic Consultants 2004).

However, in the early 1960s, the creek and upper tidal channels were dammed to create a pond for the recreational use of a proposed residential development (Northwest Hydraulic Consultants 2004). This restricted the upper extent of tidal reach by as much as 1,500 feet. At this point, significant vegetation establishment began to occur outboard of the dam, with marsh establishment visible already by 1963. Following dam construction, the marsh became relatively stable morphologically, although it burned as part of the Mt. Vision Fire in 1995. In 2008, the lower dam and pond adjacent to the marsh were removed as part of restoration project, thereby reestablishing more natural fluvial and tidal hydrologic processes. This project will increase tidal prism and undoubtedly have a broad range of physical, chemical, and biological effects on Limantour Marsh, both dramatic and subtle, including potentially reestablishing use of the marsh by salmon fisheries.

During the study period, tides from the mouth moved up Limantour Estero into the large main tidal channel at which point they flow into many of smaller channels within the marsh. There is no information available on attenuation of tidal range between the former tide gauge at Point Reyes/Drakes Bay and Limantour Marsh (Northwest Hydraulic Consultants 2004).

Fluvial Surface Water or Fresh Water

Lagunitas Creek

The 83.1-square-mile Lagunitas Creek watershed is the largest watershed in Tomales Bay (KHE 2006a). Two-thirds of the freshwater inflow to Tomales Bay comes from Lagunitas Creek and its tributaries (Fischer et al. 1996). Between 1987 and 1993, Lagunitas Creek flow averaged 1.307 billion ft^3/yr (37 million m^3/yr; Smith et al. 1996). Its tributaries, Olema Creek, Bear Valley Creek, and Haggerty Gulch, are located, from east to west, respectively, along the southern margin of the Project Area. Lagunitas Creek drains the Coast Range mountains located east and southeast of the Project Area (Figures 5-6). The watershed is underlain by a variety of Franciscan Complex rocks, mostly greywacke and metavolcanics (Figure 6).

Lagunitas Creek looking east towards East Pasture and Black Mountain

Lagunitas Creek is a perennial system. The stream gradient of the creek within the Project Area is relatively flat. Other than the large bend to the west at the south end of the Project Area, its course is relatively straight and lacks sinuosity, as is common with fluvial-dominated deltaic systems. Considerable debate centers around the reason for the large, almost unnatural 90 degree bend in Lagunitas Creek near White House Pool: it may be due to the alluvial fan present near the Giacomini Ranch dairy or related somehow to the fault. Prior to restoration, the creek was strongly to moderately entrenched in the Project Area due to presence of the Giacomini Ranch levees and steep creek banks on the south side of Lagunitas Creek along Levee Road. East Pasture levees upstream of the old summer dam location ranged from 14- to 17-feet NAVD88 in height and dropped to as low as 8- 10 feet NAVD88 at their northern end (KHE 2006a). Around White House Pool and the location of the old summer dam, the levees had apparently been removed at some point in the past, and pastures elevations were essentially similar to the adjacent creek bank -- about 11- to 12 feet NAVD88 in elevation (KHE 2006a).

Much of the area between Levee Road and Lagunitas Creek was filled since construction of the original embankment for what is now Levee Road and is only slightly lower in elevation than the former East Pasture levees (~10-11 feet NAVD88). Levee Road itself ranges from 13- to 15 feet NAVD88 in the residential area. The West Pasture levee ranges from 12-feet at the south end to 10-feet at its northern end (KHE 2006a). Beyond the Giacomini Ranch, Lagunitas Creek has formed natural alluvial levees along its creek bank that are considerably lower in elevation (~ 7.1 feet NAVD88; PWA et al. 1993). Despite these geomorphic constraints, Lagunitas Creek still overtopped the levees and creek banks with varying frequency even prior to restoration. These flows play an important role in sediment delivery and transport through the Project Area, as well as influencing channel, floodplain, and delta form (KHE 2006a).

While flow may be perennial, Lagunitas and other creeks still have flow patterns characteristic of systems in Mediterranean climates. Creek flow, measured at USGS gauging station near Pt. Reyes Station, averages 357 cubic feet per second (cfs) in February to as low 5.5 cfs in September (USGS 2004). During the severe drought of 1976-77, average monthly summer flow rates dropped to as low as 0.45 cfs (KHE 2006a). Flow is now regulated by the State Water Resources Control Board (SWRCB) through Decision 95-17, which has mandated minimum creek base flow at Samuel P. Taylor State park gage during the summer from storage reservoir releases of 8 cfs during normal rainfall years and 6 cfs during dry years. In November, minimum flow requirements increase to 20 and range between 16 to 25 cfs between November and April 30.

Lagunitas Creek inflow to the Project Area has been significantly altered by historic water development in the basin (KHE 2006a). Approximately 70 percent of the waters from this subwatershed are controlled by dams (PWA et al. 1993). A list of infrastructure and management practices affecting fluvial or freshwater creek processes in Project Area subwatersheds can be found in Table 5. Water development was initiated in the Lagunitas Creek watershed with the construction of Lake Lagunitas in 1873 (350 acre-feet [AF] of capacity). This was followed by damming to form Phoenix Lake in 1905 (411 AF of capacity). Beginning in 1875, several water companies were created and provided water to the rural communities of Point Reyes Station, Inverness Park, and Olema (SWRCB 1995). Starting in 1955, flow from about 40 percent of the watershed area started entering six water catchment reservoirs (KHE 2006a). Reservoir construction and expansion continued through 1982 with the following facilities:

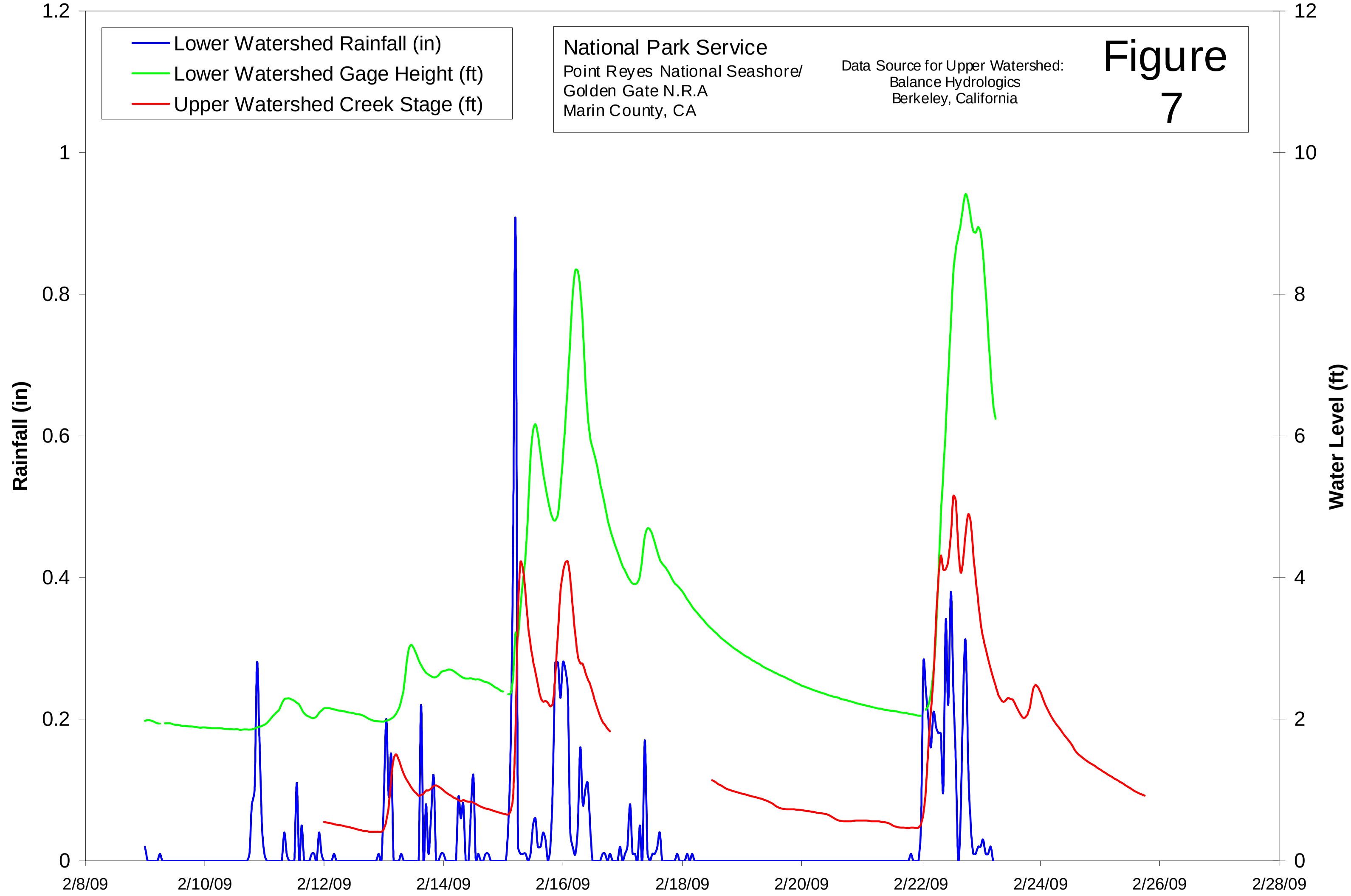
- ***Alpine Lake*** (1918) with a capacity of 3069 AF;
- ***Alpine Lake expansion*** to 4600 AF in 1924;
- ***Alpine Lake expansion*** to 8900 AF in 1941;
- ***Kent Lake*** (1953) with a capacity of 16,050 AF;
- ***Nicasio Reservoir*** (1960) with a capacity of 22,430 AF; and
- ***Kent Lake expansion*** to 32,900 AF in 1982.

The effect of these dams on hydrogeomorphic processes of Lagunitas Creek has not been specifically studied. However, in arid portions of the country, dams operated for water supply and/or flood control have resulted in a reduction in the frequency and strength of peak instantaneous flows and an increase in the duration of bankfull or ordinary high water flows during or directly after storms. In addition, many dams result in a drastic reduction in summer low flows and gravel/sediment recruitment (Fenner et al. 1985; Stromberg and Patten 1990; Johnson 1992; 1994; 1998; Friedman et al. 1998). In additions, dams and levees often reduce the lateral migration rate of meandering systems (Johnson et al. 1971; Bradley and Smith. 1986; Rood and Mahoney 1990; Friedman et al. 1998).

Recent studies suggest that the dams may also be affecting the frequency and intensity of peak flows within the creek (Stillwater Sciences 2004). Within the Lagunitas Creek watershed, the dams are operated specifically for water supply. Except for the mandated flow releases (SWRCB Order 95-17), the reservoirs are operated to fill and then spill. In general, this means that drainage area during earlier flood events is limited to the undammed, lower portions of the watershed. While still lower than if it were unregulated, the volume of streamflow for areas below dams increases once soils in surrounding watershed are satured, and run-off volumes climb: Figure 7 shows streamflow in Lagunitas Creek and tributaries following two successive rainfall events in 2009, with streamflow volume increasing much more rapidly during the second event, when soils were becoming saturated. Once the reservoirs are full, they begin to convey a portion of the peak flows generated by the upper portion of the watershed into the lower portions. The effect of the dams on flooding is specifically tied to the timing of the storm event. If the event

Lagunitas Creek Flow vs Rainfall for Two Weeks in February, 2009

Giacomini Wetland Restoration Project



occurs early in the season, when reservoirs are filling, flooding would be dramatically reduced. If the event occurs after the reservoirs are full, the dams would not dramatically change flooding scenarios. During dry years, the dams reduce the overall level of downstream flooding through increased reservoir retention of flood flows.

Former Lagunitas Creek West Pasture levees, looking south

In the Project Area, Lagunitas Creek was disconnected from its floodplains by the 8- to 17-foot levees that were constructed along its perimeter, which created a strongly to moderately entrenched creek along this reach and reduced the ability of the creek to connect with its floodplain during flood events. During 2-year flood events -- or floods of a magnitude that occur, on average, every 2 years or some recurrence interval greater than that – levees were high enough to preclude the East and West Pastures from being flooded by Lagunitas Creek. During 2-year events, then, almost all of Lagunitas Creek flood flows remained in the channel prior to restoration, greatly increasing flood stage or the vertical height of flood flows. Hydraulic modeling suggested that, under a 2-year event, peak flood flows in the portion of Lagunitas Creek in the Project Area could have reached as high as 8.2 feet, because of the lack of floodplain storage (KHE 2006a). The cumulative volume of water that could have moved through the Project Area in Lagunitas Creek under a 2-year event totaled approximately 437.8 million cubic feet of water based on hydraulic modeling estimates (KHE 2006a).

Despite levees, overbank flooding did periodically occur (KHE 2006a). During flood events such as these in which overtopping occurred, water levels within Lagunitas Creek build in vertical height or stage until they exceeded the height of the levees, at which point they overtopped and flooded into the East and West Pastures. Hydraulic modeling indicated that the East Pasture creek bank upstream of White House Pool near the old summer dam location was overtopped at its lowest point by approximately a 3.5-year flood or greater (KHE 2006a). This was the point where the Giacominis had removed the levee. Upstream of this location, the levee resumed, and the crest height ranged from 14- to 17-feet, with overbank flood recurrence intervals correspondingly increasing in this area to between 50- and 100-year storm events (KHE 2006a). Conversely, the Levee Road Lagunitas Creek bank to the south flooded, on average, during 3-year or greater flood flows (KHE 2006a). These results suggested that the height of the Giacomini Ranch East Pasture levee and creek bank effectively placed higher flood pressure on Levee Road and the 15- to 20 homes built along the creek's edge (KHE 2006a).

Downstream of White House Pool, flood frequency dropped, probably because the creek widens, thereby decreasing stage height or height of flood flows relative to the narrow creek section upstream of White House Pool for floods with the same frequency. While the East Pasture levee downstream of the cattle crossing location was lower in elevation than the one near the old summer dam, flood flows only overtopped the levee in this area during a 7-year event (KHE 2006a). The West Pasture levee was also lower in elevation than the East Pasture one, ranging from only 10- to 12-feet high, and, yet, the West Pasture was only flooded by Lagunitas Creek when flood events are quite large (≥12.5-year flood recurrence interval; KHE 2006a).

During 100-year events, flood stage or vertical height of flood flows in Lagunitas Creek prior to restoration was only slightly higher (~ 12.5 feet) than under a 2-year event (8.2 feet), because flood flows were being shunted into the East and West Pastures, thereby relieving flood pressure in the creek itself (KHE 2006a). From modeling 100-year flows, it is apparent that the West

Pasture can absorb only a fraction of the floodwaters that move through the East Pasture (~3.2 percent) and Lagunitas Creek (~1.4 percent) probably due to the generally higher elevations in this pasture (KHE 2006a).

As with many other river and creek systems, the effect of damming and levees on the watershed has been compounded by other hydrologic alterations, including past mining of the floodplain terrace for sand (> 2 stream miles upstream from Project Area) and downstream appropriative and riparian water rights stream diversions by property owners. The Giacominis undertook their own water development for the purpose of irrigating pastures. The following summary is excerpted from a SWRCB water rights hearing report for Lagunitas Creek (1995):

> *"Giacomini…graded and leveled the land, and used water from Lagunitas Creek to leach the salt out of the soil. Giacomini drilled two wells on the southwest portion of the property to obtain water; however, both wells produced water that was too brackish for irrigation. Giacomini then attempted to divert water directly from Lagunitas Creek at the most upstream location adjacent to his property; however, the tidal influence in Lagunitas Creek caused the water to become too salty about May, when the stream flow diminished. Since the mid-1940's, Giacomini has constructed an earthen dam in the creek to prevent saltwater intrusion and to provide freshwater for irrigation."*

The Giacominis diverted water from Lagunitas Creek under claim of a riparian water right (KHE 2006a). An appropriative water right license was also issued by the SWRCB in 1950. The riparian right lays claim to a maximum pumping capacity of 350 cfs year-round. The appropriated right is for 2.67-cfs between May 1 and October 1. In addition to maintaining a freshwater pool for diversion, the Giacomini summer dam ultimately ended up benefiting NMWD by preventing salt water from moving upstream of the Green Bridge during the summer and fall: NMWD constructed groundwater wells for municipal water supply directly upstream of Green Bridge in 1970. The summer dam was historically approximately 100-feet long, 10-feet high, and 60-feet wide at the base. It created a pond that was about 7-feet deep and extended about 1.75-miles upstream, inundating approximately 17 acres (SWRCB 1995). As part of SWRCB Decision 95-17, construction of the dam at this location ended in 1997.

After 1997, the Giacominis received irrigation water from the NMWD "Downey" well located approximately 0.9-miles upstream of Green Bridge (Table 8). While the Giacominis continued to manage approximately 2 cfs as part of the ranch's appropriative water right, the irrigation contract committed NMWD to delivery of 1.23 cfs to the Giacominis, but actual delivery was typically closer to 1 cfs (C. DeGabriele, NMWD, *pers. comm*.).   With turning over of the Giacomini Ranch to the Park Service in 2007, irrigation of the pastures ceased, although the contract with NMWD did not terminate until July 1, 2008. Following closure of the ranch, management of the appropriative water right for 2.00 cfs reverted to the Park Service, which intends to turn around and re-designate it as being for beneficial instream uses that will benefit salmonids and other aquatic organisms. The remaining 0.67 cfs of the Giacomini's original water right was purchased from the Giacominis by NMWD in the late 1990s.

Olema Creek

Only the mouth of Olema Creek falls within the Project Area, but a short description is provided, because of the creek's size and proximity to the Project Area. It flows directly into Lagunitas Creek just southeast of the Giacomini Ranch old summer dam location. The Olema Creek watershed is an elongated 14.7-square mile drainage basin occupying the San Andreas Fault zone immediately south of the Project Area (KHE 2006a; Figure 5). Olema Creek is the largest tributary to the Lagunitas Creek subwatershed that is not dammed with the Lagunitas Creek confluence near the upstream boundary of the Project Area. The Olema Creek basin is approximately 9-miles long and 1- to 2-miles wide. Approximately 70 percent of the drainage area consists of runoff from the west flanks of Bolinas Ridge, while the remainder of the watershed occupies the eastern slopes of the Inverness Ridge. Within this basin, the Bolinas Ridge is underlain by Franciscan Complex bedrock, and the Inverness Ridge is composed of fine-grained marine sediments of the Tertiary-aged Monterey Formation (Figure 6). A mixture of modern/historic alluvial, estuarine, and freshwater marsh deposits blankets the valley floor of this drainage.

Stream gradient of Olema Creek near the Project Area is relatively flat, with the creek following a rather straight – and, in some areas, braided – course. In recent years, the channel has aggraded considerably in its lower sections, causing the creek to jump out of its alignment of the past 80 years, and reestablish a distributary floodplain or network of secondary channels in Stewart Flat. Stewart Flat is located in the low-lying floodplains of Olema Creek between the town of Olema and Point Reyes Station. The creek appears to be moving closer toward historic conditions, when moderately sized riparian forests flourished along a somewhat sinuous Olema Creek, as shown in a map of the Berry grant produced in 1854 (Livingston 1995). This depiction is supported by a description by Schofield (1899) of Olema Creek as having banks that are "thickly grown with brush and trees. The last two miles of the creek run through low swampy land, with its banks most of the way heavily lined with willows." Some historical accounts also refer to an "Arroyo Olemus Lake" or Olema Lake, which most likely occurred at Stewart Flat (Niemi and Hall 1996). This "lake" may have been subsequently drained by construction of the Olema Canal, which straightened the section of Olema Creek between Olema and Lagunitas Creek (Niemi and Hall 1996). Currently, Olema Creek is bridged at Levee Road near its confluence with Lagunitas Creek.

The lower two-thirds of the Olema Creek watershed are perennial. The flow is sustained during the summer months principally by the perennial tributaries draining the Inverness Ridge. Tributary streams off the Bolinas Ridge are typically intermittent during the summer months. Streamflows during the winter runoff period, as determined at Olema, typically reflect baseflow conditions of about 5- to 10 cfs, with peak storm flows of several hundred to more than 1,000 cfs (Questa Engineering Corp. 1990). Because of the valley's linear nature, the watershed responds rapidly to rainfall events. Ketcham (1998) indicates that there is an approximate 3-hour lag time on Olema Creek between the onset of significant rainfall events and peak discharge. The estimated mean annual water yield for Olema Creek (at Bear Valley Road) is approximately 20,800 acre-feet (Questa Engineering Corp. 1990). This translates to an average annual flow of just under 29-cfs. However, seasonal flow variability displayed in monitoring data indicates summer baseflow rates ranged 0.1- to 1.0-cfs over dry to near-normal water year types (Questa Engineering Corp. 1990).

There is also tidal influence on Olema Creek on the downstream 0.3 miles before it joins with Lagunitas Creek (B. Ketcham, Seashore, *pers. comm*).

Bear Valley Creek and Project Area-Olema Marsh

Similar to Olema Creek, Bear Valley Creek occupies the San Andreas Fault zone valley. Within the fault zone, Bear Valley Creek is separated from Olema Creek by a 120-foot medial ridge composed of marine terrace deposits. Approximately half of the headwaters area of this 4.1-square-mile subwatershed is underlain by Monterey Formation sediments, while the other half lies atop granitic bedrock (KHE 2006a, Figure 6).

Hydrology of this watershed derives not only from surface runoff from the relatively steep upper watershed and more level floodplains in the Olema Valley, but from groundwater originating from the Inverness Ridge (Figure 5). The upper reaches of Bear Valley Creek and its tributaries are single-threaded, moderately entrenched sections that are characterized by a well-defined riparian corridor. These sections are constrained by the steep topography of ravines along Inverness Ridge and the historic ranch roads that are now being used for the Seashore's Bear Valley Trail. The lower portions of Bear Valley Creek consist of single-threaded or multi-threaded channels that are exceptionally shallow. Approximately 2,300 feet upstream of the Bear Valley Road berm, the stream channel becomes indistinct, dissolving into an open water marsh. Several small streams flow off the Inverness Ridge and converge with Olema Marsh and Bear Valley Creek on its western perimeter. The stream channel remains indistinct through Olema Marsh until just upstream of Levee Road, where a row of willows and alders marks its course through the Levee Road culverts and County White House Pool park to Lagunitas Creek.

Like the Inverness Ridge tributaries draining the Olema Creek watershed, Bear Valley Creek is a perennial system. No long-term flow monitoring has been completed in the watershed. However, a water supply study completed by the USGS in the mid-1960's does provide some estimates of late-summer creek baseflows or the amount of water in the creek once flooding from rains has ceased (Dale and Rantz 1966). This study indicates that, even though the Bear Valley Creek watershed is just over a quarter of the size of the Olema Creek watershed, summer baseflow rates (measured near Park Headquarters) are of a similar magnitude, ranging from 0.5-cfs during normal rainfall years to 0.25-cfs during dry year-types. The greater yield of Bear Valley relative to Olema reflects the higher water-bearing properties of the deposits underlying the Inverness Ridge relative to the Franciscan complex material underlying ridges to the east of the San Andreas rift valley (KHE 2006a, Figure 6).


Levee Road after 1906 earthquake

Construction of a road parallel to Bear Valley Creek to connect Point Reyes Peninsula with the town of Olema in the 1800s represented the first of many major infrastructure and management impacts that impacted the subwatershed (Table 5). During the 1800s, Bear Valley Creek was described as having numerous riffles and pools underneath a substantial riparian canopy. This fluvial system eventually flowed into Olema Marsh, which was then a large integrated tidal marsh complex with sinuous tidal sloughs (KHE 2006b). In 1892, a long, culverted berm was constructed across the mouth of Olema Marsh for Sir Francis Drake Boulevard or Levee Road. Following construction of Levee Road in the late 1800s- early 1900s, the creek was dammed by dairy ranchers in the 1920s. The SWRCB shows NMWD as having a water right on Bear Valley Creek for diversion of 0.401 cfs between January 1 and December 31, but this was only a temporary permit for use in 1977, a drought year, and has not been used since (C. DeGabriele, NMWD, *pers. comm*.).

Based on a 1942 photo, this area appears marshy and heavily grazed, and there is little riparian vegetation until the creek approaches Olema Marsh. A number of culverted berms were built for Bear Valley Road and the ranch roads in the upper portion of the watershed, all of which affected hydraulic connectivity and sinuousity. The original road from Olema to the Point Reyes Peninsula was eventually replaced with Bear Valley Road and Sir Francis Drake Boulevard. Limantour Road was constructed after World War II. In the 1970s, the Seashore moved a portion of Bear Valley Creek channel for construction of the maintenance facility yard and buildings. By the early 1980s, maintenance dredging for flood control purposes had led to the middle and lower reaches of Bear Valley Creek becoming deeply incised, with the creek bottom roughly 6-8 feet below the floodplain terrace bank at the Seashore's maintenance yard (KHE 2006b).

In 1982, Bear Valley Creek changed dramatically as a result of the New Year's Day floods. Catastrophic debris flows originating from the unstable weathered granite of the Inverness Ridge flowed through tributaries into the mainstem of Bear Valley Creek, choking the former channel, scouring existing road/trail facilities, and turning the colluvial valley bottom into a sandy, braided stream channel with extensive woody debris jams that acted to temporary dam and pond waters within the channel. Storm clean-up resulted in some of the excavated sediment being placed in the floodplain and possibly on the northern edge of Olema Marsh adjacent to Levee Road (Table 5; KHE 2006b).

The State Coastal Conservancy provided funding to Audubon Canyon Ranch in the 1980s for an enhancement project, which consisted principally of using drag-lines to create small, unvegetated ponds in Olema Marsh, some of which persist today. During the 1998 El Nino events, similar small-scale landslides and hillslope failures were observed throughout the Bear Valley Creek watershed. Sediment deposition during the 1998 flood also precipitated a change in channel course for lower Bear Valley Creek from the west to the east side of Olema Marsh. Since 1982, the County of Marin has also diverted one of the larger drainages to Olema Marsh, Silver Hills, to run alongside Levee Road and flow out of the historic outlet on the west side of the marsh.

While Olema Marsh has been heavily impacted by road construction, long-term water level monitoring in Olema Marsh and lower Bear Valley Creek show that conveyance capacity of the Bear Valley Road culverts is still sufficient to pass most streamflows without problems such as backwater flooding (KHE 2006a, Appendix B9). Culverts at Bear Valley Road consist of two 6-foot diameter culverts that have a conveyance capacity of 600 cfs (KHE 2006b). However, water levels in Olema Marsh are dramatically higher than the elevation of the downstream 6-foot by 7-foot box culvert at Levee Road, indicating water impoundment and poor hydraulic connectivity between Olema Marsh and downstream Lagunitas Creek (KHE 2006a). The minimum water surface elevation recorded during baseline studies (8.4-feet NAVD88) in Olema Marsh is almost 4-feet higher than the minimum or base water level elevation recorded immediately upstream of the Levee Road culvert (KHE 2006b).

Outflow appears to have been limited by several factors (Table 5). As noted earlier, the 1998 storm caused Bear Valley Creek to migrate from a well-defined channel on the western side of the marsh to a more amorphous, ill-defined flow path on its eastern edge, and sedimentation essentially blocked off the western outlet (KHE 2006b). Blockage of the western outlet reduced the available surface area for potential flow conveyance from the marsh from 106 square feet to 42 square feet, which translates into a reduction in conveyance capacity from approximately 630 - 700 cfs to 410 cfs (KHE 2006a). A 5-year flood event produces approximately 490 cfs in Bear Valley Creek (G. Kamman, KHE, *pers. comm.*). In addition, outflow has been severely reduced by an approximately 315-linear-foot earthen berm hardened by heavy vegetation establishment on the east bank of lower Bear Valley Creek just upstream of Levee Road (KHE 2006b).

Problems with conveyance of flows at Levee Road have caused backwater flooding that has increased water levels in Olema Marsh, as well as in lower Bear Valley Creek (KHE 2006a). Based on a comparison of water levels and culvert submergence conditions at Bear Valley Road in 1990 (Evans 1990) and 2005 (KHE 2006b), standing water levels during the summer appear to have increased approximately 6 feet since 1990, which predated the 1998 flood event and migration of the Bear Valley Creek channel in Olema Marsh (KHE 2006b). Impoundment in Olema Marsh has also resulted in an increase in water surface levels in the Bear Valley Creek marsh directly upstream of Bear Valley Road.

Without restoration, water levels within Olema Marsh (and Bear Valley Creek Marsh) were predicted to continue to increase, which could have a considerable effect on the potential for flooding during storms of Levee and Bear Valley Roads, which are frequently flooded even during smaller storm events. In Olema Marsh, standing inundation volume totals 202 acre-feet during a 2-year event (compared to 2-acre feet for the Giacomini Ranch East Pasture), with most of that water coming from Bear Valley Creek, because poor hydraulic connectivity and the large standing water volume in the marsh greatly reduce the potential of Olema Marsh to provide off-channel floodwater storage for Lagunitas Creek (KHE 2006a). During a much larger 100-year flood event, standing water volume would appear to only slightly more than double, with estimates of approximately 544 acre-feet (KHE 2006a).

In 2008, the initial phase of an adaptive restoration project for Olema Marsh was implemented by notching or creating a small (24-ft-wide) breach in the 315-ft-long berm constraining outflow. This breach should increase outflow from the marsh and decrease standing water levels, thereby reducing the potential for flooding from this marsh of the adjacent Levee Road. The effects of this intial adaptive restoration element will be studied before proceeding with additional restoration.

Project Area - Giacomini Ranch

Tomasini Creek

The Tomasini Creek watershed is over 3.5-miles long, averages 0.75-miles wide, and has an estimated drainage area of 3.3-square miles (KHE 2006a). The upper two-thirds of the watershed consist of Franciscan complex bedrock; the lower third drains lands built on marine terrace deposits that underlie the Point Reyes Mesa (KHE 2006a; Figure 6). Upstream of Mesa Road in property owned by the county as an open space easement, the creek flows down a moderately sloped section of the Tomasini Creek valley in a shallowly entrenched, albeit well-defined channel through a broad riparian zone until it reaches the road, where backwater flooding from undersized culverts and an abrupt change in creek gradient has caused the creek to broaden and become marshy (Table 5). The creek enters the eastern side of the Project Area through a pair of 6-foot diameter circular steel culverts underneath Mesa Road. From there, the stream gradient flattens considerably, encouraging deposition of sediment and debris that has created a blockage that reduces hydraulic connectivity between upstream and downstream reaches.

Tomasini Creek levee at Hunt Shack (house on right)

After construction of levees by the Giacominis between 1955 and1960, Tomasini Creek downstream of Mesa Road was contained within this leveed channel along the eastern border of the Project Area to its outfall with Lagunitas Creek near Railroad Point or the north levee of the East Pasture (Table 5). This outfall consists of a 22-foot-wide concrete weir containing a line of four 3-foot-diameter circular culverts equipped with one-way tide gates on downstream ends (KHE 2006a). This levee was constructed to divert Tomasini Creek out of its natural channel alignment, which previously meandered through the East Pasture. Review of available historic aerial photographs from 1942 and 1943 indicated that, prior to construction of the current levee, the Giacominis may have attempted to redirect Tomasini Creek in a southward direction along the base of the Mesa below the Giacomini Dairy Facility and through the Green Bridge County Park to an outfall point into Lagunitas Creek opposite Olema Creek (KHE 2006a). The historic outlet of Tomasini Creek into the former marsh floodplain is visible in the 1942 photograph as a sizeable alluvial fan (KHE 2006a).

No long-term flow monitoring has been completed on Tomasini Creek. However, flow characteristics (if not totals) for this drainage are likely similar to those on Walker Creek in the northern portion of the Tomales Bay watershed (KHE 2006a; see Walker Creek below). Based on USGS flow records for Walker Creek, winter runoff characteristics in the Tomasini watershed are probably flashy (i.e., very short lag time between rainfall and runoff) and likely similar in magnitude, per unit area, to those in the lower Lagunitas Creek watershed (KHE 2006a).

The flashiness of this system is supported by the Giacominis, who attested to the propensity for Tomasini Creek to have high-intensity, short-duration storms that cause significant flooding, particularly in combination with high tides (KHE 2006a). No information is available on how often this creek might have overtopped its berm, which varies in height near the Giacomini Hunt Lodge from 8 to 12 feet NAVD88, but overtopping events were not observed during 2001-2005. In late 2005-2006, a winter storm-extreme high tide event in January estimated as an approximately 30-

year event appeared to have breached and overtopped the berms and caused some erosion near the Giacomini Hunt Lodge.

In 2008, Tomasini Creek was realigned into one of its former historical alignments in the East Pasture as part of the larger restoration project. This realignment occurred approximately 800 feet downstream of Mesa Road. The former Tomasini Creek channel remains, but functions principally as a backwater slough now, receiving some flood overflow across a small berm in the channel during larger storm events, as well as groundwater inflow from the Point Reyes Mesa. The tidegate structure has been retained such that this backwater slough receives the full upper range of tides, but the lower range of tides is truncated by the structure, maintaining subtidal conditions.

The largest difference between this drainage and others in the Project Area is that summer baseflow rates are much lower per unit area (KHE 2006a). As with Walker Creek, the upper portions of Tomasini Creek do dry down during average and drier years in late fall, with sustained year-round flows only occurring during wet-year types. However, based on salinity monitoring conducted by the Park Service and results of hydrodynamic modeling, groundwater springs and seeps within the Point Reyes Mesa terrace deposits appear to contribute significantly to the creek base flow during summer and fall, maintaining perennial flow and brackish salinities, at least in downstream reaches (See Groundwater).

Similar to other creeks within the watershed, water is extracted from Tomasini Creek through at least three water rights agreements, primarily during the winter for off-creek storage (Table 5). One of these water rights, which covers storage of 12 acre-feet per year between October 1 and April 1, was transferred to the Park Service with purchase of the Martinelli Ranch. In addition, the creek may be negatively affected by the presence of the now-closed West Marin Landfill within its watershed: the landfill is apparently inundated on occasion by overbank flooding during high flows and may therefore potentially decrease downstream water and sediment quality (Table 5).

Fish Hatchery Creek and Inverness Ridge Drainages

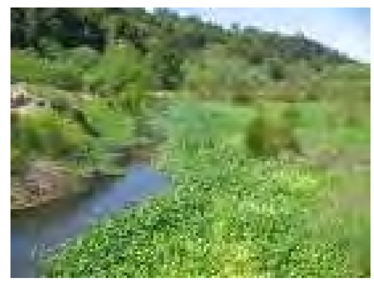
There are four small watersheds draining Inverness Ridge, which enter the Project Area between White House Pool and the North Levee (Figure 5). These drainages include (from south to north): Haggerty Gulch (1.7-square miles); Fish Hatchery Creek (0.9-square miles); the “Creek 2 or 1906 Drainage” (0.2-square miles); and the “Unnamed Tributary” (less than 0.1-square miles; KHE 2006a). Names for the latter two drainages came from a 1917 National Geodetic Survey map (KHE 2006a). All of these drainages are underlain by weathered granite (Figure 6), and each displays perennial flow and copious winter sediment production. On a per unit area basis, the amount of runoff from each of these small watersheds is similar to that for Bear Valley Creek (KHE 2006a).

All of these drainages are characterized by steep to extremely steep stream gradients as waters flow down ravines on the Inverness Ridge. Within the Project Area, the gradient abruptly flattens, representing active depositional fans. In 1899, Schofield noted that Fish Hatchery Creek was “at first fed by springs and (runs) through cool shady woods,….but on gaining the open valley,” it runs through two miles of marshy lowlands. Flows currently enter the Project Area through culverts underneath Sir Francis Drake Boulevard (Table 5). Haggerty Gulch discharges directly into Lagunitas Creek at White House Pool through a 4-foot-diameter circular steel culvert (KHE 2006a; Figure 27), which appears to be at least contributing to some bank erosion and possible undercutting of the Sir Francis Drake Boulevard road base (Land People 2005). All other drainages flow into the West Pasture or private properties on the east side of Sir Francis Drake Boulevard.

Fish Hatchery Creek enters the Project Area on the north side of the Gradjanski property where it flows to the central portion of the West Pasture (Figure 5). The channel near Sir Francis Drake

Boulevard has been frequently dredged to remove sediments deposited during storms by the Giacomini family (Table 5). During a 2-year flood event, estimated inundated area (76 acres) and standing water volume (62 acre-feet) in the West Pasture would appear to be larger than the East Pasture even under conditions when levees are not overtopped by Lagunitas Creek (<12.5 year flood event), because of surface flows from Fish Hatchery Creek and other small drainages (KHE 2006a). Under successively larger flood flows, inundation area steadily increases, with standing water volume increasing to 450 acre-feet in the West Pasture during a 100-year flood event or flood with a similar magnitude to the 1982 event (KHE 2006a).

Prior to restoration, Fish Hatchery Creek exited the West Pasture through a pair of 3-foot-diameter circular steel culverts in the North Levee equipped with modified tidegates on the downstream side (Table 5). These flap gates had been propped open slightly to permit limited two-way exchange between undiked portion of Fish Hatchery Creek and the West Pasture. As with Lagunitas and Tomasini Creeks, water is extracted from Fish Hatchery Creek through at least four water rights agreements, primarily through direct diversions. The Giacomini family has a water right for 0.5 cfs between April 1 and December 1.


Downstream portion of 1906 Drainage

After crossing under Sir Francis Drake Boulevard, the "Creek 2 or 1906 Drainage" channel crosses through the former Lucchesi property and discharges into the West Pasture (Figure 5; Table 5). After flowing through a concrete box culvert, the creek makes a roughly 90 degree turn that funnels flow directly into the south end of the West Pasture Freshwater Marsh. As with Fish Hatchery Creek, the 1906 drainage requires near-annual maintenance to remove accumulated sediment and reduce flood hazards to adjacent properties. The chronic flooding at these properties is driven by channel infilling with granitic alluvium eroded from the Inverness Ridge with subsequent increase in water levels during storm events due to aggradation of the channel bed (KHE 2006a). The 1906 Drainage flows into central southern portion of the Freshwater Marsh, after which it appears that flow largely follows topographic gradients into the depressional basin in the lower-elevation central and eastern portions of the marsh. This depressional basin has formed in response to higher elevations to the west (base of Inverness Ridge), east (West Pasture), and south (1906 Drainage alluvial fan).

The "Unnamed Drainage" has been observed flowing from a culvert in Sir Francis Drake Boulevard into a densely wooded riparian area on the east side of Sir Francis Drake Boulevard and then discharging into a remnant road-side drainage ditch adjacent to the West Pasture Freshwater Marsh (Figure 5). The water then flows north into Fish Hatchery Creek, just upstream of the former North Levee culverts. The subtle swale that constitutes this remnant roadside ditch appears to be the dominant water conveyance feature on the west side of the West Pasture Freshwater Marsh (KHE 2006a).

Another small drainage occurs in the southern portion of the West Pasture (Figure 5). This seasonal creek is also culverted underneath Sir Francis Drake Boulevard and has been ditched to connect with an existing low spot marked by a stand of arroyo willow (*Salix lasiolepis*) near the center of the pasture). Flow is typically non-existent or very minimal except during storm events.

Interior Drainage Ditches and Remnant Slough Features

In the West Pasture, a small drainage appears at the southeastern corner of the Gradjanski property that flows eastward before turning north parallel to Sir Francis Drake Boulevard and eventually connecting with Fish Hatchery Creek in the northern two-thirds of the West Pasture. As was discussed earlier, this drainage, called the West Pasture Old Slough (Figure 5), appears to be the remnant of a historic tidal slough that has been ditched by the Giacomini family in its most upstream reaches to channel surface run-off from seasonal seeps or springs on the Gradjanski property. The southern portion of the Gradjanski property near this ditch is extremely marshy and appears to be wet for most of the year, although, based on water quality monitoring, surface flows are only present in the most upstream portion of the slough for one to two months after spring rains end, typically drying up by March or April of each year.

The East Pasture contained a much more elaborate and extensive drainage ditch network to direct surface run-off and deliver and drain stormwater and irrigation waters applied to the pastures (Figure 5). Historically, water was diverted from Lagunitas Creek near the upstream end of the East Pasture in the summer after installation of the earthen dam. More recently, the Giacominis received irrigation waters from NMWD's Downey Well, with the waters being piped to the Ranch. Some of the drainage ditches in the East Pasture appeared to be former slough channels that were straightened, with the exception of the northern portion of the largest drainage channel, called the East Pasture Old Slough, which retained a prominent relict meander.

During the summer, irrigation waters were spray-irrigated in a large percentage of the northern portion of the East Pasture, with flood irrigation methods used for the southernmost pastures. Some pastures were not actively irrigated during the summer, probably because soil salinities were consistently high enough even with irrigation to preclude establishment and maintenance of pasture. In the past, the Giacominis used some of the drainage ditch waters to artificially flood the New Duck Pond and created conditions conducive to use by waterfowl. In addition to irrigation on the East Pasture, the standard dairy practice also included spray irrigation of liquid waste from the manure ponds. The waste spraying occurred in the summer months within the East Pasture, with application of concentrated manure slurry in one 13-acre pasture in the southernmost portion of the East Pasture.

As was discussed under Lagunitas Creek, prior to restoration, the East Pasture was only infrequently flooded by Lagunitas Creek during storm events in the winter because of the levees. During 2-year flood events -- or floods of a magnitude that occur, on average, every 2 years or some recurrence interval greater than that – levees were high enough to preclude the East Pasture from being flooded by Lagunitas Creek. Hydraulic modeling results showed that, during 2-year flood events, standing water volume in the East Pasture totaled only 2 acre-feet, most of which came probably from precipitation and surface run-off (KHE 2006a).

During flood events in which overtopping occurred, water levels within Lagunitas Creek built in vertical height or stage until they exceeded the height of the levees, at which point they overtopped and flooded into the pastures. Once waters flowed into the leveed pastures, the pastures filled rapidly to a maximum standing water volume, where floodwater persisted for some time as they slowly drained through the only outlets, which were the concrete spillway and tidegate/culverts. The southern portions of the East and West Pasture drained quickly, but, during larger storms, floodwaters remained ponded within the northern portions of the pastures for more than a week, because elevations were lower in these areas than the concrete spillways. In the East Pasture, drainage of stormwater was sometimes accelerated through operation of a pump on the east bank of Lagunitas Creek.

Reference Areas

Undiked Marsh

The Undiked Marsh does not necessarily have one primary source watershed, but rather acts as the downstream continuum for larger creeks such as Lagunitas, Fish Hatchery, and Tomasini Creek, as well as the outflow point for numerous smaller drainages flowing off the Inverness Ridge and eastern portion of Tomales Bay. Most of these smaller creeks that flow directly into the Undiked Marsh flow principally in the winter, with flow greatly reduced, although still present, in the summer.

Walker Creek

The Walker Creek watershed is 73 square miles, mostly in northwestern Marin County, with a small portion in Sonoma County. Significant tributaries of Walker Creek include Keys Creek, which flows through the rolling hills east of Tomales; Chileno Creek, which flows through Chileno Valley; and, in the upper watershed, Salmon and Arroyo Sausal Creeks, which flow through Hicks Valley. Keys Creek joins Walker Creek barely one mile upstream of the outlet at Tomales Bay. Frink and Verde Canyons each support ephemeral streams that join Walker Creek upstream from Chileno Creek. Soulejoule Reservoir impounds the 15 square mile drainage of Arroyo Sausal (Rich 1989 *in* Prunuske Chatham 2001).

Undiked Marsh north of Giacomini Ranch

The bedrock in this watershed northeast of the fault is Franciscan Formation, a mélange of Jurassic-Cretaceous conglomerate, sandstone, mudstone and chert, which is susceptible to debris flows and landslides on steep slopes. The Wilson Hill formation around Hicks Valley north of Walker Creek, composed of soft sands, silt and clay, is less susceptible to landslides, but more likely to erode and gully (Bush 1995 *in* Prunuske Chatham 2001). Greywacke, greenstone, and volcanics are also evident within the watershed.

Annual rainfall varies from 24 to 32 inches (Nolte 1965 *in* Prunuske Chatham 2001). The Walker Creek drainage, which includes Chileno, Arroyo Sausal, Salmon, and Keyes creeks, makes up about 35 percent of the Tomales Bay Watershed area, but produces about 25 percent of the annual runoff into the Bay (TBSTAC 2000). Between 1987 and 1993, Walker Creek flow averaged 494 million ft^3/yr (14 million m^3/yr), compared to 1.307 billion ft^3/yr (47 million m^3/yr) for Lagunitas Creek and 1.73 billion ft^3/yr (49 million m^3/yr) for all surface flow to the Bay (Smith et al. 1996). Chileno Valley is notably hotter and drier than the coastal areas.

Soulejoule Reservoir was initially dammed in 1968 and later enlarged to 10,570 acre feet by the Marin Municipal Water District (MMWD) in 1980 for domestic water supply, which is pumped as needed to Nicasio Reservoir in the Lagunitas watershed. MMWD also has a reservoir on a tributary to Walker Creek, with a capacity of 10,572 acre-feet. Since 1980, releases from the reservoir have increased the summer and fall flows in an effort to improve the downstream fishery.

Grazing is the major land use impact in the Walker Creek watershed. Much of the watershed is in a few large parcels of privately owned livestock ranches. Dairies are concentrated in the valleys of Keys Creek near Tomales and Chileno Valley, while the rest of the watershed is predominantly beef cattle ranches and some sheep ranches (Bush 1995 *in* Prunuske Chatham 2001). Keys Creek and the Walker Creek delta still show evidence of sediment deposition from historic potato farming that peaked in the 1860s around Tomales (Bush 1995). During this period, shallow barges were able to travel upstream to what is now the town of Tomales, load potatoes and other goods, and then return to San Francisco (Prunuske Chatham 2001). Privately owned Laguna Lake at the headwaters of Chileno Creek is a large (about 200 acres) shallow water body, which until 1991 was been drained and planted with corn. In addition to use of fertilizer and pesticides for corn crops, Laguna Lake was also impacted by drainage from the Reichardt duck farm which drains to the northern tip of the lake (Prunuske Chatham 2001).

The Gambonini Mine operated as a large open pit cinnabar mine for mercury from 1964 to 1970. Since remediation in 1998, it has been monitored for mercury transport to Salmon Creek, just before the confluence with Walker Creek. A smaller mercury mine operated at the same time nearby in upper Chileno Valley, and two more inactive mercury mines are listed for Walker Creek in the Basin Plan (RWQCB 1995). For a while in the 1960s, Marin County public works extracted gravel from Walker Creek just downstream of the confluence with Chileno Creek (Bush 1995 *in* Prunuske Chatham 2001). Other significant landuse activities include gravel mining at multiple locations on the mainstem of Walker Creek.

These historic land use practices have greatly exacerbated downstream incision and aggradation of the Walker Creek channel. Haible (1980 *in* Prunuske Chatham 2001) documented that during the 60 years between 1915 and 1975 the channels in the upper watershed incised 5 to 8 feet, while the lower reaches of Walker Creek, above the Highway 1 Bridge aggraded approximately 4 feet. Conversations with long-term residents in the watershed indicate that the primary incision documented by Haible (1980) occurred prior to 1950 (Prunuske Chatham 2001). The active channel subsequently widened dramatically in many areas between the 1940s and early 1980s, and barren, active gravel bars extended across the active floodplain during this period (Prunuske Chatham 2001).

Walker Creek Marsh represents a deltaic land feature that was rapidly formed in the late 1800s – early 1900s in response to increased sedimentation in this subwatershed. Walker Creek currently flows on the northern perimeter of the marsh, which is bordered by an extensive alluvial levee. During moderate to large storm events, this levee is undoubtedly overtopped by Walker Creek flood flows. Several small freshwater drainages also flow into the southern perimeter of the marsh, forming riparian thickets or freshwater marsh on its landward edge.

Limantour Marsh

Muddy Hollow Creek is the principal subwatershed and freshwater source for Limantour Marsh, although there is also some surface run-off and perhaps even groundwater influences from adjacent uplands.

As was alluded to earlier, flows from Muddy Hollow Creek into the marsh have been greatly altered by construction of dams and reservoirs. The Muddy Hollow Creek watershed encompasses a much smaller area (8.3 km2) than Lagunitas or Walker Creek watersheds. Like the watersheds of Lagunitas and Walker Creeks, agriculture and ranching occurred in the Muddy Hollow Creek watershed beginning in the mid-1800s (Northwest Hydraulic Consultants 2004). In the 1950s, two reservoirs were constructed in the creek basin, presumably reducing sediment inputs to the tidal marsh site. Downstream of the reservoirs, the creek and upper tidal channels were dammed in the early 1960s to create a pond for the recreational use of a proposed residential development (Northwest Hydraulic Consultants 2004). This dam was removed in 2008 as part of a restoration project.

Muddy Hollow Creek is a perennial creek that flows into Muddy Hollow Pond. From there, waters “spillover” from the outflow channel located at the northwestern corner of the pond and flow into the northeastern end of Limantour Marsh. There is no information available on freshwater inflow dynamics into the marsh during different flow regimes given presence of the pond and spillway channel, but, prior to removal of the dam in 2008, freshwater inflow to the marsh occurred year-round and was substantial enough to maintain brackish salinities in eastern portions of the Limantour Marsh Slough.

Groundwater

Tomales Bay

In addition to tidal and fluvial surface water, the other major hydrologic source to the Project Area is groundwater. According to Oberdorfer et al. (1990), groundwater flow accounts for less than 1 percent of the freshwater in the watershed, but it undeniably influences the hydrology and biology of this and other coastal California watersheds. Between 1987 and 1993, groundwater flow into the Bay was estimated as 1.76 million ft^3/yr (5 million m^3/yr; Oberdorfer et al. 1990 *in* Smith et al. 1996).

Within the Tomales Bay watershed, groundwater substantially increases hydrologic complexity within wetland ecosystems by replacing the traditional upland to wetland cross-sectional transition common of most salt marsh systems with a freshwater to saltwater transition. Within many Tomales Bay subwatersheds, salt marshes are fringed with freshwater, brackish marsh, or riparian habitat due to the influence of seeps and springs along most of their perimeter (Parsons et al. 2004). Seeps and springs form the headwaters for many of the small drainages that flow to the Bay (Parsons et al. 2004).

The prevalence of these hydrologic sources within the Point Reyes area relates directly to the geologic complexity of this unstable region, with lateral and vertical movement along the San Andreas Fault fracturing basement rock and enabling underground aquifers to connect with the ground surface. However, certainly in more developed areas, groundwater and seep flow has probably been augmented to some degree by leaking septic systems, as many of the systems within Tomales Bay are antiquated and in need of repair or modernization (TBWC 2002).

Project Area - Giacomini Ranch

East Pasture

Within the East Pasture, groundwater generally flows from south to north on a northwest gradient, largely following the northwest trend of the rift valley that probably imparts a strong parallel groundwater flow pattern similar to other fault-derived flow paths (KHE 2006a). In general, the groundwater gradient mimics the topography of the East Pasture, except in the very northern portion where the flatness of the pasture disconnects the groundwater table from surface topography (KHE 2006a). The lowest portion of the East Pasture is actually in the northeastern corner.

Groundwater was not included in the hydrodynamic model developed by KHE, however, groundwater depths were monitored regularly by the Park Service through shallow groundwater monitoring wells. These data show that a very shallow groundwater table existed throughout most or all of the year prior to restoration (Appendix C2), with water depths being closer to the surface in the northern, lower elevation portions of the East Pasture. This groundwater table may have originated from water-bearing alluvial deposits or layers within the Point Reyes Mesa (KHE 2006a), the adjacent coastal marine terrace formation that consists of non-marine and marine sand, gravel, silt and clay layers (Galloway, 1977; Clark and Brabb, 1997). Past development of small-scale groundwater wells for private use on the Point Reyes Mesa for residents has uncovered several water-bearing layers within this terrace, one of which is at approximately Mean Sea Level or roughly at the same elevation as the northern portion of the East Pasture (G. Ferrando, Point Reyes resident, *pers. comm*. *in* KHE 2006a). The depth of this groundwater table, as well as the potential for presence of an aquifer beneath the East Pasture, was constrained by the stratigraphy of the East Pasture, which is underlain by deep estuarine clays of low organic content, low permeability, and low groundwater storage capacity that act as aquitards or barriers to groundwater exchange (KHE 2006a). This factor strongly argued against the possibility of freshwater aquifer of any significant thickness, lateral extent, or storage capacity beneath the East Pasture (KHE 2006a).

Groundwater depths were not always consistent with the topography. The emergent of hillside springs or seep flow from the base of the Point Reyes Mesa contributed another layer of hydrologic complexity (Figure 5). These seeps and springs have promoted establishment of dense riparian scrub and marshy areas on the edges of the Mesa or even on its slopes, which are visible in 1942 photographs of the Project Area. The Giacominis dredged ditches at the base of the Mesa in many areas to reduce flooding of pastures from groundwater. The source of these seeps and springs is undoubtedly one of the shallower water-bearing alluvial layers that have been documented by groundwater well development in the Point Reyes Mesa terrace.

Natural groundwater influences have probably been augmented to some degree by septic systems from the relatively densely populated developments on the top of the Point Reyes Mesa and, in some areas, by non-point source run-off from the town of Point Reyes Station. The relative contribution of septic influences to groundwater cannot be determined, but some limited water testing by the Park Service did detect Methlyene-Blue Active Substances (MBAS) in low concentrations at several locations around the perimeter: MBAS is a constituent of surfactant detergents and a fairly reliable indicator of septic or sewer influence.

Emergent groundwater creates mesic coastal scrub community on Point Reyes Mesa on northeastern perimeter of East Pasture

Some of the most evident seeps and springs in the East Pasture and vicinity occur on: 1) the riparian habitat and seasonal wetland on eastern perimeter of Green Bridge County Park; 2) seasonally flooded pasture and riparian scrub on the southern slopes of the dairy mesa facility; and 3) seasonally flooded pasture, freshwater marsh ditch, and riparian-marsh scrub on the northern slope of the dairy mesa facility. The most and noticeable area with seeps and hillside springs is the section of the Point Reyes Mesa north of the Giacomini Hunt Lodge and south of Railroad Point. Surface run-off of hillside springs, combined potentially with groundwater emergence at its base, have not only created an extensive riparian scrub or Mesic Coastal Scrub community on the face of the “bluff,” as it is known, but appears to contribute to some degree to base flow within the former Tomasini Creek channel Most importantly, groundwater inflow may have buffered the increased salinities within the former Tomasini Creek, which became tidal again when the tidegate failed, and thereby may have benefitted the federally endangered tidewater goby, a brackish water species.

As discussed under the section on tides, even prior to restoration, limited portions of the East Pasture bordering Lagunitas Creek appeared to have a hydraulic groundwater connection with the creek that caused shallow groundwater within these portions of the pasture to move up and down to some degree with tidal cycles (KHE 2006a). Although soils in these areas contain very porous coarse alluvium, there did not appear to be movement of water through the soils between undiked and diked areas, but rather that pressure from the tides created a corresponding hydraulic pressure on the shallow groundwater table within the pasture (KHE 2006a, Appendix B10).

West Pasture

As with the East Pasture, some groundwater monitoring was also conducted by the Park Service in the West Pasture. Based on this data, prior to restoration, the general groundwater gradient in the West Pasture appeared to run from south to north, again following the general topography and creating higher water levels within the very northern portions of the pasture (KHE 2006a). This groundwater gradient was overlain by the west to east groundwater gradient established by seeps, springs, and small drainages flowing off or emerging from the base of the Inverness Ridge (Figure 5). Groundwater well data showed that areas on the west side of the West Pasture consistently had higher groundwater levels (Appendices C3.8-3.11) than those on the east side bordering Lagunitas Creek (Appendix C3.7).

The influence of seeps and springs is more pervasive along the West Pasture perimeter than the East Pasture one, as evidenced by the thin strip of arroyo willows that fringe the pasture along almost its entire length adjacent to Sir Francis Drake Boulevard. Flooding duration varies depending upon location along the perimeter, with some areas saturated to the soil surface for a brief time, while others are wet either permanently or seasonally throughout the winter and spring (Appendices C3.1-3.6, C3.8-3.11). For seasonally saturated areas, water tables during the monitoring period typically rose slightly below or above the soil surface for five (5) to six (6) months between December or January and May or June and then dropped to between 30 to 40 inches below the ground surface for the remainder of the year (Appendix C3.8-3.11).

There have been at least four sizeable areas that are defined by groundwater influence. Two have been south of the Gradjanski property and have flooded for an extended period during the winter and spring (Appendices C3.9-3.11). The third has occurred between the Gradjanski and Kostelic residences near Fish Hatchery and is flooded or saturated for an extended period (Appendix C3.8). The fourth was the West Pasture Freshwater Marsh, which, prior to restoration, flooded from groundwater as well as from creeks (1906 Drainage, Unnamed Drainage) and occasionally tidal incursions (Appendices C3.1-3.5). This marsh is flooded or saturated at or only slightly below the surface throughout the year (Appendices C3.1-3.5). As with the creeks, groundwater flow to the marsh appears to be perennial, with much of the flow at least initially routed into an old drainage ditch alongside Sir Francis Drake Boulevard that has not been maintained for some time.

Emergent groundwater in West Pasture during winter being used by waterfowl

As with the East Pasture, groundwater volume (and quality) appears to be potentially influenced by septic discharge. The relative contribution of septic influences to groundwater cannot be determined, but some limited water testing by the Park Service did detect MBAS in low concentrations in the West Pasture Freshwater Marsh. (As noted earlier, MBAS is a constituent of surfactant detergents and a fairly reliable indicator of septic or sewer influence). Interestingly, much of the West Pasture Freshwater Marsh appears almost to be completely tidal marsh in 1942, when this area was not diked, which potentially suggests that there has been a substantial increase in localized freshwater flow in this particular area of the West Pasture.

Project Area – Bear Valley Creek and Olema Marsh

As with the Giacomini Ranch West Pasture, the western perimeter of Olema Marsh appears to have a strong groundwater influence that is probably fed by seeps, springs, small drainages, and, to some unknown extent, septic discharges flowing off or emerging from the base of the Inverness Ridge.

Reference Areas

While no groundwater monitoring has been conducted in specifically in reference marshes, the similarity in geology to many of the other Tomales Bay and coastal Marin subwatersheds and the presence of brackish or freshwater marsh or willow scrub pockets along the upland perimeter of many of these marshes would suggest that groundwater probably plays some role in the hydrology of these systems. This creates a strong salinity gradient across these marshes, much as it does for many of the Tomales Bay subwatersheds.

Stormwater Run-Off Sources for Project Area

Another source of hydrology for the Project Area is non-point source discharge run-off from adjacent communities and developments (Figure 5). The Project Area is bordered by two towns and at least three developed areas – Point Reyes Station, Levee Road, and Inverness Park. While some non-point discharge probably occurs from roadside run-off on Sir Francis Drake Boulevard and Levee Road flowing into the West Pasture and Olema Marsh, respectively, larger non-point source discharge occur at least three locations on the eastern and southern perimeters of the East Pasture or Tomasini Creek.

One shallow ditch conveys run-off from the southern portion of the town through the Green Bridge County Park to a discharge location on Lagunitas Creek just upstream of the Giacomini Ranch. Another ditch conveys run-off from the central and western portions of town to the north-facing portion of the Dairy Mesa facility, where run-off flows down a vegetated swale into the Tomasini Triangle pasture at the eastern edge of the East Pasture. This ditch runs directly what used to be one of the unvegetated feedlots for young heifers or cattle run by the Giacomini Ranch and probably received run-off from this lot during storm events. A third ditch parallels Mesa Road in a vacant lot west of the road and eventually joins with Tomasini Creek just after it flows underneath Mesa Road. Flow patterns for these discharges are unknown, but almost all of them are dry by summer, with the possible exception of the one at the Green Bridge County park, which has flow perennially. Groundwater flow from the bottom of the Point Reyes Mesa appears to be channeled into this ditch, as well, possibly explaining the extension of flows beyond the winter and spring rainy season.

Circulation Patterns and Salinity in the Watershed and Project Area

Tomales Bay

Tomales Bay is a relatively well-studied system for a small estuary. Previous hydrographic studies conducted as part of the Land-Margin Ecosystem Research (LMER) and Biogeochemical Reactions in Estuaries (BRIE) programs of Tomales Bay have documented the bay's metabolism, its water composition, the dynamics of its nutrient circulation, and the influence of coastal upwelling (TBWC 2003). One of the first such studies was a 1960 hydrographic survey by Johnson and colleagues (Johnson et al. 1961). Additionally, Tomales Bay has been the subject of an intensive study into the biogeochemistry, for example, (Smith et al. 1987; 1989; 1991; 1996) (Hollibaugh et al. 1988; 1991) and hydrologic dynamics (Hearn and Largier 1997; Largier et al. 1997a; 1997b; Harcourt-Baldwin 2003) of estuaries. Cole et al. (1990) studied the hydrographic, biological and nutrient properties of Tomales Bay. Chambers et al. (1995) studied the nitrogen and phosphorus dynamics in fringing tidal marshes of the bay.

Circulation – and, therefore, sediment, nutrient, and contaminant dynamics -- in Tomales Bay are predominantly influenced by the Bay's physical shape, tidal cycles, and watershed run-off (TBWC 2003). Historically, circulation within the bay has been characterized as alternating between a classical estuary (net dilutive or "positive" basin) during wet winter months and a hypersaline estuary (net evaporative or "negative" basin) during dry summer months (Hollibaugh et al. 1988). However, as with many other estuaries, advances in computer modeling such as three-dimensional modeling using detailed bathymetric or bottom topography data has revealed that circulation patterns within Tomales Bay and many estuaries are incredibly complex, both spatially and temporally. Several recently developed 3-D hydrodynamic models of Tomales Bay have shown that different transport mechanisms are important in the outer and inner regions of the Bay (Harcourt-Baldwin 2003, Gross and Stacey 2003).

Gross and Stacey (2003) developed a three-dimensional hydrodynamic model of Tomales Bay using the TRIM (Tidal, Residual, and Intertidal Mudflat) program through a contract with the San Francisco RWQCB that will provide information to staff that can be used to establish Total Maximum Daily Load (TMDL) goals for loading of pollutants to Tomales Bay. Harcourt-Baldwin (2003) generated a three-dimensional model using a different program as part of Largier's hydrodynamic research, which was conducted as part of Smith and Hollibaugh's LMER/BRIE studies referenced above.

Tomales Bay is often divided into two or three regions – outer, inner, and sometimes middle bays – that are distinguished by differences in bathymetry and distance from its relatively narrow mouth. Most of these models do not incorporate what might be termed the "inner" inner bay, which would cover the Project Area and the undiked marsh north of the Giacomini Ranch, which is shallower, more vegetated, and driven more by fluvial- or creek processes than the open water portions of Tomales Bay (KHE 2006a; see Project Area discussion below).

In the outer portion of the bay, which is characterized by deep channels and shallow shoals or sandbars and strong tidal currents, tides drive the circulation (Harcourt-Baldwin 2003, Gross and Stacey 2003), although heavy freshwater inflows may temporarily affect circulation patterns (Harcourt-Baldwin 2003). Maximum velocities at the mouth are 6.56 feet/second, but these are reduced over neap tides (Harcourt-Baldwin 2003). Near the mouth, these strong tidal currents and a channel-shoal structure consistently maintain ocean water salinities, although salinities may briefly be reduced periods of heavy freshwater inflow (Hollibaugh et al. 1988, Harcourt-Baldwin 2003, Gross and Stacey 2003). When periods of freshwater inflow occur, the currents are strong enough to vertically mix waters so that stratification of tidal and freshwater flows seldom last longer than a day (Harcourt-Baldwin 2003). These modeling results support earlier research that concluded that water in the northern 3.73 miles of the bay exchanges with nearshore coastal waters on each tidal cycle (Hollibaugh et al. 1988). As distance increases from the mouth, the importance of tidal currents decreases relative to other mechanisms, including differences in density between the less-dense freshwater inflow and the more-dense saltwater tides (Harcourt-Baldwin 2003).

In the middle and inner portions of the bay, which are more uniformly shallow than the outer bay, density-driven flow circulation is the dominant process controlling water movement (Harcourt-Baldwin 2003, Gross and Stacey 2003). During the winter, the classic estuarine circulation pattern of gravitational circulation prevails, with less dense freshwater flowing over more dense seawater. Winter freshwater inflow enters Tomales Bay from two primary sources -- Lagunitas Creek near the Project Area and the head of the bay and Walker Creek near the mouth, generally creating a “lens” or layer of the less-dense freshwater on the surface and more dense seawater on the bottom. Lagunitas Creek accounts for 66 percent of the freshwater inflow to Tomales Bay, while Walker Creek represents approximately 25 percent, with the rest of the freshwater inflow coming from the numerous small tributaries to the Bay (Fischer et al. 1996).

The strength and persistence of the stratification depends on the intensity and duration of the freshwater inflow (Harcourt-Baldwin 2003). The estuary rapidly (< 1 day) returns to initial conditions after small freshwater inflow events (Harcourt-Baldwin 2003). This is evident from data collected during the LMER/BRIE study between 1985 and 1996 in which salinity was monitored synoptically at least every two months when water samples were collected. Despite the fact that some sampling occurred during the winter, salinities in the open water portions of the Bay averaged 32.4 ± 2.8 (SD) practical salinity units (psu; ocean water =~ 35 psu), with the median salinity estimated at 33.3 psu (LMER/BRIE data). The strength of marine influences on the Bay are also evident in the 5th and 95th percentiles, estimated at 27.5 and 34.5 psu (LMER/BRIE data).

Because sampling was tied to collection of water samples roughly every other month, sampling events may not have always corresponded with storm events or post-storm event conditions with much higher than average freshwater runoff. Depending on rainfall patterns, these runoff periods can be short-lived in nature or “flashy” – a characteristic of the Mediterranean climate’s winters. Therefore, these runoff periods and their effect on salinity patterns may have been underrepresented relative to their actual frequency in the LMER/BRIE dataset. In addition, climatic patterns can also dramatically affect results: for six (6) of the 11 years of monitoring, California experienced drought conditions, with greatly reduced rainfall and runoff that was less than half the long-term average, although record rains were recorded in 1995 (Smith and Hollibaugh 1997).

While dry winters and episodic rainfall events may result in rapid returns to more uniform saline conditions, particularly in waters of the outer Bay, continuous or higher than average freshwater inflow often leads to stratification of the middle and inner regions (Harcourt-Baldwin 2003). Recent research in other estuarine systems, including San Francisco Bay, has shown that seasonal variability in stratification may also be accompanied by finer scale variation related to depth and tidal cycle, with unstratified conditions developing during spring tides or in shallower areas of channels and bays (Schoellhamer and Burau 1998). Spatial and temporal variability in stratification within Tomales Bay may result not only from factors such as depth and tidal cycle, but differences in freshwater inflow dynamics following storm events.

While Walker Creek and other small drainages flow into Tomales Bay along its entire length, as noted above, the majority of the Bay’s freshwater inflow comes from Lagunitas Creek at the head or southern portion of the bay (Fischer et al. 1996). This large volume of freshwater inflow creates a longitudinal salinity gradient between the southern end or head of the Bay and the northern end or mouth to the Pacific Ocean (Harcourt-Baldwin 2003). This gradient increases flushing or seaward movement of estuarine waters and increases exchange between the middle and outer estuarine regions.

The importance of gravitational circulation within the middle and inner bays decreases during the late spring and summer (Harcourt-Baldwin 2003). As freshwater inflow decreases over the summer, and evaporation increases, estuarine salinity in the middle and inner bays increases, reducing the longitudinal salinity gradient and, consequently, stratification based on difference in density between salt- and fresh waters (Harcourt-Baldwin 2003). The lack of a strong longitudinal salinity gradient within Tomales Bay decreases flushing times from a few days during the winter to approximately 120 days for at least the southern 9 miles of the bay during the summer (Hollibaugh et al. 1988).

In contrast to many other estuaries, however, the density gradient within the estuary does not disappear during the summer, but rather switches from a salinity-driven one to a temperature-driven one (Harcourt-Baldwin 2003). The temperature gradient balances warm temperatures in the middle and possibly inner Bay, which is shallow and more responsive to solar radiation, with upwelling of cold waters in the nearshore Pacific Ocean. Due to strong, persistent offshore winds that churn bottom ocean waters towards the surface during the spring and summer, cold, nutrient-rich water is upwelled along California's central coast (Smith and Hollibaugh 1998, Harcourt-Baldin 2003). The dense, cold upwelling water moves some distance landwards into the estuary with flood tides as a bottom current due to the fact that cold waters are denser than warm surface waters (Harcourt-Baldwin 2003). Significant subtidal intrusions of cold water have been observed a few times during some summers, with colder waters penetrating halfway into the middle and inner bays (Harcourt-Baldwin 2003).

These intrusions may represent key sources of nutrients, particularly organic carbon, during the summer to the estuary (Harcourt-Baldwin 2003). Additionally, this longitudinal temperature gradient maintains some type of exchange of waters between at least the outer and middle portions of the Bay (Harcourt-Baldwin 2003), which has important implications for summer water quality. Unlike many other shallow estuaries, including portions of San Francisco Bay, the strong spring winds along the coast, which, on average, can reach as high as 35 miles per hour (mph), do not appear to have a substantial effect on circulation within the Bay (i.e., inducing strong vertical mixing or turnover of waters), perhaps because of the sheltering effect of the steep Inverness Ridge along the western perimeter (Tomales Bay Shellfish Technical Advisory Committee (TBSTAC 2000).

The very innermost portions of Tomales Bay do not appear to be affected by intrusions of upwelling water, and the lack of a strong salinity or temperature gradient with the middle and outer bays can substantially decrease exchange and increase water residence times (Hearn and Largier 1997; Largier et al. 1997). The lack of connection with the ocean and outer bay can result in at least transient periods of hypersaline conditions, such that salinities slightly exceed salinity in the outer Bay or ocean because solar radiation increases evaporation of waters and concentration of existing salts (Hearn and Largier 1997, Largier et al. 1997). However, despite increases in salinity and temperature relative to the middle and outer bays, longitudinal salinity and temperatures are too weak to increase exchange. This weak temperature gradient between inner and outer portions of the Bay disappears during autumn, when solar radiation decreases, and water temperatures cool in the inner Bay (Harcourt-Baldwin 2003).

Occasionally, this autumn cooling, combined with hypersaline conditions, causes yet another circulation pattern to develop for several days that is common in more tropical estuaries, inverse circulation (Harcourt-Baldwin 2003). Inverse circulation results from evaporation concentrating salts in the now cooler surface waters, which then, because of higher density, sink to the bottom and flow oceanward beneath the less dense ocean waters. Hearn and Largier (1997) speculated that the degree of hypersalinity and the duration of inverse circulation, which results in greater exchange between inner and outer portions of the Bay, may have been greater during historic times than now. This change appears to have occurred, because the Bay has become shallower, and because minimum flow requirements within creeks cause reservoir releases of freshwater throughout the summer, decreasing salinities in the inner Bay (Hearn and Largier 1997, Largier et al. 1997).

This physical interface between freshwater and saltwater -- which, as suggested by monitoring and modeling results, can vary from year to year both spatially and temporally -- results in creation of a very dynamic portion of estuarine systems: the estuarine transition zone. Based on the volume of freshwater inflow, the Project Area represents the largest transition zone within Tomales Bay. Unlike salt marshes in marine-dominated systems, where salinities remain relatively constant throughout and between years, salinities change dramatically both within and between years in these transition zones in response to seasonal and annual changes in freshwater flow. Salinities within most estuarine transition zones vary markedly throughout the season, ranging from freshwater conditions (0.2 to 0.5 ppt) in the winter and spring to saline or euhaline (30-40 ppt) conditions in summer. Salinity conditions are not only determined by the volume and duration of freshwater flow, but by the forces driving circulation patterns as discussed above. One of the largest transition zones in the San Francisco Bay region is Suisun Bay in the San Francisco Bay – Sacramento Delta estuary.

These seasonal and annual changes in salinity within transitional zones can exert a tremendous influence on ecosystem dynamics by radically altering the diversity and types of organisms present, as well as influencing localized and downstream water quality conditions through sediment deposition and resuspension. Long term changes in freshwater flow related to decadal trends in climate or anthropogenic disturbances such as increases in freshwater flow diversion or increased freshwater flow during the summer can even alter the composition of vegetation communities.

One of the most well-studied components of transition zones in San Francisco Bay is the Low-Salinity Zone or X2. The LSZ or X2 refers to a hydrologic zone or geographically variable portion of the estuary with salinities of approximately 2 psu (~2 ppt), which has been used in San Francisco Bay as an index of the physical response of estuary to freshwater flow and the effect of freshwater diversions in the Central Valley (Kimmerer 2004). In San Francisco Bay-Sacramento Delta Estuary, investigations into the LSZ and target organism abundance have found significant relationships, at least some of the time, for estuarine-dependent copepods, mysids (*Neomysis mercedis*), bay shrimp (*Crangon franciscorum*), and several fish including longfin smelt (*Spirinchus thaleichthys*), Pacific herring (*Clupea pallasii*), starry flounder (*Platichthys stellatus*), Sacramento splittail (*Pogonichthys macrolepidotus*), American shad (*Alosa sapidissima*), and striped bass (*Morone saxatilis*; Kimmerer 2004). The timescale over which salinity changes can also have a profound effect on estuarine organisms, with gradual changes or stable conditions more beneficial for many species than abrupt changes or fluctuating salinity (Kimmerer 2004).

As will be discussed under Sediment Transport, salinity can also affect transport and depositional patterns of suspended sediments through creation of Estuarine Turbidity Maximum (ETM) or zones of increased suspended sediment concentration and deposition to a number of physical processes or properties, including gravitational or classic estuarine circulation, bathmetry, geomorphology, tidal cycles, and flocculation of river-borne sediments and organic material due to increased electrostatic charge of saltwaters (Arthur and Ball 1979, Schoellhamer 2001, Ganju et al. 2004, Kimmerer 2004) .

In addition to varying seasonally or in response to short-term climatic trends, salinities can also change in response to long-term factors such as climate change and its effect on sea level rise, ocean and estuarine circulation patterns such as upwelling, and freshwater runoff dynamics. In 2005, the USGS completed a relative coastal vulnerability study that depicted most of Tomales Bay as having low to moderate vulnerability to sea level rise (Pendleton et al. 2005). In the 1993 feasibility study (PWA et al. 1993), sea level was predicted to rise at a rate somewhere between 1.5 and 5.0 feet over the next 100 years. NOAA reports that, based on review of historic (1854-1999) water level gauge data, sea level has risen at a rate of 0.00328 to 0.0079 feet/year over the last century and that sea levels have risen 0.007 feet/year in San Francisco since 1906 (NOAA 2001 *in* KHE 2006a). Based on 25 years of Point Reyes water level records, NOAA predicts a local sea level rise rate of 0.0082 feet/year in this region (NOAA 2001 *in* KHE 2006a). From recent satellite altimetry studies, Cazenave and Narem (2004) report a "very accurate" sea level rise rate of 0.0092 ± 0.0013 feet/year for the 1993-2003 decade. This rate is notably higher than what NOAA's rate of change based on measured changes in tide gauges over the preceding half century (KHE 2006a).

Within the past few years, climate change researchers, including a group from University of Arizona, the National Center of Atmospheric Research, and other institutions, have postulated that accelerated melting of the Arctic and Antarctic ice caps and Greenland glaciers could raise sea level by as much as 3 feet by the end of this century and 13 to 20 feet in coming centuries (Overpeck et al. 2006; Velicogna and Wahr 2006). However, despite these relative high profile studies, many researchers continue to rely on more conservative rates of sea level rise estimated by the Intergovernmental Panel on Climate Change (IPCC), which most recently estimated sea level rise of 1.7 feet (0.5 m) within the next 100 years.

Project Area

Lagunitas Creek

While earlier studies reference the "Inner Bay" of the Tomales Bay watershed, the boundaries for most of these studies or models end well ocean-ward of the Project Area. The Project Area is located in an area of the estuary that would constitute what could be called the "Inner Inner Bay." This "Inner Inner Bay" represents one of the largest estuarine transition zones in Tomales Bay, areas characterized by the dynamic interface both seasonally and interannually between freshwater and saltwater. This portion of the Bay is characterized by even shallower bathymetry than the Inner Bay, prominent gravel and sand bars in creek channels, and large expanses of undiked tidal marsh and intertidal mudflat, some of which is being actively colonized by Pacific cordgrass (*Spartina foliosa*).

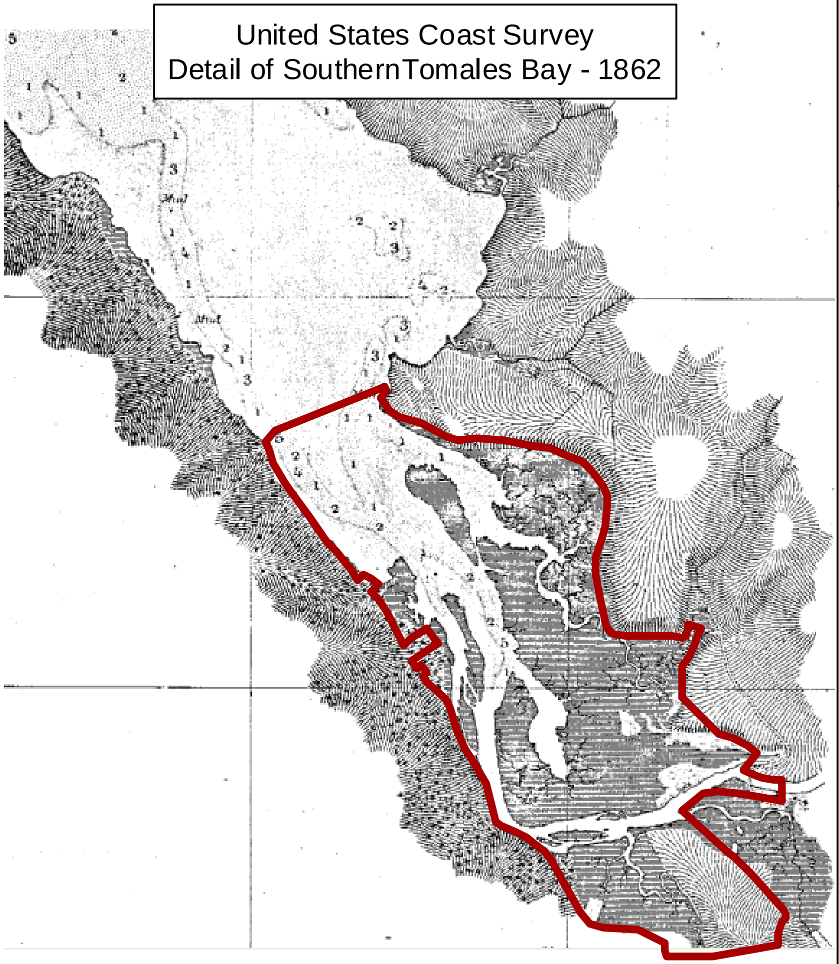
In actuality, the "Inner Inner Bay" is part of the Lagunitas Creek – and, to a lesser extent, Fish Hatchery Creek – alluvial delta and is, therefore, dominated more by fluvial than tidal processes (KHE 2006a). The importance of tidal processes may have been higher historically. Prior to 1862, a substantial amount of the Giacomini Ranch was actually open water and intertidal mudflats, with the historic coastal salt marsh concentrated in the eastern portion of the Giacomini Ranch, Olema Marsh, and the mouth of Olema Creek (PWA et al. 1993, Niemi and Hall 1996, Figure 8). At that time, tidal influence is believed to have extended as far south as Bear Valley during extreme storm tides (Evens 1993).

However, during the latter half of the 19th century, sedimentation rates rose dramatically, resulting in rapid deltaic aggradation of coarse alluvium in the southern end of Tomales Bay (Figure 8). This increase in sedimentation probably resulted from an increase in logging and other changes in land use practices (PWA et al. 1993, Niemi and Hall 1996), but undoubtedly was exacerbated by the geologic instability characteristic of this region. Between 1860 and 1950, approximately 5 vertical feet of sediment are estimated to have been deposited within southern Tomales Bay (PWA et al. 1993). The Lagunitas Creek delta more than doubled in acreage and length during this period, with the tip of the delta extending approximately another 2,100 feet beyond its 1863 boundaries by 2001. The greatest sedimentation occurred between 1860 and 1910 (PWA et al. 1993; Figure 8).

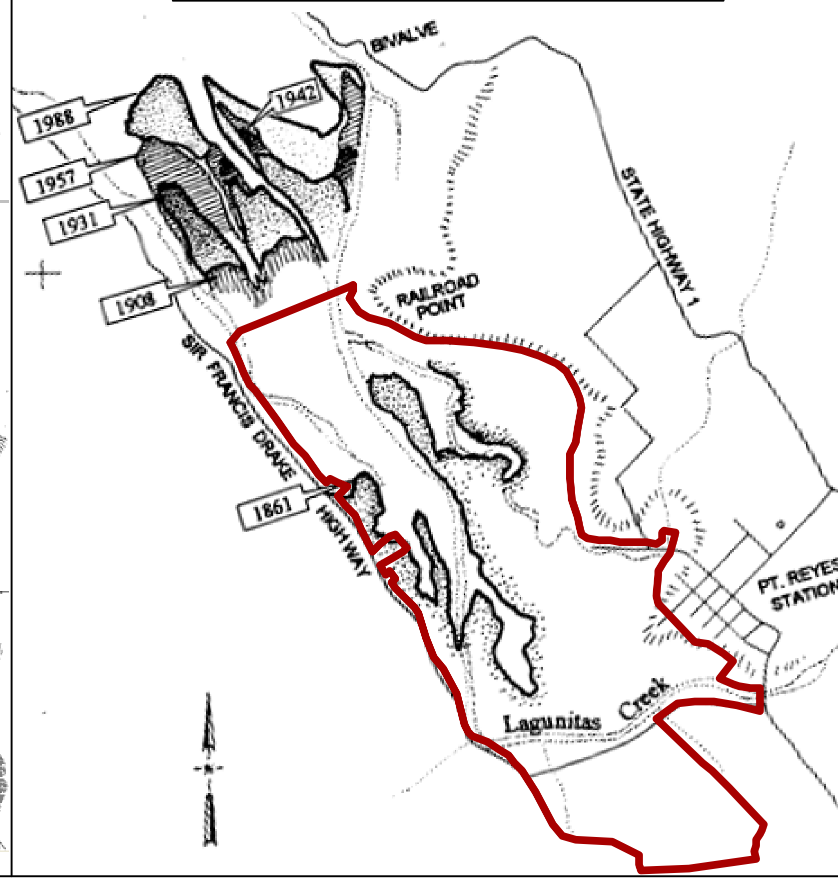
Historic Map of Southern Tomales Bay

Giacomini Wetland Restoration Project

United States Coast Survey
Detail of SouthernTomales Bay - 1862



Expansion of Lagunitas Creek Delta
Location of Marsh Edge from 1861-1988



National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA

Source: Maps provided by Phillip Williams and Associates, Ltd., 1993
San Francisco, California

Figure 8

The 1906 earthquake may have subsequently "drowned" some of this deltaic aggradation. The surface rupture caused by the 1906 earthquake extended from Bolinas Lagoon to Tomales Bay, with lateral displacement ranging from 14 to 20 feet in the Olema Valley (Gilbert 1908). Despite the earthquake, sedimentation and deltaic aggradation continued to be high until at least the 1950s, when construction of several dams and reservoirs began to curtail sediment delivery (Figure 8). By the early 1940s, rapid sedimentation had converted this open water/mudflat-marsh area from the tidally dominated system depicted in the 1863 map to a fluvial or creek-dominated one, with remnants of the tortuously meandering sloughs once present and characteristic of tidal systems restricted to the eastern perimeter of what would become the East Pasture.

The topographic map of the Giacomini Ranch prepared by the (USGS 2003b) indicates that, as with many deltas, the pasturelands of the Giacomini Ranch are sloped downwards as distance to the Bay decreases (Figure 9). In general, the East Pasture is highest along the south margin (11- to 16 feet NAVD88) and slopes down to an average elevation of 4-feet NAVD88 (KHE 2006a). This sloping surface is part of two similar geomorphic features, one being the face of a natural alluvial fan building out onto the historic marsh plain from the mouth of Lagunitas Creek and the other being a wedge of fine grained sediment splayed onto the East Pasture through a low spot in the levee during repeated flooding (KHE 2006a). The east half of the West Pasture (located immediately west of the Lagunitas Creek levee) slopes gently and evenly from approximately 8-feet NAVD88 at the south end to 5-feet NAVD near the North Levee (KHE 2006a). A slope also exists from east to west, with ground surface elevations along the western margin of the West Pasture and along Sir Francis Drake Road ranging from 14-feet NAVD88 (at the south end) to 21-feet NAVD88 (at the north end; KHE 2006a). Topography in the West Pasture is heavily influenced by alluvial fans that have formed at the mouths of several creeks that discharge onto the West Pasture along the base of Inverness Ridge (KHE 2006a).

Diking of the Project Area has not resulted in extensive subsidence or lowering of elevations within the Giacomini Ranch. In San Francisco Bay, marshes largely developed from organic- or peat-rich clay materials that rapidly compacted once levees were constructed between the 1860s and 1960s. The base elevation of diked marshes in San Francisco Bay is often 7- to 12- feet below that of undiked areas, and subsidence is even greater in the Sacramento Delta, often ranging between 15- to 20-feet. Conversely, in Tomales Bay, there was a period of rapid marsh formation in the late 1860s and early 1900s in response to increased sedimentation within watershed tributaries. Many of these "young" marshes were largely composed of low-organic coarse alluvial mineral soils that have compacted little, if at all, if and when these marshes were diked (Parsons et al. 2004). Elevations of the adjacent undiked marsh to the north of the Giacomini Ranch range from +3 (low marsh) to +7 feet (high marsh/upland ecotone) NAVD88, with the marsh plain at approximately +5 to +6 feet NAVD88 (USGS 2003b). This information suggests that elevations behind or inside the levees have decreased, at most, 1- 2 feet at the northernmost portions of the Giacomini Ranch and have aggraded within the southernmost portions. Some of the aggradation may result from land leveling and deposition of fill and manure, but the Giacominis also removed the southwestern portion of the East Pasture levee deliberately to preferentially direct flood flows into this portion of the property (KHE 2006a). This dynamic is illustrated in Figure 9, which shows higher elevation areas that would not be subject to tidal flooding even if levees were not present in green: Subtidal and lower intertidal areas exist only in existing creeks, sloughs, and ditches.

The importance of fluvial geomorphic processes within the tidally influenced sections of Lagunitas Creek is evident not only from the deltaic morphology and the presence of alluvial fans, but in the series of gravel and sand bars that have formed from the Green Bridge to the open water portions of Tomales Bay in response to episodic flooding. These gravel and sand bars strongly regulate circulation patterns in this reach of Lagunitas Creek. As with any dam, gravel bars or sills in estuaries can impound waters and disrupt tidal circulation patterns through causing tidal truncation or reduction in the extent of drainage during low tides and increasing water residence time.

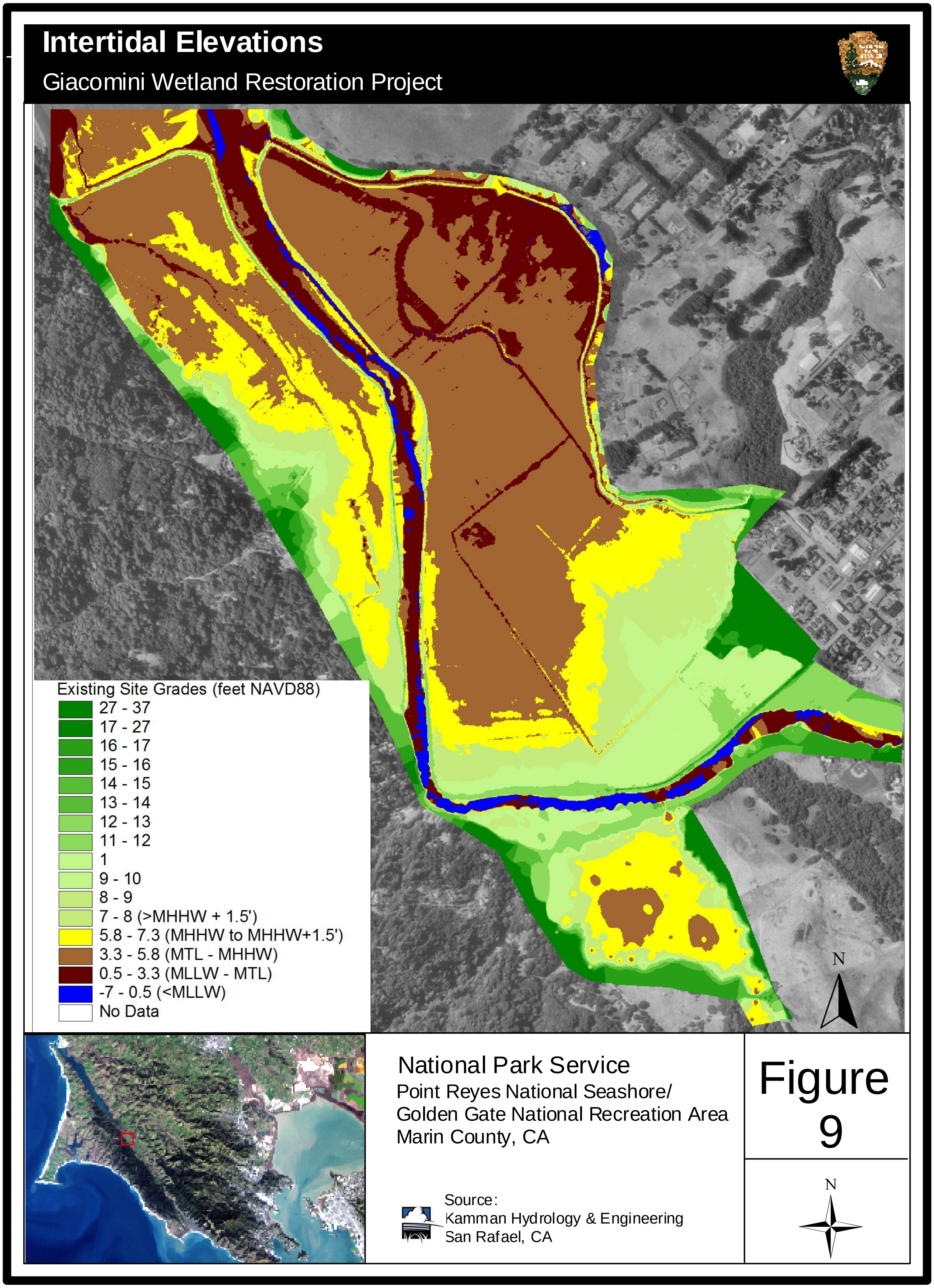

Intertidal Elevations
Giacomini Wetland Restoration Project
Existing Site Grades (feet NAVD88)
27 - 37
17 - 27
16 - 17
15 - 16
14 - 15
13 - 14
12 - 13
11 - 12
1
9 - 10
8 - 9
7 - 8 (>MHHW + 1.5')
5.8 - 7.3 (MHHW to MHHW+1.5')
3.3 - 5.8 (MTL - MHHW)
0.5 - 3.3 (MLLW - MTL)
-7 - 0.5 (<MLLW)
No Data
N
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
Source:
Kamman Hydrology & Engineering
San Rafael, CA
Figure
9
N

Figure 10 is a schematic longitudinal profile of channel bed and top of bank elevations, as well as water levels, along Lagunitas Creek through the Project Area from the Green Bridge at the southeastern end of the Project Area to the Ranch's northern levees at the northern end of the Project Area. There are two major gravel or sand bars within the Project Area that affect circulation patterns: one is located near where the Giacomini Ranch cows cross Lagunitas Creek to reach the West Pasture (cattle crossing), and the other occurs just south or upstream of the Giacomini Ranch North Levee (KHE 2006a). This graphic shows the weir-type effect that these gravel bars have on water levels, with the base or minimum water levels observed increasing in elevation in a step-wise manner in an upstream direction (KHE 2006a). Within this section of creek, the gravel bars appear to function as a series of "dams" that truncate tidal amplitude and preclude upstream waters from draining completely.

While, from a tidal perspective, these sills limit drainage during low tides and decrease the amount of exposed mudflat available for species such as shorebirds, from a fluvial perspective, these sills create deepwater, almost lagoonal-type pools that are somewhat analogous in function to pools found in creeks in the upper portion of the watershed. Both types of pools provide important permanently flooded habitat for many aquatic species. Retention of water upstream of gravel bars can reduce water quality through decreasing dissolved oxygen concentrations, but tidal exchange during high tides can decrease the potential for stagnant conditions to develop.

The broad and long gravel bar just south of the Giacomini Ranch North Levee controls the lowest water level observed between the North Levee and the cattle crossing location so that water levels do not drop below approximately 1.9-feet NAVD88, even though portions of the channel are 0-feet NAVD88 (KHE 2006a; Figure 10). Circulation patterns within this reach vary seasonally, but, based on long term monitoring data, are typically either well-mixed (fresh in the winter and saline in the late summer-fall) or partially stratified (partial stratification of freshwater at the water surface), although strong stratification occurred very infrequently. The shallowness of this reach, combined potentially with currents and wind, appear to discourage stratification.

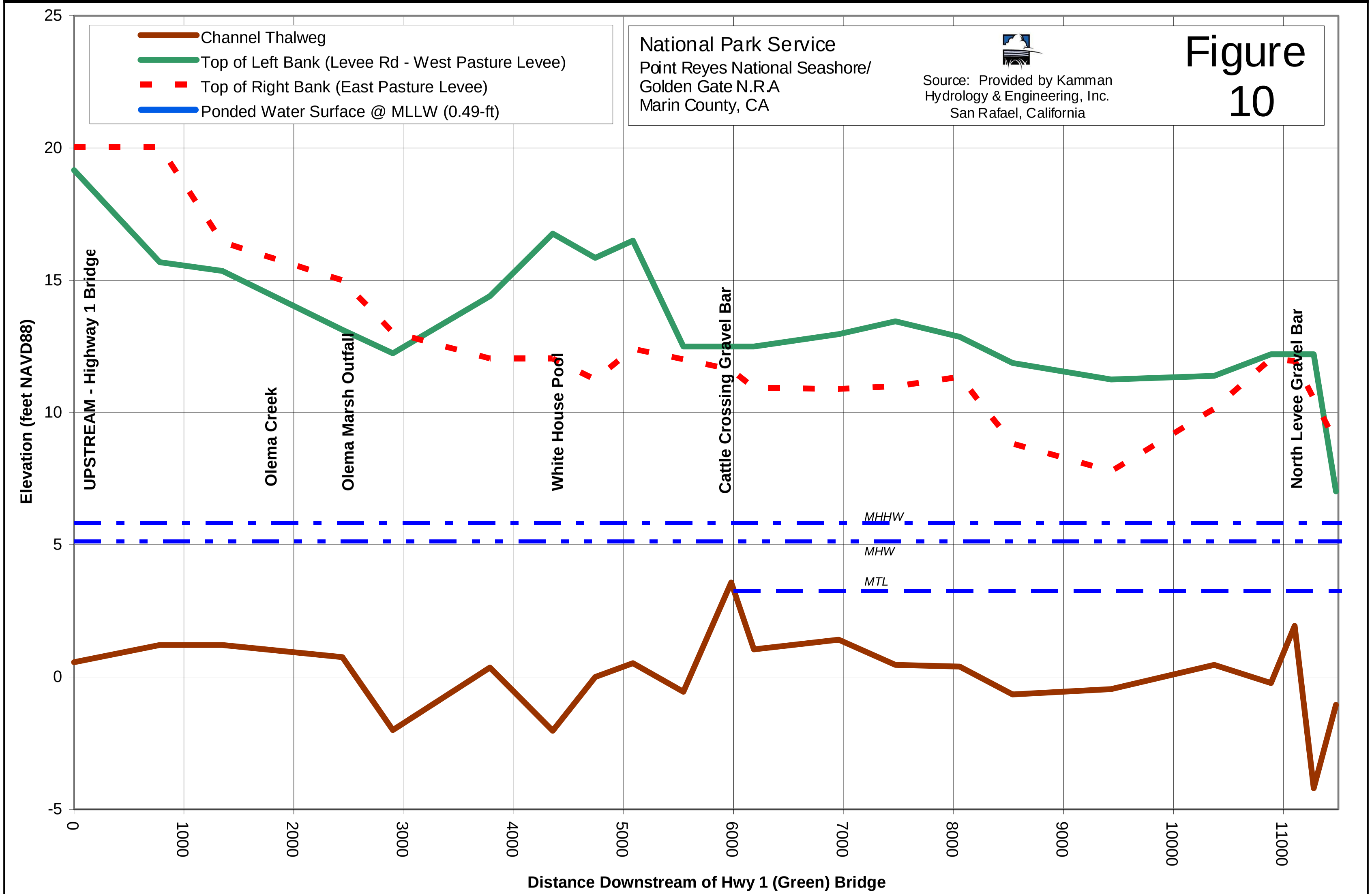
Within the Project Area, salinities in Lagunitas Creek between the Green Bridge at the northern end and West Pasture North levee at the southern end averaged 6.5 ± 8.6 (SD) ppt, with the 5^{th} and 95^{th} percentiles estimated at 0.1 and 26.4 ppt. These salinities support the characterization of this portion of Lagunitas Creek as being primarily brackish in nature and acting as an estuarine transition zone between upstream freshwater influences of the surrounding watershed and marine or estuarine influences of Tomales Bay and the Pacific Ocean. North of White House Pool, salinity typically ranges from 0.1 ppt in the winter to 25-30 ppt in the summer. At the northern end of the Project Area, fresh to slightly brackish conditions (0.1 ppt) are present typically only during the months with rain, with salinities climbing rapidly to 20 to 30 ppt starting in early summer.

The influence of bathymetry on salinity concentration and structure is not only apparent from the stratification within the "Pool" at White House Pool, but the fact that, occasionally, higher salinity waters appear to pool between the cattle-crossing location and North Levee gravel bars, creating a saltwater "pool" in the midst of the Project Area. In October and November 2003, higher salinity waters ranging around 28 ppt were observed midway through the Project Area, while waters downstream at the North Levee ranged from 21 to 24 ppt. Hydraulic modeling results point to the cattle crossing gravel bar having a significant effect on salinities within the creek: if the gravel bar were not present, maximum salinities within the creek upstream of White House Pool could increase by as much as 35 percent (KHE 2006a).

Upstream of the cattle crossing location and another prominent gravel bar, the creek becomes noticeably narrower and deeper, functioning almost like what is called a glide with relatively deep water and low velocities. The cattle crossing gravel bar again increases the amount of truncation in the observed low or minimum tidal water levels within Lagunitas Creek at approximately 2.8-feet NAVD88 (KHE 2006a; Figure 10). Circulation patterns within this reach differ noticeably from

Topography and Bathymetry of Lagunitas Creek Channel Banks and Bottom

Giacomini Wetland Restoration Project



those downstream. While both upstream and downstream reaches are well-mixed and fresh during winter and spring, the White House Pool reach becomes strongly to at least partially stratified during summer and fall, probably due to the decreasing, but continued, influence of freshwater inflows. The degree of stratification may also be driven by tidal cycle, as other researchers have noted more stratification during neap tides or low tide conditions (Reed and Donovan 1994; Schoellhamer 2001).

Monitoring data shows that, in the winter (December – April), very uniform freshwater conditions (< 1 ppt) can persist in the Green Bridge – White House Pool reach until June or July. For example, during June 2003, salinities increased above freshwater conditions everywhere except at the Green Bridge, with slight stratification within the White House "Pool" (e.g., 0.9 to 1.3 at the surface and 2.5 to 2.8 at the bottom). Strong stratification starts to occur in this reach of the creek in June or July with as much as 16 ppt difference in salinities in surface and bottom waters. For example, during July 2003, surface salinities at White House Pool were measured at 3.7 ppt, with bottom salinities of 21.6 ppt. In August and succeeding fall months of that same year, the degree of stratification upstream of White House Pool decreased or even disappeared at times and appeared to become more dependent on an interaction between freshwater flows and the phase of tidal cycle. In the late fall, surface salinities once reached as high as 14 ppt near the Green Bridge, but salinities are typically much lower (< 5 ppt). During a one-day synoptic sampling of salinity and depth on October 24 in 2003, partial stratification in this reach was still evident, with surface salinities ranging from 9.6 to 12.9 ppt and bottom salinities ranging from 16 to 22 ppt (Allen and Donovan 2003; Appendix E). During this period, the so-called LSZ, represented by bottom salinities of 2 ppt, entirely disappeared from this section of Lagunitas Creek.

Summer and early fall freshwater inflow to the Project Area is maintained at minimum levels during both average (8 cfs) and dry (6 cfs) years due to releases from reservoirs mandated by the SWRCB (95-17), which may affect not only overall water salinity, but salinity structure in the Project Area. In unregulated systems within Mediterranean climate systems, salinities might increase steadily in response to natural hydrologic patterns of steady decreases in freshwater inflow superimposed over small-scale daily variations in evaporation and evapotranspiration. Diurnal variations in flow from evaporation or evapotranspiration associated with vegetation represented as much as 10 percent of the mean stream discharge for the Merced River, with rate dependent on total vegetation cover and ambient temperatures (Lundquist and Cayan 2002).

However, in regulated systems such as Lagunitas Creek, salinity structure may also be influenced by daily variation in reservoir releases, as well as pumping or withdrawal rates for wells and other stream diversions. Randomly selected average daily discharge data from the USGS Point Reyes Station gage shows some interesting small-scale variations in freshwater inflows during the summer of 2001 and 2002 (Figure 11). This gage is far enough upstream that it is not subject to tidal influence, except during extreme events (G. Kamman, KHE, *pers. comm.*). For example in 2001, stream discharge dropped from 12 cfs to 6.75 cfs within approximately 9 days, followed by a sharp, temporary increase from 7.0 cfs to approximately 9.4 cfs over a period of one to two days (Figure 11). In summer 2002, stream discharge dropped from 13 cfs to 9.5 cfs over 1 to 2 days, followed later by a sharp increase by approximately 2 cfs over another 1 to 2 days (Figure 11). Whether natural or unnatural, fluctuations in freshwater inflow, particularly sharp ones, as shown in Figure 11, would have substantial effects on salinity patterns and structure, both within stratified and mixed portions of the creek. Hydrodynamic modeling results for Lagunitas Creek suggest that changes in stream discharge of 2.0 cfs can result in increases in doubling or 100 percent increases in maximum water salinities (KHE 2006a).

Changes in mandated stream baseflow due to the SWRCB decision in 1995 may also account for the large variation seen in average salinities at the Giacomini Ranch North Levee between the LMER/BRIE study conducted from the summer of 1987 to September 1995 and our study conducted from 2002 to 2006. Salinities averaged 30.0 ± 6.6 (SD) psu (~ppt) during the eight-year LMER/BRIE study period, which included consistent sampling during winter and early spring months, when salinities would have been expected to have been fairly low (LMER/BRIE data). The mean was not skewed either by occasional spikes in salinity, because the median was actually higher (32.1 psu), with the 5th and 95th percentiles estimated at 14.7 and 35.8 psu, respectively (LMER/BRIE data). Conversely, during our monitoring, salinities at the Giacomini North Levee averaged 13.7 ± 10.7 (SD) ppt , with a median of 11.1 ppt and estimates for the 5th and 95th percentiles of 0.1 and 30.2 ppt, respectively (Figure 12). Granted, the LMER/BRIE study was conducted largely during a drought period with higher-than-average rainfall occurring only in the very latter years of sampling (Smith and Hollibaugh 1997), however, some of the substantial decrease in average salinities must also be attributed to the effect of a mandated increase in stream baseflow that effectively pushed back the salt wedge downstream towards Tomales Bay during the summer. If so, this change had a considerable impact on habitat structure and conditions within this reach of Lagunitas Creek, which was exactly the intent of this SWRCB decision.

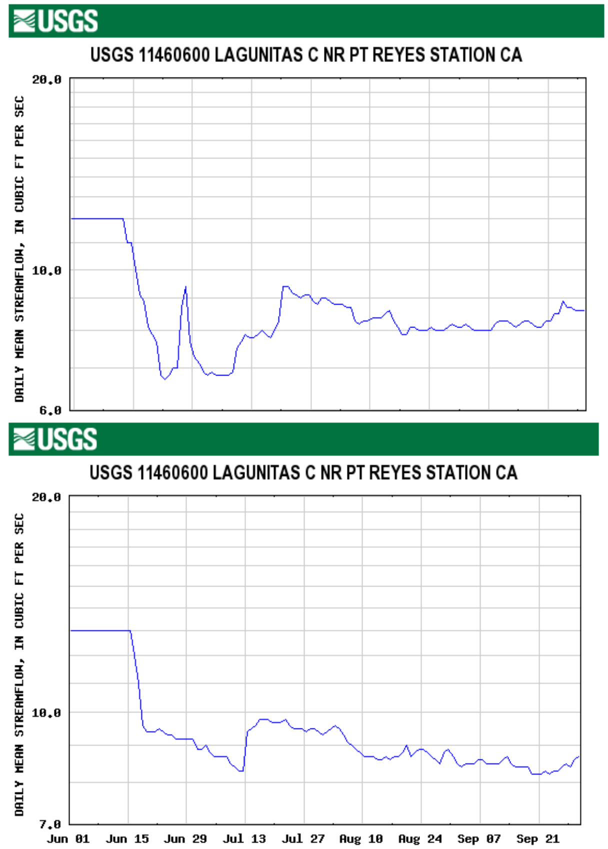


FIGURE 11. Lagunitas Creek – Point Reyes Station USGS stream gage. Daily average flow, June 1- September 30, 2001 (upper); Daily average flow, June 1-September 30, 2002 (lower)

Stratification within the Green Bridge- White House Pool reach during summer and fall could result either from reestablishment of gravitational or classic estuarine circulation driven by the opposing forces of tidal currents and reservoir release- regulated freshwater inflows – the pattern in much of the open waters of Tomales Bay – or stratification or resorting of "pooled" waters based simply on vertical differences in density. While the strength of tidal currents decreases at least by tenfold in the "inner" bay relative to the mouth of Tomales Bay (Smith et al. 1971), the presence of longitudinal salinity gradient between the Green Bridge and White House Pool during the summer and fall suggests that gravitational circulation might be occurring despite the shoaling effect on tidal flows caused by the downstream shallow creek channel and gravel bars. Longitudinal salinity gradients, particularly strong gradients, are associated with gravitational circulation patterns (D. Schoellhamer, USGS, *pers. comm*.).

Near and upstream of the Green Bridge, Lagunitas Creek is primarily a fluvial system, although it continues to be influenced by tides. Scour pools within the Green Bridge reach appear to be partially stratified for most of the summer and fall, although strong stratification may occur during higher high tides. Directly upstream of the Green Bridge, Lagunitas Creek transitions into a predominantly freshwater system such that salts are only present in detectable and comparatively small amounts during high tide conditions, with freshwater conditions quickly restored during low and neap tide conditions (KHE and NPS data; Appendices B3, D2, D3.2-D3.4, D4.1). Conditions are often fresh (<0.2 ppt), except during higher high tides when salinities increase after a short time lag to approximately between 1 and 1.6 ppt (NPS and KHE data; Appendices B3, D2, D3.2-D3.4, D4.1). Just upstream of the Coast Guard wells, the influence of tides on salinity structure of the creek is even further reduced (<<<< 1 ppt; NPS data; Appendices D4.2-4.3). Even further upstream, such as at or upstream of the NMWD Downey Well, the influence of tides is restricted to changes in water levels with no change in salinities (KHE data; Appendices D3.1-3.4).

Bear Valley Creek and Olema Marsh

Circulation patterns within Bear Valley Creek and Olema Marsh are poorly understood. Tidal influence on circulation is limited to the furthest downstream portions of Bear Valley Creek that receive some tidal action during high tide events. Upstream of the culvert on Levee Road, most of the influence on circulation comes from the dense vegetative structure within the marsh, the berm that limits outflow from the one remaining culvert at Levee Road, and the culverts themselves. Tidal exchange upstream of the culvert does not occur unless tides exceed 4.5 ft NAV88, and, even then, the effects of this exchange appear to be limited to areas downstream of the berm that acts as a funnel or control on both outflow from and inflow to Olema Marsh (KHE 2006a).

Circulation patterns, then, within the marsh and creek are probably driven by several factors. The dense vegetation, berms, and culverts act to reduce velocities and outflow rates of Bear Valley Creek streamflow, thereby creating a pond effect within the marsh. At this point, circulation patterns would seemingly begin to resemble those of lakes and other impounded water bodies than creeks in the estuarine transition zone. In deeper areas, waters would potentially become temperature- rather than salinity stratified, particularly in spring, with dense, cooler waters at the bottom overlain by warmer surface waters exposed to thermal radiation. This thermal stratification could persist until late fall or early winter, when cooling ambient air temperatures reduce the temperatures of surface waters and potentially allow for greater mixing between bottom and surface waters. Wind-mixing is unlikely to play a large role in “overturn” of marsh waters, because the marsh is relatively sheltered from the Bay’s winds and the dense vegetation in the marsh would reduce the ability of the wind to mix waters.

Within the primary Bear Valley Creek channel, salinities averaged 1.7 ± 5.2 (SD) ppt, with the 5^{th} and 95^{th} percentiles estimated at 0.1 and 9.9 ppt (Figure 12). Salinities never exceeded 0.2 ppt upstream of Bear Valley Road and only exceeded 0.2 ppt upstream of Levee Road on two (2) of nine (9) sampling events between 2004 and 2006. No consistent salinity sampling has been conducted in the marsh itself, however, the type of vegetation presents attests to the marsh almost exclusively freshwater in nature.

Giacomini Ranch

Tomasini Creek

As with Fish Hatchery Creek, circulation patterns of Tomasini Creek have been strongly driven by the failed tidegate structure, as well as potentially by other topographic features within the channel. As discussed earlier, because the tidegate structure has failed, Tomasini Creek still experiences substantial tidal exchange over the upper portion of the tidal range, with only minor reduction of the peak flood-tide water levels of less than 0.5-feet (KHE 2006a, Appendices B4-B6). Tidally driven fluctuations in water level -- at least in upstream portions of the creek -- appear to occur when high tide water levels exceed the base level of 4.5-feet NAVD88 (KHE 2006a). However, the gate-dam structure continues to truncate low tides or control the extent of drainage during low tides to approximately 2.0-feet NAVD88, at least 1- to 2 feet above the deepest portions of the channel (KHE 2006a, Appendices B4-B6). This maintains subtidal conditions even during the lowest low tides through most of the lower sections of Tomasini Creek.

Based on results of hydraulic and hydrodynamic modeling, the tidegate-dam structure did not appear to be the only feature that is acting to impound water (KHE 2006a). As with Lagunitas Creek, several topographic features within the creek channel appear to control low or minimum water levels – one between the tidegate and the Giacomini Hunt Lodge and one closer to Mesa

Road (KHE 2006a). Close to Mesa Road, an extended debris and sediment jam occurs just downstream of the Mesa Road culverts at a point where the creek gradient flattens. This debris and sediment jam appears to have hydrologically disconnected the lower reach from the upper reach, at least during low flow conditions, thereby limiting water and tidal exchange. Surface water often disappears just below the debris jam during the late summer and fall until the creek reaches the tidally influenced portion of Tomasini Creek near the Giacomini Hunt Lodge.

Between 2002 and 2006, salinity concentrations within Tomasini Creek varied between a maximum of 27-ppt during the summer and 0.1-ppt during the winter (KHE 2006a). Water salinities averaged 6.8 ± 9.1 (SD) ppt, with 5^{th} and 95 percentile salinities ranging from 0.1 to 24.5 ppt (Figure 12). As with Lagunitas and Fish Hatchery Creeks, the creek appeared to be well-mixed and largely fresh during the winter and early spring. Starting in late spring and extending through late fall, most of the creek remained well-mixed -- or at least partially stratified -- but salinities were more brackish, varying both spatially and temporally along the creek, seemingly in response to the phase of tidal cycles and decline in surface and subsurface creek flow. (The downstream end near the tidegate was typically well-mixed and brackish throughout the year.)

As with Fish Hatchery Creek, a "salt wedge" appeared to move up the creek as freshwater inflows decline during the summer and fall. The movement of the salt wedge upstream resulted in mixed or weakly stratified brackish water conditions (~18 – 22 ppt) occurring near the Giacomini Hunt Lodge by early- to late summer (KHE 2006a; Appendix D5.1). The advance of the "salt wedge" appears to be blocked by the debris and sediment jam south of Mesa Road, however. While early hydrodynamic modeling results suggested that, based on creek gradient, tidal influence could extend as far as Mesa Road (KHE, unpub. data), creek waters near Mesa Road have almost always been fresh (0.1 ppt) and well-mixed.

Brackish salinities persisted in the central portions of the diked section of Tomasini Creek even when surface flows in upstream portions of Tomasini Creek disappeared. Groundwater seepage from the Point Reyes Mesa may have contributed to creek hydrology through run-off from hillside springs, seepage along the base of the Mesa, and subsurface groundwater inflow. Salinities simulated from modeling based on creek flows and attenuated tides, but not groundwater, suggested that the contribution from groundwater to the Tomasini Creek water budget may have been considerable (KHE 2006a). Based on modeling, salinities near the Giacomini Hunt Lodge during the summertime with typical low summer flows should have ranged from 20.5 to 25.0 ppt (KHE 2006a), but actual salinities recorded during monitoring by the Park Service show that salinities ranged from 15.0 to 18.0 ppt in both surface and bottom waters.

While the creek was generally well-mixed or only partially stratified, it did occasionally become strongly stratified. During some of these periods when this reach was strongly stratified, bottom salinities exceed that of upstream and downstream (bayward) monitoring locations, suggesting that saline waters may have pooled in this section of creek, perhaps in response to an earthen sill or other topographic feature downstream.

East Pasture

Circulation patterns and salinity structure in the drainage ditches and ditched sloughs of the East Pasture have been strongly influenced by seasonal storage of precipitation and run-off, as well as irrigation waters during the summer. While these ditches and old sloughs were not directly influenced by tides, they did show seasonal patterns and stratification in salinities. However, the patterns in salinity structure were somewhat reversed relative to undiked systems.

For example, during the summer and fall 2003-2004, salinities within the drainage ditches and East Pasture Old Slough remained relatively low (~0.2 to 0.8) probably due to pumping of irrigation water into the ditch and slough system. However, during the months of January through March, salinities within the ditch and Old Slough actually increased to between 1.5 to as high as

9.4, with stratification of fresh and saltwater occurring in some of the relatively deep sections. Starting in April or May, salinities decrease again and remain low until the following January. Storage of irrigation waters appeared to drive down salt concentrations during the summer months. The only exception to this is the very northern end of the East Pasture Old Slough, which, despite being cut off from Lagunitas Creek by a dike and one-way flapgate, showed more typical patterns in salinities, with salinities increasing through the summer and fall and dropping during the winter.

Water salinities in East Pasture ditches and ditched sloughs averaged 2.6 ± 5.5 (SD) ppt, with 5th and 95 percentile salinities ranging from 0.1 to 14.5 ppt (Figure 12). Areas such as the shallowly flooded vegetated flat near the Point Reyes Mesa and the New Duck Pond were often seasonally flooded, with salinities averaging approximately 4 and 1 ppt, respectively. Only the drainage ditch in the Tomasini Triangle at the base of the north-facing Dairy Facility Mesa slope showed consistently fresh- to very low brackish salinities, with salinities never exceeding 0.6 and averaging 0.2 ppt.

While the groundwater table underlying the Point Reyes Mesa would be considered “fresh,” groundwater within the East and West Pastures is saline, with salinities generally ranging from 5- to 12 ppt (brackish) in most of the sampling areas, although salinities in one well reached more than 60 ppt (hypersaline) at times according to results of Park Service groundwater monitoring (Appendices C2.1-C2.10). Even the highest elevation area of the East Pasture that appears to be strongly influenced by groundwater from the Mesa had salinities as high as 5-6 ppt, which is brackish. The source of salts for surface waters within diked portions of the East Pasture seemingly came from persistence of residual marine salts deposited when the areas were not diked (KHE 2006a). In addition, the northeastern portion of the East Pasture was being affected by tidal inflows from Tomasini Creek that are being routed through a culvert in the levee into the drainage ditch and shallowly vegetated flat used by waterfowl and shorebirds. Salinity of groundwater was consistently higher throughout the year than that of surface waters, probably due to the limited infiltration of irrigation waters and direct contact with soil horizons containing high concentrations of residual salts.

Research conducted on the groundwater aquifers within the Point Reyes Station area have documented elevated chlorides, an indicator of salinity, in groundwater, even during the winter (Questa Engineering Corp. 2001). However, groundwater within the East Pasture displayed an ionic composition more characteristic of marine systems than that of the local aquifers or that would be expected from the presence of cattle and other agricultural practices such as manure spreading. Salts observed within groundwater, then, appeared to be marine salts that were trapped within sediment during deposition prior to diking of the pastures (KHE 2006a). These salts are bound tightly to clay sediments and apparently leach into the groundwater table when it comes into contact with the clays. As noted earlier, early attempts by the Giacominis to use groundwater from two wells installed at the southeast portion of the East Pasture for irrigation failed due to poor water quality (SWRCB 1995).

Groundwater salinities were quite variable in the northern and central portions of the East Pasture, ranging from 0.1 ppt to as high as 38 ppt from fall 2002 through spring 2006 during the three years of monitoring, although salinities typically ranged between 10- to 25 ppt (Appendices C2.1–C2.4). Salinities in the southern portion of the East Pasture, which represents the highest elevations, ranged from only 2- to 5 ppt (Appendices C2.5-C2.6), probably due to the minimal influence of tides historically at the base of the alluvial fan and the presence of significant groundwater seep and spring flow from the Mesa. Groundwater salinities in the Tomasini Triangle in the far eastern portion of the East Pasture surprisingly ranged as high as 5- to 9 ppt (Appendices C2.8–C2.11). Based on modeling, topography, and historic maps, this area appears to have once been part of an alluvial fan or plain at the mouth of Tomasini Creek and, at least based on current topography, would be above the influence of almost all tides (KHE 2006a). However, the presence of elevated bromides during a one-time sampling of the ionic composition of the groundwater table suggests that salinities are a result of tides and not grazing and other agricultural practices that can also increase salts in the soils and water table.

Fish Hatchery Creek

Circulation patterns in the diked portion of Fish Hatchery Creek have been largely dictated by the tidegate structure, as well as the creek's shallow nature. The tidegates on Fish Hatchery Creek reduced amplitude of both the low and high tides to 3.25 feet and 5.25 feet NAVD88, respectively (KHE 2006a; Appendices B7-B8). Waters within this system have been usually shallow (<25 cm) and well-mixed or weakly stratified, although strong stratification occurred periodically with occurrence dependent on the interaction between freshwater inflow and tides. Salinity ranged from perennial fresh waters at the furthest upstream location near Sir Francis Drake Boulevard, progressing toward more saline and seasonally variable waters downstream in the West Pasture. During the summer and fall, salinities at the North Levee and in the undiked portion of Fish Hatchery Creek were closer to euhaline, ranging from 20 to 30 ppt.

Within these lower sections of Fish Hatchery Creek, uniform or partially stratified waters that were slightly brackish to saline depending on distance upstream occurred within the creek through September (0.3 ppt in upstream sections to 31 ppt in downstream sections). Stronger stratification sometimes occurred in deeper sections of the creek starting in October. For example, in November 2003, salinities of 0.4 ppt were recorded at the water surface at one of the central sampling locations in Fish Hatchery Creek, with salinities of 24.1 ppt recorded at the creek bottom. This periodic stratification resulted from movement of the "salt wedge," or edge of tidal influence, into upstream sections of the creek over the season, as the volume of permanent freshwater flows decrease. Stratification within these deeper sections disappeared during some of the early winter storms, with conditions turning uniformly fresh once rainfall is persistent. Water salinities within Fish Hatchery Creek averaged 10.5 ± 11.7 (SD) ppt, with 5^{th} and 95 percentile salinities ranging from 0.1 to 32.5 ppt.

The West Pasture Old Slough is a tributary to Fish Hatchery Creek that appears to be a remnant historic tidal slough that has been converted in its upstream reaches into a ditch to channel seasonally high surface run-off from a seep on the Gradjanski property (Figure 5). It connects with Fish Hatchery Creek in the northern portion of the West Pasture and, therefore, also had a muted tidal regime (Figure 5).

The slough was typically well-mixed and strongly brackish to saline (~22.4 to 30 ppt) in the late summer and early fall. During the winter, spring, and early summer, the slough was either well-mixed or strongly stratified, depending on the phase of tidal cycle and freshwater inflow conditions. Water salinities during this period ranged from fresh in the winter to brackish in the early summer (~0.1 to 5 ppt during the winter and ~20-22 ppt in the early summer). Water salinities within the West Pasture Old Slough averaged 9.4 ± 10.5 (SD) ppt, with 5^{th} and 95 percentile salinities ranging from 0.2 to 29.1 ppt.

In general, between 2002 and 2006, salinities of the West Pasture Old Slough tributary were consistently higher during sampling periods than those of Fish Hatchery Creek, probably due to the more seasonal nature of the freshwater inflow. The slightly higher average salinity and 95^{th} percentile recorded for Fish Hatchery Creek may result from the fact that the Giacominis diverted Fish Hatchery Creek into West Pasture Old Slough in 2006, thereby reversing somewhat the salinity pattern observed initially. Prior to 2006, salinities were also frequently higher in upstream reaches of the West Pasture Old Slough than in downstream reaches that are closer to the tidegate. This pattern in salinities may reflect longer residence time of tidal waters that can extend into this reach, combined with potentially a backwater flooding effect such that lower salinity waters from Fish Hatchery Creek flow back up into the West Pasture Old Slough when seasonal freshwater flows in the slough decrease appreciably.

West Pasture and Freshwater Marsh

Within the West Pasture, saltwater not only flows south up established channels such as the diked portion of Fish Hatchery Creek and the West Pasture Old Slough, but, during the highest tides, overbank floods into marsh and pasture areas, particularly at the northern, lowest ends of the West Pasture. On the pasture's western perimeter, these tidal influences are moderated by strong and often persistent freshwater inflow from small drainages and groundwater flow from the Inverness Ridge. These hydrologic sources have generally created a freshwater to saltwater gradient from west to east, as well as from south to north.

As was discussed under the East Pasture, much of the groundwater table in the central portion of the West Pasture appears to be saline, with salinities ranging from 5 to 12 ppt (Appendix C3). Salinities of groundwater in marshy areas along Sir Francis Drake Boulevard -- directly where the groundwater flow from Inverness Ridge first interfaces with the pasture -- averaged less than 1 ppt, but these salinities increased with distance from the road, with some areas even having salinities as high as 60 ppt during the summer (Appendix C3).

This juxtaposition between saltwater and freshwater influences also occurred within the West Pasture Freshwater Marsh. Counter intuitively, most of the problems with salinity occurred only during the winter. At tides where water levels within the diked portion of Fish Hatchery Creek reached 5.25 feet NAVD88 (KHE 2006a), saltwater entered the northwest end of the Freshwater Marsh and appeared to preferentially flow alongside Sir Francis Drake Boulevard before spreading through sheetflow to the central and eastern portions, the lowest elevations within the marsh. Tidal events triggering water levels of 5.25 feet NAVD88 appeared to only occur when water levels within undiked areas exceeded 6.25 to 6.5 feet NAVD88 (KHE 2006a, Appendices B7-B8), which are at the higher end of high tides and relatively infrequent, occurring mostly in the winter. The one known exception to this occurred in the summer and fall of 2003, when failure of the tidegate during the previous winter caused more frequent salinity intrusions into the Freshwater Marsh.

Long-term salinity patterns within this marsh prior to 2003 are unknown, but some spot sampling in a few areas associated with amphibian surveys found salinities during the winter that ranged from 0.1 ppt to 0.8 ppt (Fellers and Guscio 2002). Interestingly, while vegetation composition during 2002-2003 pointed to the marsh largely being "fresh," salts were regularly detected in the groundwater (Appendices B3.1-B3.6). Salinities in shallow groundwater wells within the marsh ranged from 0.3 to 4.4 during late fall 2002 to early 2003. This is suggestive of a historic source of salts within the soils, probably to tidal influence prior to diking. Based on the 1862 U.S. Coast Survey map, the West Pasture freshwater marsh was almost completely subtidal or unvegetated intertidal habitat with just a thin fringe of land apparent on the western perimeter. Salts from tidal influence during this period have probably remained in the peaty clay soils despite diking and a conversion from marine or brackish to predominantly freshwater conditions.

In winter 2003, the West Pasture freshwater marsh experienced much higher salinities due to collapse of the culverts at the North Levee, which appeared to increase the range of tides allowed into the West Pasture and the freshwater marsh. Monitoring of salinities within the surface waters in July and August 2003 showed that salinities increased to as high as 6 - 35 ppt within this marsh, although groundwater seepage and flow from drainages appear to maintain a freshwater lens of less than 1 ppt at the western perimeter of the marsh or on the water surface. Following repair of the tidegate, tidal amplitude within the West Pasture was compressed, limiting the range of tides to between 3.4 and 5.25 ft NAVD88 (Appendices B7-B8).

Culvert and tidegate repair appeared to reduce the extent and duration of salinity intrusion events in the marsh. However, salinity intrusion events still occurred. Based on some continuous water quality monitoring in 2004, salinities in the marsh appear to have been highest between December and March, despite increased freshwater flow from rainfall (Appendix D6). In addition, because the marsh is a highly vegetated depressional basin, drainage of tidal flows from the marsh does not appear to occur during low tides or even within days as high tidal flows recede, but rather to pond for perhaps as long as several months.

In mid-January 2004, high tides exceeding 6.2 ft MLLW occurred within Tomales Bay. Two months later, salinities in the marsh ranged from as high as 4.68 to 8.13 ppt, averaging 4.2 and 7.4 ppt, in the deepest and shallowest portions of the marsh, respectively (Appendix D6). Over the next two months, salinities dropped to an average of 2.53 ppt in April 2004 and 1.6 ppt in May 2004 (Appendix D6), and subsequent monthly spot sampling in the summer showed that salinities remained at these levels throughout the summer. This water salinity pattern suggests that saltwater intrusion events occurred principally in the winter and that the volume of saltwater was high enough to create an extended period of saline conditions despite very high freshwater inflows from creeks, drainages, and groundwater from the adjacent Inverness Ridge.

Saltwater intrusion events did not necessarily affect the entire West Pasture freshwater marsh. Based on long-term salinity monitoring, it appeared that saltwater intrusion occurred exclusively in the northern and central portions of the marsh, representing approximately two-thirds or 5.3 acres of the marsh. A rise in topographic gradient associated with the base of the Inverness Ridge to the west and the alluvial fan of the 1906 Drainage to the south appeared to minimize salinity intrusion in the southern one-third (1.9 acres) of the marsh, particularly in combination with perennial freshwater flows from the 1906 Drainage. Salinities in the 1906 Drainage never exceeded 0.1 ppt.

Reference Areas

Undiked Marsh

Circulation patterns within the undiked marsh north of Giacomini Ranch are driven by perennial freshwater inflow from Lagunitas and Fish Hatchery Creeks and numerous smaller drainages flowing off the Inverness Ridges. These fluvial influences are counterbalanced to some degree by tides that flowing from open water portions of Tomales Bay into Lagunitas and Fish Hatchery Creeks, as well as into Fault Slough and the numerous other smaller distributary tidal creek channels.

During even moderate high tide events, tidal water flows into channels and then overbank floods onto the marshplain surface. Draining of water from the marshplain during low tides encourages development over time of new distributary channels to existing channels. The Undiked Marsh supports a dense network of primary, secondary, and tertiary tidal channels, most of which have very little sinuosity and are relatively straight, as befits a deltaic marsh system principally shaped by fluvial processes.

The pattern of salinities in waters of tidal channels in the Undiked Marsh suggest that waters are generally well-mixed, probably due in part to the shallowness of the water column, with minor to moderate stratification only present occasionally. Stratification did not appear to occur particularly within specific seasons, although there appeared to more episodes in late summer, fall, and winter than in spring and early summer. For example, in August 2005, surface water salinities in two different tidal channels in the marsh averaged 5-7 ppt, while those of bottom waters averaged 18- 21.6 ppt. Water salinities in the Undiked Marsh tidal channels and marsh ponds averaged 17.4 ± 10.4 (SD) ppt, with 5th and 95 percentile salinities ranging from 0.7 to 32.7 ppt (Figure 12).

Walker Creek Marsh

Within this system, freshwater influence from Walker Creek has less of a direct impact on circulation patterns within the marsh, except during storm events, when creek waters can overtop the sizeable alluvial levee. During the remainder of the year, freshwater influence on the marsh from Walker Creek is constrained by the fact that few of the marsh's channels directly connect to the creek itself. Most of the tidal channels outflow directly to Tomales Bay and so are influenced more by salinities of waters at the mouth of the Bay – a product of the mixing of saline waters of the ocean with freshwater of Walker Creek -- than directly by Walker Creek itself.

There are some small drainages that flow off the hills to the south into the marsh, creating small pockets of freshwater marsh, brackish marsh, and riparian scrub at the interface. Waters from these small drainages, including potentially emergent groundwater, flow into the distal end of the limited number of tidal channels that have developed in the marsh. Most of Walker Creek marsh delta remains unchannelized marshplain, with elevation gradient gradually tapering downward from north to south until the marshplains eventually transition into unvegetated mudflat at the creek's mouth. Tidal waters, then, not only enter the marsh through tidal channels, but also through overland flow at the marsh's low-elevation interface with the Bay.

Walker Creek Marsh shows a similar circulation pattern to that of the Undiked Marsh in that its waters are generally even more well-mixed than those of the Undiked Marsh and only very infrequently show any kind of stratification. The reduced potential for direct freshwater influence during most of the year relative to that of the Undiked Marsh may partially account for that, as well as the generally even shallower nature of the water column. The effect of reduced freshwater influence can be seen in average water salinities. In general, water salinity in Walker Creek Marsh averaged 24.4 ± 11.3 (SD) ppt, with the 5^{th} and 95 percentiles ranging from 3.6 to 36.9 ppt (Figure 12).

Most of the stratification observed occurred in some of the larger tidal channels such as Walker Creek itself and one of the large internal channels in the southern portion of the marsh. These events again did not necessarily display any consistent seasonal pattern, although strong stratification occurred mostly during the winter. In January 2005, surface water salinities in Walker Creek averaged 5.7 ppt, while bottom salinities were as high as 28.5 ppt. During this same period, the largest tidal channel in the marsh, conversely, had surface water salinities of 15.1 ppt, while bottom water salinities reached as high as 40 ppt.

Limantour Marsh

Circulation patterns in Limantour Marsh are driven by the juxtaposing influences of tidal influence from Limantour Estero and perennial freshwater inflow from Muddy Hollow Creek. Tidal waters move from Limantour Estero into Limantour Slough and then into some of the smaller tidal creek channels that branch off the slough. The timing and intensity of freshwater inflow into Limantour Marsh during this period was altered by the presence of Muddy Holllow Pond, which impounded creek flow with excess flow diverted through a spillway into the landward portion of the marsh.

Similar to the other undiked marshes, waters in the large tidal slough and small tidal channels were generally well-mixed, but periods of strong stratification occurred more frequently than in the other marshes, particularly in the large tidal slough. The location of these stratification episodes varied between upstream and downstream locations in the Slough, rarely occurring in both locations at the same time. Apparently, depending on the relative strength of freshwater inflow and height of the tide, stratification moved upstream or downstream, particularly during the winter, when freshwater flows and extreme high tides are often at their peak. In March 2002, surface water salinities in upstream portions of Limantour Slough averaged 8 ppt, while bottom salinities were as high as 29.9 ppt, while, in January 2003, surface water salinities at downstream locations in the slough averaged 2.6 ppt, while bottom salinities reached as high as 27.2 ppt.

In general, water salinity in Walker Creek Marsh averaged 24.0 ± 12.2 (SD) ppt, with the 5th and 95 percentiles ranging from 0.3 to 34.9 ppt (Figure 12).

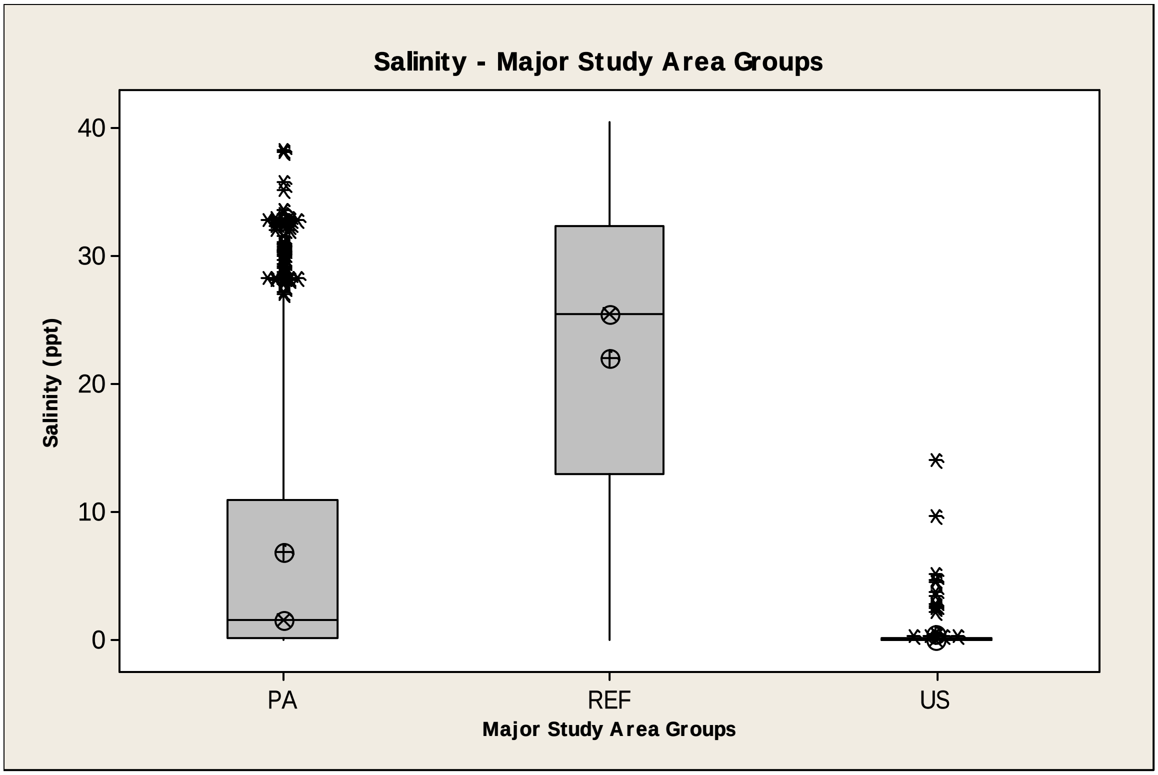
Comparison Between Project Area and Reference Areas

With the exception of perhaps Lagunitas Creek, most of the creeks in the Project and Reference are well mixed systems that show weak to moderate stratification only periodically. Stratification typically only occurs in most systems when freshwater flow and water depth peak, decreasing the ability of the weaker tidal currents present in most of the Project Area to mix the two different source waters. The generally shallow nature of most of these creeks encourages mixing within these systems. More frequent stratification occurred in those systems with stronger freshwater flows. As freshwater flows decrease in the summer and fall, a “salt wedge” appears to move up creeks such as Lagunitas, Fish Hatchery, Tomasini, and, perhaps, to a lesser degree, Limantour Slough.

The downstream portion of Lagunitas Creek north of White House Pool displays a similar circulation pattens in that it is generally well-mixed (fresh in the winter and saline in the late summer-fall) or partially stratified, with strong stratification occurring very infrequently. The shallowness of this reach, combined potentially with currents and wind, appear to discourage stratification. Conversely, the White House Pool reach that is just upstream from White House Pool, becomes strongly to at least partially stratified during summer and fall, probably due to the decreasing, but continued, influence of freshwater inflows from mandated reservoir releases. Stratification within this reach could result either from reestablishment of gravitational or classic estuarine circulation – the pattern in much of the open waters of Tomales Bay – driven by the opposing forces of tidal currents and reservoir release-regulated freshwater inflows or stratification or resorting of “pooled” waters based simply on vertical differences in density.

Comparison of salinity patterns between the Reference and Project Areas is complicated by the fact that the Project Area receives a greater abundance of both seasonal and perennial freshwater inflow than many of the reference systems. This is reflected in some of the summary data (Figure 12, Table 6). Within Reference Marshes, salinities averaged 22.0 ± 11.8 (SD) ppt, with a median salinity of 25.2 ppt, which shows that the mean was strongly influenced by some very low values. Even within reference marshes, however, differences in salinity existed (ANOVA, n=314, df=2. F=12.57, p<0.001), with the Undiked Marsh having a significantly lower mean salinity (17.4 ± 1.01 (SE) ppt) than either Limantour Marsh (24.0 ± 1.15 (SE) ppt) or Walker Creek Marsh (24.36 ± 1.10 (SE) ppt; Dunn-Sidak, p<0.001) due probably due to the abundant freshwater inflow from Project Area creeks, as well as surface flow from numerous small drainages and groundwater flow from the Inverness Ridge that flows directly into the Undiked Marsh (Figure 12). The 5th and 95th percentiles for Reference Areas were estimated as 0.68 and 36.0 ppt, respectively. This wide range of variability is reflected in the broad range for standard deviation and percentiles, as well as the coefficient of variation, which was 0.54: variables with a CV of less than 0.2 are considered to have low variability.

In contrast, salinity averaged 6.9 ± 9.9 (SD) ppt in the Project Area, with a median salinity of 1.6 ppt, which suggests that the mean was strongly influenced by a few areas or periods of hypersalinity in the diked system (Figure 12, Table 6). Median salinities also differed between subsampling areas within the Project Area that excluded upstream sampling sites (Kruskal-Wallis, n=817, df=4, H=60.35, p<0.001), with the range of medians for the West Pasture, Tomasini Creek, and the Project Area portion of Lagunitas Creek (3.8 to 4.8 ppt) higher than that for Olema Marsh and the East Pasture (0.2 to 0.6 ppt). For the Project Area, the 5th and 95th percentiles were estimated at 0.1 and 29 ppt, respectively. The fact that these percentiles did not differ that substantially from the Reference Marshes is evident in the fact that approximately 60 percent of the Project Area values fell within the range of natural variability (95 percent of the population values) found in reference marshes.



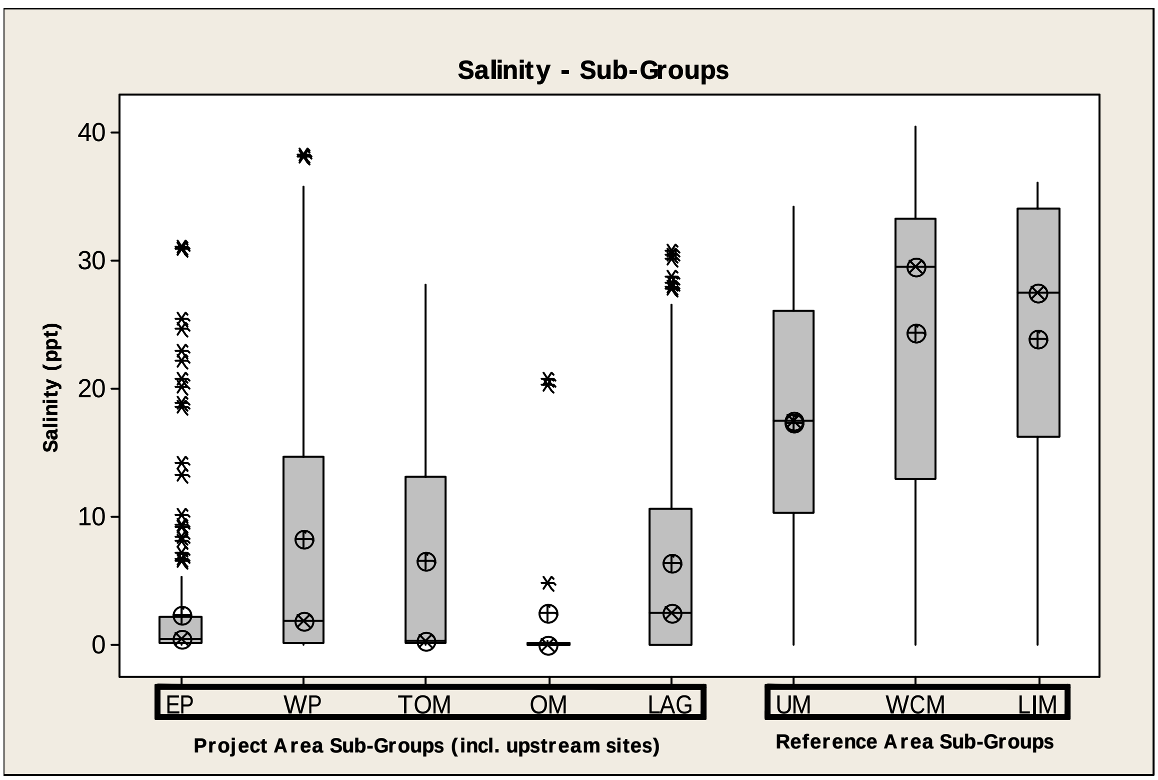


FIGURE 12. Salinity in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10^{th} and 90^{th} percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.

The difference in median salinities between the Project Area and other Study Areas was strong enough to be statistically significant (Kruskal-Wallis, n=1261, df=2, H=472.6, $P < 0.001$). Understandably, salinities for areas upstream of the Project Area (Upstream Areas) fell below those of either the Project Area or Reference Marshes, as they receive less or no tidal influence and strong perennial or seasonal freshwater influences (Kruskal-Wallis, n=1261, df=2, H=472.6, $P < 0.001$). Salinity averaged 0.6 ± 3.6 (SD) ppt in Upstream Areas, with a median salinity of 0.1 ppt (Figure 12, Table 6). The mean was influenced by occasional higher salinities during high tides during summer months. The 5th and 95th percentiles were estimated at 0.1 and 5.6 ppt, respectively.

TABLE 6. Summary data for water salinity – Giacomini Wetland Restoration Project pre-restoration water quality monitoring. Major Study Area Groups include Project Area (PA), Reference Areas (REF), and Upstream Areas (US). Project Area sub-groups in this chart include upstream sampling sites that are broken out as US in other analyses.

	Major Study Area Groups					**Project Area Sub-Groups (including upstream sites)**						**Reference Area Sub-Groups**		
	PA	***Range***	**REF**	**US**		**EP**	**WP**	**TOM**	**LAG**	**OM**		**UM**	**WCM**	**LIM**
Mean	7.4		21.8	1.1		2.6	9.2	6.8	6.5	1.7		17.4	24.4	24.0
SD	9.9		11.8	3.6		5.5	11.4	9.1	8.6	5.2		10.4	11.3	12.2
Median	1.6		25.2	0.1		0.6	2.7	0.5	1.3	0.1		17.3	30.0	28.8
5th	0.1 0.7	↕60%		0.1		0.1	0.1	0.1	0.1	0.1		0.7	3.6	0.3
95th	29.0		36.0 5.6			14.5	32.4	24.5	26.4	9.9		32.7	36.9	34.9
CV			0.54											

Sediment Transport Dynamics in the Watershed and Project Area

One of the most important processes for bays and creeks involves movement of sediment from upstream source watersheds to downstream water bodies, such as Tomales Bay or even the Pacific Ocean. This process of moving sediment does not take place instantaneously, but rather over a longer period of time, with large and small-grained material such as gravel, sands, silts, and clays being moved incrementally downstream during different storm events. Through this process, the shape or geomorphology of creek channels is formed. Once sediment finally reaches tidally influenced downstream water bodies, a new type of transport process takes place. Sands from the ocean and river-borne sediments, particularly fines, are continually resuspended by tides and redistributed within estuaries, helping to build sandbars, mudflats, and fringing marshes.

Fluvial or Creek-Dominated Processes

While large flooding events are often accompanied by huge inputs of sediment to downstream water bodies, more frequently occurring flood events, even as frequent as annual or ordinary high water flows, usually move more sediment and have a greater influence on channel shape (Leopold 1994). Reaches of channel tend to go through periods where they either accrete or lose more sediment, however, over time, the aggradation and erosional processes remain in balance in undisturbed natural systems. Should natural catastrophic events change sediment loads, the system will move toward what might be called a new dynamic equilibrium state, ultimately coming into balance with sediment inputs and outputs, although the channel may assume a new form or shape.

Anthropogenic disturbances can create discontinuities in the sediment transport process that can tilt the equilibrium scale towards either net aggradation or erosion and radically change the shape or form of the channel. Dams can drastically decrease the amount of sediment or gravel available for downstream recruitment. Areas in which no sediment movement or aggradation is occurring often have what is called “armored” or hardened gravel bars, signifying that material is not depositing or moving downstream.

Conversely, areas in which the equilibrium is tilted toward aggradation often have conversion of subtidal or unvegetated intertidal habitats to vegetated ones. One of the most vivid examples of this is the conversion of southern Tomales Bay from a low-energy subtidal and low intertidal system primarily shaped by redistribution of fine-grained clays and silts from Tomales Bay to a fluvial-dominated deltaic system composed of large-grained sands, small gravel, and fines. The massive influx of sediment due to logging and other disturbances associated with development of the upstream watershed tilted the sediment equation from transport to aggradation, with rapid expansion of the intertidal delta into Tomales Bay (Figure 8). It has been estimated that the peak sedimentation period between 1860s and 1910 resulted in deposition of almost 5 vertical feet of sediment (PWA et al. 1993) and 250 -300 acres of new intertidal marsh in very southern portion of Tomales Bay, principally the Giacomini Ranch and area directly north of the Ranch (Figure 8).

During storm events, creeks are moving large or coarse-grained sediment (cobble, gravel, sand, and even boulders), as well as fine sediment (clays, silt, finer sands). Much of the coarse-grained material is deposited within the channels in gravel bars or immediately adjacent to the channel, sometimes forming alluvial or natural levees along the creek channel. Fine sediment typically deposits further from the stream channel through overbank flooding onto floodplains, although changes in channel morphology such as a sudden flattening of the creek gradient or slope, substantial widening of the creek channel, or transitioning from creek to a large open water body such as a bay can cause fine sediment to deposit within the stream channel itself. Gravel bars are depositional features within creek channels; on floodplains, sediment transport in creeks often manifests as alluvial fans.

Within many alluvial or classic riverine systems, certain discharge or flow events are believed to perform the most work over the long-term in terms of sediment transport (Wolman and Miller 1960). The dominant discharge is often linked to intermediate streamflow or discharge events, which correspond to “bankfull flow” or flood events that occur every 1- 3 years or very 1.5- 2 years on average. However, there are systems in which the dominant discharge appears to be the largest floods on record such as the Santa Clara River (Stillwater Sciences 2005).

Estuarine Sediment Transport Processes

Within bays and estuaries, sediment is stored within mudflats, sand bars, and shoals or shallows. Storage within estuaries represents a very dynamic process, with frequent remobilization of sediments, particularly fines, from these storage “reservoirs” through resuspension by tides, storms, and wind mixing. These sediments are redistributed to marshplains, mudflats, and channels of the bay or even eventually exported to the ocean. Most of this sediment comes from the surrounding watershed, but sand moved by longshore sediment transport along the Point Reyes coast also moves into the bay to be redistributed by wind-generated waves (PWA 2005).

As discussed earlier, construction of dams within the watershed appears to have dramatically reduced watershed sediment contributions to Tomales Bay (Rooney and Smith 1999), increasing the importance of resuspension to sedimentation patterns within Tomales Bay. Construction of dams in the Sacramento-San Joaquin watershed has also dramatically reduced the Central Valley contribution to the San Francisco Bay sediment budget, potentially accounting for large erosional losses in shallow areas in San Pablo and Suisun Bays observed between 1942 and 1990 (Jaffe et al. 1996, 2001 *in* McKee et al. 2002).

Estuarine circulation patterns largely dictate the pattern of sediment deposition within estuaries, particularly deposition of suspended or fine sediments. As with fluvial sediment transport processes, bathymetry and currents can exert tremendous influence on where suspended is resuspended and where it is deposited. However, estuarine areas are unique in that sediment transport and deposition processes can also be influenced by salinity.

Bathymetry, currents, and salinity, either in combination or separately, appear to drive formation of concentrated zones of sediment deposition, which have been referred to as Estuarine Turbidity Maximum (ETM). During recent decades, extensive research has been conducted into this phenomenon, because of its implications for aquatic organism diversity and trapping of sediments, nutrients, and contaminants (Peterson et al. 1975, Arthur and Ball 1979, Kimmerer et al. 1998, Columbia River Estuary Turbidity Maxima (CRETM) 2001). Classically, ETM was linked to the Null Zone observed in transitional regions of estuaries with classic estuarine or gravitational circulation (e.g., strong stratification of fresh and tidal flows) near the landward boundary of tidal influence, which often occurs around 2 ppt (Postma and Kalle 1955, Festa and Hansen 1976, Festa and Hansen 1978, Peterson et al. 1975 *in* Kimmerer 2004). In these zones, sediment resuspended by strong tidal currents moving along the channel bottom and sediments carried by river or creek flow converge and are trapped by the upward moving current created by stratification at the landward extent of tidal influence, greatly increasing water turbidity and eventual sediment deposition on the channel bottom.

In recent years, physical controls other than the Null Zone have been linked to ETM, including abrupt changes in bathymetry or shoaling (Schoellhammer 2001), ebb and flood tidal currents in river mouths (Ganju et al. 2004), and redistribution of dissolved and particulate fractions in intermediate rather than low salinity reaches (Rasheed 1997). In addition to the effect that salinity has on stratification of estuarine waters and longitudinal gradients and currents, salinity can also play a direct role in determining patterns of sediment deposition through flocculation or aggregation of river-borne sediment particles caused by the increased electrostatic charge present at the landward edge of the "salt wedge" (Arthur and Ball 1979).

Sediment Transport Dynamics within Tomales Bay

For the Bay as a whole, the trend towards net aggradation continues, although construction of dams apparently caused deposition rates to drop substantially after the 1950s (TBWC 2002).

Comparison of hydrographic charts prepared in 1861 and 1994 and correction of the charts for changing sea level yields a baywide average infilling rate of about 0.2 in/yr (5 mm/yr; Rooney and Smith 1999). This is equivalent to a watershed erosion rate of approximately 80,000 tons/yr (Rooney and Smith 1999). The highest rates of sedimentation at the southern end of Tomales Bay occurred between 1861 and 1908 (PWA et al. 1993), but, apparently for other portions of the Bay, the largest sediment influx to the bay seems to have been in the decades between about 1930 and 1960 (Rooney and Smith 1999). Since 1957, sedimentation rates have dropped, slowing the pace of Bay infilling (Rooney and Smith 1999, PWA et al. 1993).

Between 1861 and 1931, sedimentation accumulation rates within Tomales Bay averaged 94 tons per square kilometer per year, increasing to 357 tons/k^2/yr between 1931 and 1957 and decreasing to 101 tons/k^2/yr between 1957 and 1994 (Rooney and Smith 1999). These sedimentation patterns contrast somewhat with findings from the PWA et al. (1993) study of southern Tomales Bay and delta expansion, which pointed to the 1861-1931 period as having the highest sedimentation rates. Sedimentation resulting from erosion induced by agricultural development of the watershed is likely to have been highest first at the southern end or mouth of the Bay, with the rapidly accreting delta and construction of the Giacomini Ranch levees eventually shifting the primary area still available for sediment deposition downstream and more into the Bay itself.

Rooney and Smith (1999) noted, however, that sediment yield in the Bay is not necessarily synonymous with erosion and that there can be "decades long delay between maximum level of soil surface disruption and maximum sediment deposition." During these decades, sediment is typically stored in streambeds, gradually moving towards the Bay through episodic resuspension during storms. Another storage reservoir for sediment is stream deltas such as Lagunitas Creek: "A similar delay was found between initial deposition of sediment at stream deltas and subsequent redistribution other areas of the Bay more geographically remote from deltas" (Rooney and Smith 1999).

While watershed sediment contribution has decreased in the last 50 years, Tomales Bay continues to become shallower through sediment inputs. In addition, colonization – or re-colonization – by native Pacific cordgrass (*Spartina foliosa*) appears to be causing a conversion in some areas of shallow intertidal mudflat to vegetated marsh. The present sedimentation rate in the bay, based on both bathymetric changes since 1957 and sediment yield measurements, is estimated at about 0.04 to 0.08 in/yr (Smith and Hollibaugh 1998).

The dynamics of Null Zones or ETM have not been specifically investigated on a system-wide basis in Tomales Bay, but ETM may exist at the mouth of Lagunitas, Walker, and other tributaries to Tomales Bay that undoubtedly has many of the same benefits for biota documented in San Francisco Bay. The three-dimensional models developed recently for Tomales Bay would be invaluable in evaluating transport and depositional processes such as Null Zones and ETMs throughout the system, particularly as it could strongly bear on the fate of suspended sediment and associated nutrients, pathogens, and contaminants.

Sediment Transport Dynamics within the Project Area

Lagunitas Creek and Undiked Marsh

Construction during the 1950s of the five dams within the Lagunitas Creek watershed, which controls 70 percent of the runoff for this subwatershed, has obviously greatly affected sediment dynamics within this system. MMWD studies conducted in 1979-1980 concluded that total suspended sediment delivery from Lagunitas Creek to the Project Area and vicinity averaged 34,300 tons/water year and 2,140 tons/water year of bedload or coarse sediment as calculated at the Point Reyes stream gage (H. Esmaili and Associates 1980).

Annual bedload and suspended sediment transport totals actually decreased at the Point Reyes stream gage relative to the reach immediately upstream at the old Tocaloma Bridge, suggesting that increased channel storage or bank deposition was occurring in what was then – and probably still is now -- an aggrading reach or portion of the stream (H. Esmaili & Associates 1980). Many low-gradient or flatter reaches of creeks in coastal California undergo periods of net deposition during periods of high run-off followed by removal or net erosion during normal run-off conditions (H. Esmaili & Associates 1980).

While the subwatershed of its largest tributary, Olema Creek, is less than a fifth the size of Lagunitas, Olema contributed significantly more suspended and bedload sediment to Tomales Bay -- 68,300 tons and 20,800 tons/year, respectively (H. Esmaili & Associates 1980). Higher sediment transport rates for Olema Creek were attributed to possibly climatic change, grazing, or other land use factors (H. Esmaili & Associates 1980), while work conducted in the late 1980s (Questa Engineering 1990) also identified differences in geology and the fact that Olema Creek flows along the active San Andreas Fault Zone.

While sediment transport generally increases with stream discharge or the size of the flood event, some streams have a diminishing rate of increasing suspended sediment transport at higher flows (Leopold 1994, Esmaili & Associates 1980). As noted earlier, more frequently occurring floods known as the “dominant discharge,” that occur even as frequently as annually or during ordinary high water flows, usually move more sediment and have a greater influence on channel shape (Leopold 1994). Sediment studies conducted by H. Esmaili & Associates (1980) in 1979-1980 suggested that the rate of sediment transport in the lower sections of Lagunitas Creek just upstream of the Project Area begins to decrease during relatively small flood events (~1-year flood event), but that sediment load continues to increase through at least approximately the 7.5-year flood event and probably through even larger storm events.

Stream rating curves developed for Lagunitas Creek at the Point Reyes gage based on 1979-1980 data suggest that, at least during the early 1980s, a 2-year flood event with flow of 3,515 cfs would move a considerable amount of suspended sediment -- approximately 10,000 tons per day – but substantially less bedload material, only 170 tons/day (H. Esmaili & Associates 1980). A recent sediment delivery analysis for the middle reaches of the Lagunitas Creek subwatershed supported the premise that suspended materials represent the primary component of sediment transport (est. 81 percent or 9,344 metric tons/yr) in the middle reaches of Lagunitas Creek, with bedload estimated as being considerably lower (2,690 metric tons/yr; Stillwater Sciences 2007). Historically, none of this suspended material would have been deposited on Giacomini Ranch floodplains because of the levees and/or lack of hydrologic connectivity.

While sediment transport patterns appear to have changed substantially in Olema Creek since the parks purchased portions of the watershed, land use factors affecting sedimentation rates in Lagunitas Creek would not appear to have changed substantially since construction of the dams in the 1950s. Within the Lagunitas Creek watershed, the dams would appear to exert the most control over sedimentation rates and patterns. Because dams tightly regulate some of the smaller flood flow events and their sediment loads, the highest rates of sedimentation in this subwatershed may now come with catastrophic flooding just as is seen currently in the Santa Clara River (PWA et al. 1993, Stillwater Sciences 2005).

The 1982 flood caused deposition of 160 acre-feet of sediment on the Lagunitas and Walker Creek alluvial deltas (Anima et al. 1983 *in* PWA et al. 1993). The 1979-1980 study, however, demonstrates that there are still substantial sediment contributions from unregulated tributaries and their watersheds, even with the dams (H. Esmaili & Associates 1980). Current trends in the upper portions of the Lagunitas Creek watershed have not been formally studied, but several researchers have reported problems with "fining" or excessive deposition of fine sediments such as clays and silts relative to coarse materials such as gravel and cobble; poor sediment recruitment below the dams; and armoring of smaller gravel and fine sediments (Stillwater Sciences 2004).

To determine current trends in sediment transport processes within the Project Area, KHE sampled gravel bars in Lagunitas Creek between the Green Bridge and north of the Giacomini Ranch's North Levee (KHE 2006a). As described earlier, there are several prominent gravel bars within the Project Area, including one downstream of the Green Bridge, one near the cattle-crossing location midway through the Project Area, and one just south of the North Levee. Results show that grain-size distributions for the Green Bridge and North Levee bars are very similar and are dominated by fine-grained gravel (KHE 2006a). The cattle crossing gravel bar is composed of coarse-grained gravel (KHE 2006a). Field observations of the creek between the North Levee and Tomales Bay also indicate a relatively coarse-grained, firm bed, grading from fine-grained gravel at the North Levee to medium- to coarse-grained sand at the deltaic outfall to Tomales Bay (KHE 2006a). The coarse-grained nature of these surficial bed deposits indicates that Lagunitas Creek possesses a relatively high sediment transport capacity through the Project Area (KHE 2006a).

Conclusions made from grain-size distribution are supported by modeling results that indicate creek flows are sufficient to mobilize and transport coarse-grained materials observed within the Project Area (KHE 2006a) despite flattening of the creek gradient or slope. As might be expected based on channel geomorphology, the narrow, confined reach upstream of White House Pool and downstream of the Green Bridge tends to transport fines, as well as coarse sand and fine gravel, although stream energy is not high enough to convey coarse gravel and cobble (KHE 2006a). Downstream of White House Pool at the cattle-crossing "gravel bar," stream power drops slightly where the creek widens, and there is some loss of transport, but relatively little (KHE 2006a). Transport rates generally increase again downstream of the cattle crossing bar through the North Levee (KHE 2006a).

Based on stratigraphy, fine or suspended sediment appear to be deposited within adjacent floodplains when flows are sufficient to crest the levees (KHE 2006a). One of the highest depositional areas in the East Pasture appears to be the southwestern corner opposite White House Pool, where the Giacomins apparently deliberately removed or lowered levees to preferentially direct flooding (KHE 2006a), perhaps because of repeated flooding problems in the past during more frequently occurring flood events (~ 3 to 5 years). The 1942 aerial photograph shot just prior to establishment of the Giacomini Ranch and following an average winter without excessive flood scour or sedimentation clearly shows overbank scour and sediment deposits within the southeast portion of the East Pasture, along Lagunitas Creek, and within the West Pasture, from historic overbank flooding events (KHE 2006a).

For overbank flooding events, sediment transport rates were highest just at the point of entry near the south levee of the East Pasture, with flow velocity dropping sharply throughout the remainder of the pasture (KHE 2006a). Modeled flow velocity in the south was high enough to transport coarse sand and fine gravel, which, then, based on modeling results, would be deposited in the southernmost fields, which appears to agree with information from sediment coring and aerial photographs (KHE 2006a). Sediment transport in the northern portion of the East Pasture was hindered by persistent ponding of floodwaters caused by reduced outflow, which is limited by the concrete spillway and culvert capacity (KHE 2006a). In the West Pasture, flow velocity during highly infrequent overbank flooding events (> 12 years on average) did not appear sufficient to transport sediment through the pasture, with most sediment probably deposited immediately on the floodplain after cresting the levee (KHE 2006a).

While the upstream reach of Lagunitas Creek does have the highest and perhaps most intrusive levee system, from historic maps, it appears that this section of creek was naturally somewhat narrow and confined, at least during recent recorded time. Therefore, the levees may not have changed fluvial sediment transport processes substantially in the reach upstream of White House Pool relative to "natural" conditions. The other potential impediment, Green Bridge, which almost completely spans the active floodplain of the creek, also does not appear to be having a substantial negative impact on transport processes (KHE 2006a), although the presence of the gravel bar directly downstream again may attest to some effect of the bridge on sediment deposition patterns.

Unlike San Francisco Bay, not much is known within Tomales Bay or the Project Area about estuarine sediment transport processes. Within the Project Area, Lagunitas Creek is well-mixed and fresh, usually well below 2 ppt, during the period of highest freshwater flows and contaminant contribution. If the classic Null Zone were to occur during the winter and early spring, it would be at some point in Tomales Bay itself, where channels are deep enough – and tidal currents are strong enough – to create gravitational circulation and strongly stratified conditions despite the high volume of freshwater flow.

Based on longitudinal salinity gradients, gravitational circulation does exist upstream of White House Pool, but only very briefly in the late spring and early to mid-summer, when sediment, nutrient, and contaminant loads are much lower. Typically, ETM are generated through a combination of sediments resuspended by strong tidal currents and carried in suspension by fluvial flows. Based on hydraulic modeling results, the strength of tidal currents is not sufficient within the portion of Lagunitas Creek in the Project Area to mobilize even fine sediments except for directly downstream of the cattle crossing gravel bar (KHE 2006a), however, the full complexity of stratified estuarine circulation and associated transport processes may not be captured by a one-dimensional model that does not incorporate differing vertical depths within the water column.

ETM may also develop within the Project Area based on other physical forces such as flocculation of creek-borne sediment and organic material induced by increased salinity within waters (Arthur and Ball 1979) or bathymetrically controlled changes in creek circulation and sediment transport patterns due to shoaling at the two gravel bars downstream of White House Pool. While estuarine sediment transport processes have not been as well studied in this watershed as fluvial ones, these processes also have strong implications not only for patterns of sediment deposition in the Project Area, but the potential for the Project Area to improve water quality conditions within southern Tomales Bay by trapping suspended sediment that may be bound to nutrients, bacteria, or other contaminants.

Project Area - Giacomini Ranch

Tomasini Creek

There is no information on sediment transport processes within Tomasini Creek. However, based on the amount of sediment deposited both upstream and directly downstream of Mesa Road, this creek conveys large amounts of suspended sediments to lower gradient regions of its subwatersheds, as do many of the creeks in this region.

Fish Hatchery Creek

Fluvial transport processes were not specifically modeled, but historical information on past flooding events indicates that flow velocities decrease appreciably once the creek gradient begins to flatten at the base of the Inverness Ridge, creating excessive deposition or debris flow even during relatively mild storm events. During storms, substantial amounts of loose, granitic material from the Inverness Ridge mobilizes and moves down to the valley below, with anecdotal reports suggesting that as much as 10- 12 feet of sediment may have deposited along the base of the Inverness Ridge as a result of extensive debris flows.

Over longer periods, these repeated mobilizations of sediment manifest as large alluvial fans on which most of the adjacent homes are constructed. Alluvial fans also occur along the West Pasture perimeter where other Inverness Ridge creeks flow into the West Pasture, including the 1906 drainage. Based on the extent of past excavation, the depositional zone probably extends just downstream of where Fish Hatchery Creek makes a 90 degree turn to flow northward towards the North Levee. Tidal current velocities were only high enough near the North Levee to move sediment under average and extreme conditions, although extreme tides may have been capable of moving silt and fine sand downstream of the levee in the undiked portion of Fish Hatchery Creek (KHE 2006a).

Project Area - Bear Valley Creek and Olema Marsh

Similar to Lagunitas Creek, the history of Bear Valley Creek is one also marked by discontinuities in the sediment transport, this time, due to infrastructure and creek maintenance activities. As described earlier, Bear Valley Creek has been subjected to a variety of disturbances, including damming; road and berm construction within and across its floodplain; culvert installation; natural and anthropogenic fill in the active floodplain and terraces; channel realignment for construction of the Park Service maintenance facility; and dredging to decrease flooding of the Park Service administrative headquarters.

All these disturbances have served to disrupt the sediment transport equilibrium within the creek and Olema Marsh. As was noted earlier, during the 1960s-1970s, the middle section of Bear Valley Creek was incised, meaning that the depth from the top of channel bank to the channel bottom was pretty deep, measuring roughly 6 to 8 feet (KHE 2006b). The incision showed that the channel was out of equilibrium, with sediment loss greatly exceeding sediment gain.

After the 1982 flood, Bear Valley Creek underwent some very dramatic changes as a result of catastrophic debris flows from the Inverness Ridge (USGS 1982). Debris flows originating in the two major tributaries of Bear Valley Creek carried into the mainstem of Bear Valley Creek, choking the former channel and turning the colluvial valley bottom into a sandy, braided stream channel with extensive woody debris jams that acted to temporary dam and pond waters within the channel. In essence, the natural event reshaped Bear Valley Creek, converting at least the middle reach from a net erosional to a net depositional system.

Dynamics of this system are complicated, however. While sedimentation did increase after the 1982 flood, it appears, based on sediment borings conducted by KHE, that much of this sediment is not moving from the middle reach of Bear Valley Creek into the lower and Olema Marsh portions (G. Kamman, KHE, *pers. comm.*). Sediment borings in these areas point to increases in elevation being from accumulation of peat or undecomposed organic matter, rather than sediment. Sediment within Bear Valley Creek may be trapped upstream in the reach that has been dredged historically (G. Kamman, KHE, *pers. comm.*).

Modeling results suggest that, if sediments were capable of reaching Olema Marsh, that it would be a depositional environment because of the reduction in flow velocities (KHE 2006a). Under extreme flooding, flow velocities might be high enough for transport of silt and fine sands, but these would drop out of suspension mid-way through Olema Marsh (KHE 2006a). In the case of both floods and tides, which are limited in extent in Olema Marsh, conveyance of sediment would appear to be highest at the Levee Road culvert, where funneling of flows through a narrow constriction tends to increase stream power and velocity (KHE 2006a).

Reference Areas

Walker Creek

Intensive farming and ranching practices in upper valleys of the Walker Creek watershed caused severe erosion and subsequent sedimentation in the creek channels (Prunuske Chatham 2001). Riparian vegetation clearing and channel straightening increased the erosivity of flood flows and the volume of sediment eroded from stream bed and banks and created discontinuities in sediment transport capacity of upper and lower reaches (Prunuske Chatham 2001).

As noted earlier, Haible (1980 *in* Prunuske Chatham 2001) documented that during the 60 years between 1915 and 1975 the channels in the upper watershed incised 5 to 8 feet while the lower reaches of Walker Creek, above the Highway 1 Bridge, aggraded approximately 4 feet. As siltation problems worsened in Keys Creek and lower Walker Creek, it was necessary to continuously move the wharves downstream. By 1870, the docks were relocated to Ocean Roar at the mouth of Walker Creek and then to the northeastern shore of Tomales Bay in Hamlet in 1875 (Prunuske Chatham 2001). A study by Wahrhaftig and Wagner (1972) focused on the rate of erosion required to fill the lower channel of Keyes Creek from the period of 1852 to 1902. Their rough calculations determined that the rate of erosion was 2,000 tons/square mile/yr (TBWC 2003).

The 1982 and 1998 floods exacerbated sediment transport issues in the Walker Creek Watershed, much as they did in other Tomales Bay subwatersheds. In 1982, shallow landslides appeared throughout the watershed; gullies were reinitiated or widened, and widespread bed and bank erosion occurred (Prunuske Chatham 2001). Large amounts of sediment were mobilized throughout the channel network, scouring upstream reaches, depositing sizeable gravel bars in the middle reaches, and causing further aggradation near the mouth (Prunuske Chatham 2001).

Despite these problems, most of the perennial channel reaches appear to be able to adequately transport their available sediment loads (Prunuske Chatham 2001). They may be transport-limited at some flows, as is evidenced by fine grained, in-channel deposits and poorly sorted gravel bars (Prunuske Chatham 2001). A few reaches are clearly transport-limited with no equilibrium between their sediment and flow regimes; appearing to be inundated with high annual sediment delivery (Prunuske Chatham 2001). Lower Chileno Creek is a reach where significant in-channel accumulations of unconsolidated sand and fine gravels are present and available for delivery downstream (Prunuske Chatham 2001). Prior to the last 10-15 years, sediment deposition and long-term storage in the watershed has been limited to the tidally influenced sections of Walker and Keyes Creek (Prunuske Chatham 2001). Now, significant storage occurs in some upstream reaches that have widened and that contain near-channel riparian vegetation (Prunuske Chatham 2001).

Currently, approximately one-third of the sediment carried into Tomales Bay comes from the Walker/Keyes Creek drainage (TBSTAC 2000).

Limantour Marsh

Muddy Hollow Creek is characterized by frequent pulses of bedload and suspended sediment transport during flood events. In addition, there have been catastrophic events that have triggered mobilization of sediments from upper portions of the watershed. One of the upstream reservoirs failed during a storm event in 1982, delivering a large amount of sediment to the lower basin in the years that followed (Collins and Ketcham 2001). Another large sediment pulse occurred after the Mt. Vision Fire, which burned 100 percent of the watershed, including the marsh itself. This fire is believed to have caused deposition of 0.5 to 1.5 feet of sand within a 600-foot section of the channel directly upstream of Muddy Hollow Pond (Collins and Ketcham 2001).

Most of the sediment was trapped in the pond, but presumably some of it escaped to the tidal marsh below. While the Muddy Hollow Pond and lower portions of the creek before it flows into the pond appear to have captured most of the bedload transport of this system, fine sediments were apparently entirely carried through the pond and delivered to downstream areas in the marsh (Northwest Hydraulic Consultants 2004).

General Water Quality Conditions In the Watershed and Project Area

Some of the most important parameters for determining the condition of water and the suitability for supporting aquatic organisms involve basic measurements of water "quality." These basic measurements include pH, temperature, the amount of dissolved oxygen, and salinity or conductance, which was discussed previously. The importance of these measures to health of aquatic ecosystems is attested by the fact that the RWQCB has developed specific objectives for many of these parameters in its San Francisco Basin Plan (1995), which includes Tomales Bay (Table 1). Factors affecting these parameters are numerous.

Conductivity and pH can be influenced by the geology of the surrounding watershed, as well as by tides or ocean water, and internal factors such as residence time, water depth, phytoplankton productivity, and on-site management practices such as grazing or fertilizer application. Dissolved oxygen represents a critical measurement of ecosystem health for aquatic organisms and one that can vary dramatically on a diurnal basis depending on factors such as phytoplankton and zooplankton densities, fish densities, residence time of waters, and wind mixing. Temperature often represents a balance between the cooling influence of waters from shaded freshwater streams, groundwater discharge, and deeper ocean waters and the warming influence of solar radiation on surface waters of bays and larger and/or shallower creeks without a dense riparian canopy. Ultimately, these variables not only affect the health of the ecosystem, but can also affect nutrient dynamics and the availability of these nutrients to consumers.

Basin Plan and Other Standards for General Water Quality Parameters

The RWQCB Basin Plan (1995) stipulates that, in tidal waters, dissolved oxygen must have a minimum concentration of 5.0 mg/L (approximately 50 percent dissolved oxygen at 15.0 degrees Celsius), and the oxygen concentration for three consecutive months shall not be less than 80 percent of the saturated dissolved oxygen concentration (Table 1). For non-tidal waters, the dissolved oxygen concentration minimum is 7.0 mg/L for cold water habitat and 5.0 mg/l for warm water habitat. While oxygen concentration data were collected as both milligrams per liter and percent saturation, the analysis focuses on the milligrams per liter data, because water quality standards are tied to this measure of dissolved oxygen, not percent saturation.

Several factors control pH within waters of estuarine transitional zones, including tidal influence, the chemistry of surface waters and groundwater, seasonal variation in primary productivity, and biogeochemical reactions within underlying soils. According to the Basin Plan, pH should fall within the range of 6.5 and 8.5 (Table 1). USEPA standards for freshwater stipulate that pH should be within the 6.5 and 9.0.

Water temperature is controlled by standards established in a separate document that focuses primarily on elevated temperature water discharges such as cooling waters from power plants, but the Basin Plan does specify that the natural receiving water temperature of inland surface waters shall not be altered unless it can be demonstrated that such alteration in temperature does not adversely affect beneficial uses (RWQCB 1995).

While all organisms are sensitive to high temperatures, temperature has been identified as limiting factors for certain species, including salmonids. Salmonids use downstream transitional zones of tidal creeks for resting habitat during upstream migration in the winter and for refugia and foraging during outmigration during the spring and summer. Through compilation of information on salmonids, 25 degrees Centigrade has been identified as the lethal limit for salmonids (Moyle 2002), while salmonids typically do not persist for extended periods of time above 22 degrees Centigrade (Moyle 2002). Twenty-five (25) degrees Centigrade is also the upper limit listed for tidewater goby, another federally listed species considered endangered found in the Project Area (USFWS 2009). The preferred temperatures for spawning have been characterized as ranging from 15- to 24 degrees Centigrade (Stillwater Sciences 2006).

Tomales Bay

Tomales Bay has been subjected to intensive study on water quality through the National Science Foundation and LMER/BRIE programs (Kimmerer et al. 1993; Chambers et al. 1994a,b; Joye and Hollibaugh 1995; Smith et al. 1996; Smith and Hollibaugh 1997a; Largier et al. 1997; Freifelder et al. 1998 and others).

Previous studies conducted in Tomales Bay have documented the bay's hydrographic properties and water composition, its metabolism, circulation dynamics, its interface with the ocean, and the influence of coastal upwelling (TBWC 2003). As part of many of these studies, some data on basic water quality parameters were collected. The most recent information comes from the LMER/BRIE program (Kimmerer et al. 1993; Chambers et al. 1994a; Joye and Hollibaugh 1995; Smith et al. 1996; Largier et al. 1997a; Smith and Hollibaugh 1997a; Freifelder et al. 1998, and others). Between 1985 and 1996, investigators from the University of Hawaii's School of Ocean and Earth Science and Technology (SOEST), San Francisco State University's Tiburon Center, and other institutions studied characteristics of the bay's biogeochemistry, with more intensive sampling of seasonal and interannual variations initiated in 1987 with surveys at least every two months. As part of this program, some of the data collected during the study were archived on the Internet, including some of the basic water quality data.

No information was available on dissolved oxygen from the LMER/BRIE study, but dissolved oxygen was monitored as part of a 10-year study conducted by CDFG at 20 stations along the eastern and southern margins of Tomales Bay. Results from sampling between 1991 and 2001 showed that oxygen levels were constantly at or near saturation (Rugg 2000, Rugg 2002 *in* Smith 2003). According to CDFG, water quality problems encountered were principally the result of runoff of animal wastes from loading areas, walkways, disposal areas, or the resultant eutrophication and disruptive effects upon oxygen dynamics (Rugg 2000, Rugg 2002 *in* Smith 2003).

While dissolved oxygen was not studied as part of the LMER/BRIE program, continuous monitoring of water temperature was conducted from 1987 until 1995 at several stations in Tomales Bay, including some stations sampled under this program (~Giacomini Ranch North Levee near the downstream end of the Project Area). For the Bay from the mouth to just north of the Undiked Marsh near Inverness, temperatures averaged 14.43 ± 3.06 (SD) degrees Centigrade (LMER/BRIE data). The median temperature differed little from the mean (14.47 degrees Centigrade), with the 5th and 95th percentile estimated at 9.72 and 19.26 degrees Centigrade, respectively (LMER/BRIE data). Temperatures would appear to have been coolest near the mouth (mean = 12.99 ± 0.04 (SE) degrees Centigrade), warming as waters moved inland to between approximately Marshall to Inverness (range = 13.62 to 15.56 degrees Centigrade; SE = 0.04 to 0.08 degrees Centigrade; LMER/BRIE data). Waters became cooler again in upstream areas of Lagunitas Creek, with mean temperature during the somewhat shorter sampling period of 1990-1995 estimated at 12.8 ± 3.09 (SD) degrees Centigrade.

During the LMER/BRIE study period, temperatures did not exceed the thresholds considered as either lethal (25 degrees Centigrade) or suboptimal (22 degrees Centigrade) for salmonids, except at Station 16, which is directly north of the Undiked Marsh near Inverness. At this station, temperatures exceeded the lethal limit less than 1 percent and the suboptimal limit during approximately 3 percent of the sampling intervals (LMER/BRIE data).

Most of the other data were collected synoptically during sampling of waters for nutrients and other factors that were ultimately analyzed in the laboratory. During the LMER monitoring period, pH (as well as temperature) of collection waters was assessed. While mean pH was relatively high (8.17, where 7 is considered circumneutral), it was seemingly relative stable, even considering that pH is logarithmic data (SD = 0.11 and median = 8.17; LMER/BRIE data). The 5th and 95th percentiles for pH were estimated at 7.98 and 8.36 (LMER/BRIE data). Some further analysis of pH data does suggest that pH varies in the Bay seasonally and perhaps even interannually in response to stormwater flows and wet and dry years, respectively (Ann Russell, UC Davis, *pers comm*.). Despite this seasonal variability, pH never fell below Basin Standards of 6.5 and only exceeded standards of 8.5 less than 1 percent of the sampling periods (LMER/BRIE data). Most of these exceedances occurred in stations at the southern portion of Tomales Bay (stations 8 through 14; LMER/BRIE data). Higher pH in Bay waters reflects the strong influence of marine alkalinity sources on bay chemistry, although it may reflect the fact that surface flows from some of the subwatersheds appear to have higher pHs than might be expected (see West Pasture below).

Project Area

Lagunitas Creek

Dissolved Oygen: Dissolved oxygen in the Project Area portion of Lagunitas Creek averaged 8.76 ± 1.7 (SD) mg/L, with the median estimated only slightly lower (8.77 mg/L) and the 5^{th} and 95^{th} percentiles estimated at 5.9 and 11.8 mg/L (Figure 14, Table 7). Corresponding percent dissolved oxygen estimates were 91.8 ± 16.1 (SD) %, with 5^{th} and 95^{th} percentiles of 59.9 and 166.8%. There were only 3 instances in which dissolved oxygen concentrations were below 5 mg/L, which, taking into account both surface and bottom readings, accounted for less than 1 percent of the readings (Table 7). In at least one of these instances, bottom oxygen concentrations dropped as low as 0.15 mg in winter 2003 at the northernmost sampling location: <0.5 mg/L is considered anoxia. The other two instances occurred in April 2003. These comparatively low concentrations may be tied to upstream reservoir releases of poor quality water or nutrient loading from cattle in portions of the creek upstream of the Project Area (KHE 2006a).

Upstream of the Green Bridge, dissolved oxygen concentrations were fairly consistent during a 1.5-month sampling period in the summer of 2007. Based on continuous monitoring data from 2007, oxygen levels in waters directly upstream of the NMWD water supply wells averaged between 8.40 and 8.89 mg/L during three separate sonde deployment periods in the months of August and September (Appendix D4.1-D4.3). Standard deviation for these means did not exceed 0.48 mg/L during any of the sampling periods, and oxygen levels never dropped below 5.0 mg/L, even during the night. A similar pattern of oxygen concentrations was observed in continuous monitoring data collected adjacent to the NMWD water supply wells in August 2006, with oxygen levels ranging between 8 and 10 mg/L (Appendix D3.3-D3.4).

PH: The geometric mean for pH of waters in the Project Area portion of Lagunitas Creek averaged 7.8 and was relatively consistent with a standard deviation of 0.3 (Figure 15, Table 7). The 5th and 95th percentile estimates during the four years of sampling were 7.3 and 8.3, respectively. There was only one instance in which pH in Lagunitas Creek exceeded the Basin Plan (if not the EPA) limit of 8.5, which occurred at the Green Bridge sampling location when pH reached 8.7 in early December 2002 (Table 7).

There has not been much previous monitoring of water quality in this section of Lagunitas Creek, however, during the LMER study, pH was assessed at the northern end of the Giacomini Ranch in Lagunitas Creek (~LAG5 in Appendix A1) and further upstream near the Point Reyes Station stream gage. During the 5 to 8-year period in which these areas were monitored as part of sample collection events, pH averaged 7.72 ± 0.24 (SD) at the Lagunitas Creek stream gage station and 8.15 ± 0.1 (SD) at the Giacomini Ranch North Levee station (Station 18; LAG5; LMER/BRIE data). For the upstream Lagunitas Creek station, the median pH was 7.66, with the 5th and 95th percentiles estimated at 7.36 and 8.13 (LMER/BRIE data). For the Giacomini Ranch North Levee station, median pH was 8.17 – very close to the mean – and the 5th and 95th percentiles were estimated at 7.98 and 8.30, respectively. Only once in each location did pH exceed the Basin Plan standards of 8.5 (LMER/BRIE data). The strong variation in means for pH between downstream (8.15 ± 0.10 (SE)) and upstream (7.72 ± 0.02 (SE)) Lagunitas Creek sampling locations probably relates to the effect of tidal influence, with tidal waters typically higher in pH. Tidal influence in the downstream station may have been magnified by the fact that California was suffering from a drought period during the LMER study, with rainfall totals less than half the average (Smith and Hollibaugh 1997b). In addition, freshwater inflow was lower during that period, because the SWRCB had not yet instituted mandated baseflow conditions during the summer and fall.

Interestingly, while the Project Area had only one exceedance of Basin Plan objectives during our sampling period, some limited sampling on portions of Lagunitas Creek between the Green Bridge and Nicasio Creek revealed that pH levels in deeper portions of some of the pools were considerably reduced, with pHs ranging from 3.9 to 5.2 (KHE, *unpub. data*). These low values were never observed during continuous water quality monitoring conducted in Lagunitas Creek adjacent to the NMWD water supply wells in 2006 and 2007, with average values from three (3) 0.5-month deployments in 2007 ranging as little as from 7.66 ± 0.09 (SD) in early August to 7.76 ± 0.09 (SD) in early September (Appendix D3.3, D4.1-D4.3). During this deployment, pH never dropped below 6.5 or exceeded 8.5. Low pH periods may not have been detected during continuous water quality monitoring for several reasons. First, it is possible that they only occur infrequently and that sampling did not capture a low pH episode or that low pHs were present, but not captured because the sonde sensors are not directly at the bottom of the pool in the creek. Lastly, low pH episodes may only occur upstream of this location.

Temperature: During four years of monitoring, including two years of monthly monitoring, temperature in the Project Area portion of Lagunitas Creek averaged 16.2 ± 5.5 (SD) degrees Centigrade (Figure 16, Table 7). The mean must have been skewed somewhat by episodically high temperatures, as the median was lower (14.3 degrees Centigrade, Table 7). The 5th and 95th percentiles were estimated at 9.2 and 25.4 degrees Centigrade (Table 7).

This compares remarkably well with results of the LMER/BRIE study, which monitored temperature at two separate locations on Lagunitas Creek for 5 to 8 years. Temperature at the upstream station near the USGS stream gage was understandably lower, averaging 14.4 ± 4.0 (SD) degrees Centigrade (LMER/BRIE data). However, at the downstream location near the Giacomini Ranch North Levee, temperatures averaged 16.6 ± 2.6 (SD) degrees Centigrade (LMER/BRIE data). The 5th and 95 percentiles were understandably dissimilar for these two very different reaches of the estuary: 8.4 and 20.7 degrees Centigrade, respectively, for the stream gage station area and 12.7 and 21.0 degrees Centigrade, respectively, for the Giacomini Ranch North Levee area (LMER/BRIE data).

Within the Project Area – downstream of the Green Bridge -- temperatures exceeded the lethal limit for salmonids (25 degrees Centigrade) during approximately 6 percent of the sampling periods, while temperatures exceeded the suboptimal limit (22 degrees Centigrade) during approximately 20 percent of the sampling period. During the LMER/BRIE study, temperatures only exceeded the suboptimal approximately 3 percent of the time at the downstream Lagunitas Creek station and fell below this threshold 100 percent of the time at the upstream Lagunitas Creek station (LMER/BRIE data).

Interestingly, during our monitoring, average temperatures did not vary substantially between the shallow, wide section of Lagunitas Creek downstream of White House Pool (16.5 ± 0.5 (SE) degrees Centigrade) and the deeper, narrower section upstream of White House Pool (16.0 ±0.4 (SE) degrees Centigrade) despite dramatic differences in physical and hydrologic structure of the two reaches (Figure 10; t-test, n=161, df=159, t=0.61, p=0.54). Neither did the upper 95^{th} percentile range differ – 25.4 versus 25.5 degrees Centigrade for upstream and downstream areas, respectively.

Within this portion of the system, salmonids are not present throughout the year – they are moving into and out of the upper watershed at specific times of the year. Therefore, water temperature is most critical during these periods -- particularly the outmigration period in the late spring and early summer when young salmon will use estuarine transition zones to increase food reserves and start adapting to higher water salinities. With the Project Area portion of Lagunitas Creek, outmigrating salmon have largely been found in the reach upstream of White House Pool. To further evaluate temperature conditions in the White House Pool Reach during peak outmigration period, continuous temperature monitoring was conducted in this reach during the spring and early summer of 2003. Water temperatures showed a steady increase from an average of approximately 13.5 degrees Centigrade and a range of 9 to 18 degrees Centigrade in April 2003 to an average of approximately 18.5 degrees Centigrade and a range of 15 to 22 degrees Centigrade in June 2003 (Figure 13).

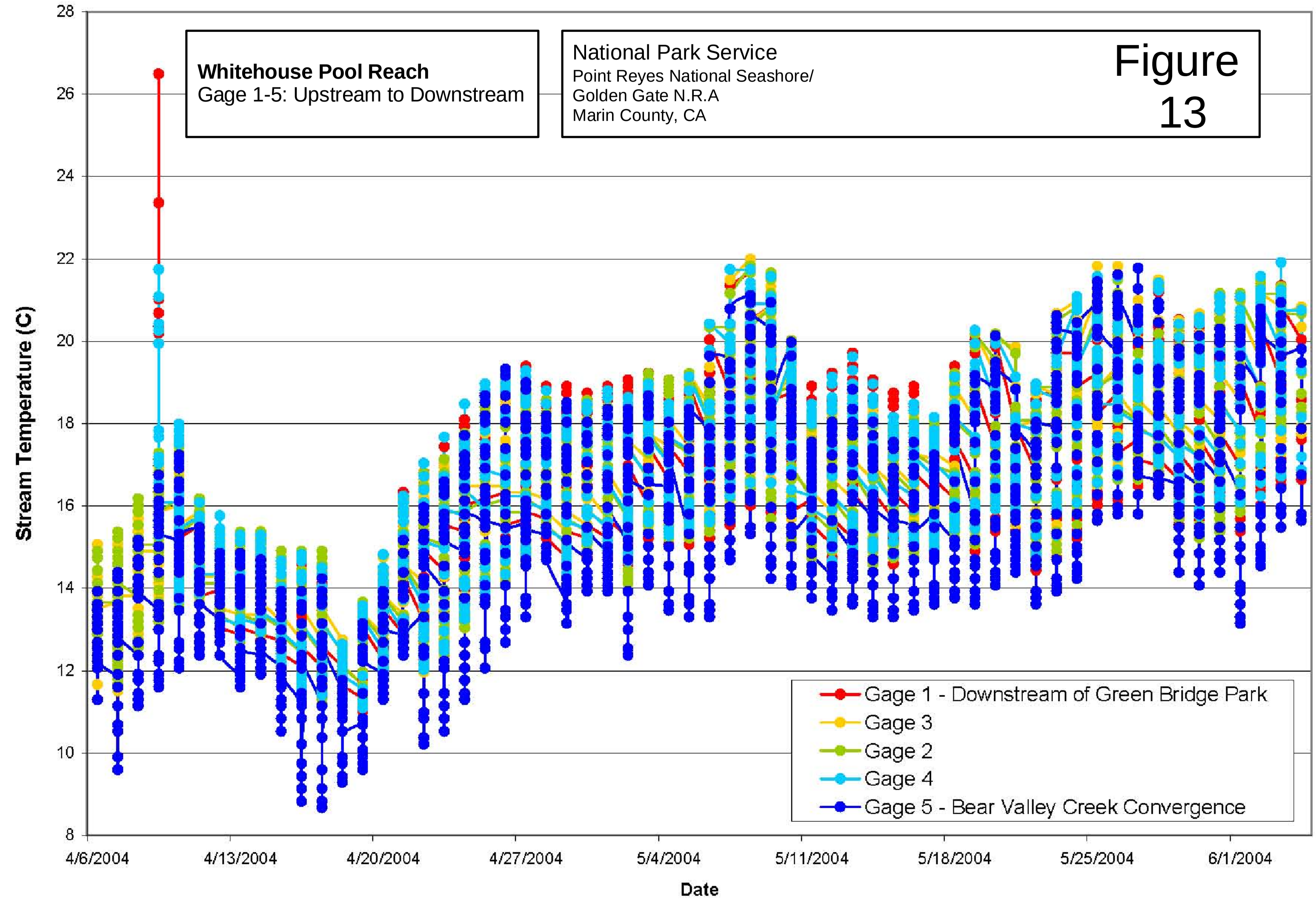
Water temperatures between monitoring locations both in open water and underneath overhanging riparian trees were almost identical despite the fact that riparian vegetation usually helps to keep water temperature lower due to the effects of shading on solar radiation. During a 24-hour period, temperatures typically varied by as much as approximately 6.3 to 10.5 degrees (Figure 13). One monitoring location consistently had the both the lowest temperatures and the widest daily variation in temperature: the lowest temperatures were consistently 0.5 to 2.0 degrees lower than other monitoring locations, although the daily highs were often similar (Figure 13) This monitoring location occurs just downstream of the confluence of Bear Valley Creek and Lagunitas Creek on the south bank underneath overhanging riparian vegetation and may be affected by nighttime cooling of waters within Olema Marsh that subsequently flow into Lagunitas Creek.

Upstream of the Green Bridge, continuous water quality monitoring conducted during fall 2005 and summers of 2006 and 2007 showed some minor diurnal variation in water temperature adjacent to or slightly upstream of the NMWD water supply wells (Appendix D2, D3.2, D4.1-D4.3). During early July 2006, water temperatures in the portion of Lagunitas Creek directly adjacent to the NMWD water supply wells varied between 18 to 22 degrees Centigrade, with temperatures peaking during the day (Appendix D3.2). In early August 2007, temperatures varied typically by 2 degrees between night and day. During the three (3) 0.5-month deployment periods in 2007, temperature average declined slightly from 17.98 ± 1.31 (SD) degrees Centigrade in early August to 17.37 ± 0.75 (SD) degrees Centigrade in early September (Appendix D4.1-D4.3). During this period, temperature never exceed 25 degrees Centigrade, the lethal limit, and exceeded the suboptimal limit of 22 degrees Centigrade less than 1 percent of the time, all of which was in early August 2007.

In addition to expected seasonal variations, water temperature also appeared to correspond with tidal stage, with temperatures during the August 2006 deployment adjacent to the NMWD water supply wells appearing to be elevated during a high tide event (Appendix D3.3). Water temperatures during the same period approximately 1 mile upstream at the Downey Well showed no variation with high tide, even though water levels increased slightly. As discussed earlier, this section of creek appears to be freshwater tidal such that water levels increase in responses to the tides, but the salt “wedge” itself does not extend this far upstream.

Lagunitas Creek Continuous Stream Temperatures, April - June 2004

Giacomini Wetland Restoration Project



Giacomini Ranch

Tomasini Creek

Dissolved Oygen: While part of the Giacomini Ranch, Tomasini Creek was leveed to flow separately from the East Pasture and was, therefore, less directly impacted by agricultural management and grazing. Flow on the gate was also originally controlled by one-way tidegate, but that has since failed and now allows two-way flow. Because the failed tidegate allowed tidal inflow to the leveed portion of Tomasini Creek, Tomasini Creek should meet the tidal waters standards for dissolved oxygen of 5.0 mg/L established by the RWQCB Basin Plan (1995).

During the four years of sampling, Tomasini Creek did not meet these minimum approximately 22 percent of the time, and, at least 4 percent of the time, oxygen concentrations dipped into hypoxic levels (<2 mg/L; Table 7). At least 2 percent of the time, oxygen depletion reached anoxic levels (<0.5 mg/L). Most of these exceedances occurred in upstream portions of Tomasini Creek within or just upstream of the Project Area, and low oxygen concentrations were not restricted just to bottom waters, but were found in surface waters, as well.

In general, dissolved oxygen in the Project Area portion of Tomasini Creek averaged 7.28 ± 2.90 (SD) mg/L, with the median estimated at 7.78 mg/L and the 5th and 95th percentiles estimated at 2.4 and 11.9 mg/L (Figure 14, Table 7). Corresponding percent dissolved oxygen estimates were 74.1 ± 33.0 (SD) %, with 5th and 95th percentiles of 20.7 and 112 %.

An examination of data from the two years of monthly monitoring between 2002 and 2004 shows that oxygen concentrations remained high until mid to late spring, when bottom waters started to have levels below 5 mg/L or even 2 mg/L. By mid summer, oxygen concentrations were uniformly low throughout the water column in sampling locations at or upstream of the Giacomini Hunt Lodge. By late summer and fall, all of the sampling locations often had levels below 5 mg/L or even 2 mg/L. The decrease and eventual loss of freshwater inflow from the upstream watershed and decrease in groundwater inflow from Point Reyes Mesa combined with the impoundment effect of the flashboard dam undoubtedly led to long water residence time and stagnant water conditions that increased phytoplankton densities and large diel variations in oxygen levels.

Continuous water quality monitoring conducted at a sampling location adjacent to the Giacomini Hunt Lodge from June 2004 showed large diel variation in oxygen levels of as much as 8 mg/L in the early part of June 2004, with concentrations consistently dropping below 4 mg/L at night (Appendix D5.1). Interestingly, the amplitude of oxygen diel variation dropped dramatically in mid-June, as salinities increased, probably in response to drops in streamflow and groundwater flow. During this period, oxygen concentrations largely varied no more than 3 mg/L between approximately 2.5 to 5.5 mg/L (Appendix D5.1). Monitoring was resumed again at this same location in September – October 2004, and oxygen concentrations during this period again showed some diel variation, but with only slight differences in concentration and consistently averaged below 5 mg/L. (Appendix D5.2). During the months of June, September, and October, 2004, oxygen levels were below 5 mg/L, the minimum Basin Plan standard, approximately 88 to 98 percent of the time. Oxygen levels fell below 2 mg/L, the hypoxic limit, 2 percent (September 2004) to 12 percent (June 2004) of the time.

One other interesting anomaly observed in dissolved oxygen patterns was that occasionally oxygen levels of bottom waters would exceed those of surface waters, and the disparity would be large enough to not ascribe it necessarily to measurement error. Typically, due to the higher densities of phytoplankton in surface waters, oxygen levels are higher in surface waters than bottom waters, where the limited oxygen production cannot offset respiration demands. This somewhat reversed pattern of oxygen concentrations with depth was even more pronounced in the West Pasture Old Slough (see below). In Tomasini Creek, this anomaly did not occur as frequently as the West Pasture Old Slough, but, when it did, most of the time, it was found in downstream portions of Tomasini Creek that were more influenced by tides. In May 2002, surface water oxygen concentrations were 10.72 and 10.34 mg/L at the two downstream sampling locations, while bottom water levels were 14.08 and 15.28 mg/L, respectively. There are several possible explanations for this phenomenon, one of which is that cold freshwater has the potential to carry more oxygen than warm freshwater, and cold water is denser and more likely to sink to the bottom. Oxygen supplies may also be subsidized by tidal inflow or groundwater, which is more likely to flow along the bottom of creeks due to density differences and stratification, or by oxygen production by benthic microalgae.

PH: The geometric mean of pH for Tomasini Creek surface waters was 7.70 and was relatively consistent between sampling periods with a standard deviation of 0.52 (Figure 15, Table 7). The 5^{th} and 95 percentiles were estimated at 6.9 and 8.5. The pH exceeded Basin Plan standards of 8.5 – but not EPA standards of 9 -- less than 4 percent of the time (Table 7). These exceedances occurred in the downstream portions of Tomasini Creek during the summer and fall and were probably related to an increase of phytoplankton productivity during the day and corresponding increase in the relative hydrogen ion concentration with uptake of carbon dioxide and production of oxygen. Higher pH levels for this creek were not necessarily always related to phytoplankton productivity or tidal influence, as pH in portions of Tomasini Creek waters upstream of tidal influence also had a median value of 7.7: Tomasini Creek flows off of the more Franciscan Formation-dominated ridges on the east side of Tomales Bay.

During spot sampling, there were no recordings of pH of less than 6.5 in surface waters, which is the Basin Plan minimum pH. However, during continuous water quality monitoring conducted in June and September-October 2004 in Tomasini Creek near the Giacomini Hunt Lodge, pH frequently dropped below 6.5 frequently – approximately 7 percent of the time -- during the month of October 2004, although it never exceeded 8.5 (Appendices D5.1-D5.2). In the months of June and September 2004, there was only one instance in September where pH dropped below 6.5 (September 2004), and it never exceeded 8.5 (Appendices D5.1-D5.2).

In general, mean pH declined from the start of the summer into fall, with pH averaging 7.05 ± 0.16 (SD) in June 2004, 6.83 ± 0.09 (SD) in September 2004, and 6.65 ± 0.12 (SD) in October 2004 (Appendices D5.1-D5.2). The reason for the decline in water pH is not entirely clear. Alkalinity may have dropped because of breakdown of organic matter and production of humic acids or other biogeochemical acid-producing processes or because of the relatively greater influence of groundwater from the Point Reyes Mesa once Tomasini Creek surface flows have disappeared in the late summer and fall. Because of underlying geologic substrate, the groundwater may be slightly more acidic in nature, while surface flows may be more alkaline. This section of creek is tidally influenced during the late summer and fall, and, in general, with surface flows drying up in late summer and early fall, the higher pH seawater would be expected to drive pHs up rather than down or at least to buffer acid production through introduction of carbonates and bicarbonates.

Even during periods where pH was relatively low, a clear diurnal pattern in pH could be seen in the early part of June 2004 and in October 2004, with pH values peaking with oxygen level and, to a lesser degree, temperature values (Appendices D5.1-D5.2).

Temperature: As with Lagunitas, Tomasini apparently also supports steelhead and some coho, although population size is unknown, and only a few individuals have been directly sighted. The portion of Tomasini Creek in the Project Area does not represent spawning habitat, but rather habitat used by salmon during in- and out-migration. During the four years of monitoring, including two years of monthly monitoring, temperatures averaged 14.2 ± 4.9 (SD) degrees Centigrade (Figure 16, Table 7). The median temperature was estimated slightly lower (13.1 degrees Centigrade), and the 5^{th} and 95 percentiles for temperature were estimated at 8.7 and 23 degrees Centigrade (Table 7). Water temperatures exceeded 25 degrees Centigrade – the lethal limit for salmonids – during less than 1 percent of the sampling periods, but temperatures exceeded 22 degrees Centigrade – the suboptimal limit for salmonids – during approximately 11 percent of the sampling periods (Table 7).

Continuous water quality monitoring in Tomasini Creek near the Giacomini Hunt Lodge – where some of the salmon have been observed – showed a seasonal decline, as would be expected, from the summer to the early fall, with temperatures averaging 17.32 ± 0.74 (SD) degrees Centigrade in June 2004, 16.60 ± 1.19 (SD) degrees Centigrade in September 2004, and 13.6 ± 1.71 (SD) degrees Centigrade in October 2004 (Appendices D5.1-D5.2). As with oxygen levels and pH, temperature showed some diurnal variation (0.5 to 2 degrees), as well as some variation seemingly in response to tidal influence, with increases in water salinity appearing to correspond with a slight increase in the overall range of water temperature (~ 1 degree; Appendices D5.1-D5.2). Water temperatures exceeded 25 degrees Centigrade less than 1 percent of the time in June 2004 and exceeded 22 degrees Centigrade less than 1 percent of the time in June and September 2004 (Appendices D5.1-D5.2).

East Pasture

Dissolved Oxygen: The East Pasture was not hydrologically connected to Lagunitas Creek or Tomasini Creek, except during periods of flooding, although there may have been some connection during periods of pumping of pasture waters by the Giacominis or via leaking tidegates. Within some of the ditches and channels in the East Pasture, dissolved oxygen concentrations consistently fell below 5 mg/L within both surface and bottom waters of some ditches and ditched sloughs and were typically even below 2 mg/L. The RWQCB objective of 5.0 mg/L was exceeded during 56 percent of the sampling periods in the East Pasture, with oxygen levels below hypoxia (< 2.0 mg/L) and anoxia (<0.5 mg/L) during 31 percent and 14 percent of the sampling periods, respectively (Table 7).

The observed hypoxia-anoxia in drainage ditches was probably caused by increased oxygen demand from bacteria breaking down organic matter or detritus from vegetation disturbed by ditch maintenance. Low dissolved oxygen concentrations also occurred in some of the non-ditched features in the East Pasture, including the East Pasture's New Duck Pond, where a majority of values were below 5 mg/L: the New Duck Pond is a shallowly ponded, artificially created feature that was maintained until recently through seasonal flooding of pumped irrigation waters.

Consistently low oxygen levels drove down the mean oxygen concentrations to 4.98 ± 3.86 (SD) mg/L, with the median estimated at 4.56 mg/L and the 5^{th} and 95 percentiles estimated at 0.17 and 11.1 mg/L (Figure 14, Table 7). In terms of percent oxygen, oxygen saturation averaged 48.57 ± 41.07 (SD) %, with the 5^{th} and 95^{th} percentiles values of 1.8 and 125.06 %.

There were a few instances where dissolved oxygen of bottom waters exceeded those of surface waters, primarily in the East Pasture Old Slough. On one date, surface water oxygen concentrations at the middle East Pasture Old Slough (EPOS2; Appendix A1) sampling location averaged 0.98 mg/L, while those of bottom waters averaged 4.11 mg/L. These waters are not tidally or fluvially influenced, nor were temperatures between surface and bottom waters substantial enough on most sampling occasions to account for these differences. In some cases, increased oxygen depletion of surface waters relative to bottom waters may have been related to recent ditching activities, with subsequent microbial activity on floating organic matter highest at the water surface, where oxygen supplies from the atmosphere are generally higher.

PH: The pH in East Pasture drainage ditch and ditched slough surface waters exceeded Basin Plan standards of 8.5 approximately 7 percent of the time, while pH dropped minimum standards of 6.5 approximately 3 percent of the time (Table 7). The geometric mean for pH of East Pasture surface waters averaged 7.48 ± 0.62 (SD), with the 5th and the 95th percentiles estimated at 6.6 and 8.4 (Figure 15, Table 7).

Water pHs with more basic or alkaline values (>8.5) typically occurred during the spring and summer when primary productivity of phytoplankton is highest due to nutrient loading, warm temperatures, and decreased flow conditions. Water pHs with more acidic values (~5.9 - 6.4) were typically found in drainage ditches and shallow seasonally flooded areas due probably to breakdown of organic matter after ditching or seasonal vegetation die-off and subsequent production of humic acids or other acids related to biogeochemical processes. At least one instance where pHs were consistently lower than circumneutral (~7) may have resulted from the strong emergent groundwater influence on this particular ditch, which directly borders the Point Reyes Mesa. As noted earlier, the pH of groundwater appears to be lower than that of surface water and tidal water flows.

Temperature: Because of its lack of hydrologic connectivity, the East Pasture does not currently support salmon or have salmonid habitat. However, other aquatic organisms do subsist in certain portions of the ditches and ditched sloughs, including the federally endangered tidewater goby, threespine stickleback, mosquitofish, and crayfish. As noted earlier, the acceptable temperature for goby ranges from 8 to 25 degrees Centigrade (USFWS 2009), with a narrow optimal range for spawning of 15 to 24 degrees Centigrade (Stillwater Sciences 2006). In East Pasture ditches and ditched sloughs, water temperatures exceeded 25 degrees Centigrade – the lethal limit for salmonids -- during approximately 3 percent of the sampling periods and 22 degrees Centigrade – the suboptimal limit for salmonids -- during approximately 7 percent of the sampling periods. Within the East Pasture, temperature of waters averaged 15.4 ± 4.7 degrees Centigrade, with the median estimated at 15.2 degrees Centigrarde and the 5th and 95th percentiles estimated at 8.2 and 23.8 degrees Centigrade (Figure 16, Table 7). As would be expected, temperatures follow a seasonal pattern, with water temperatures highest in summer months.

West Pasture - Fish Hatchery Creek and West Pasture Old Slough

Dissolved Oxygen: Dissolved oxygen concentrations in Fish Hatchery Creek were below minimum standards (5 mg/L) set by the RWQCB in its Basin Plan approximately 5 percent of the time, with concentrations below hypoxic levels (<2 mg/L) or anoxic levels (<0.05 mg/L) less than 1 percent of the time. Comparatively, concentrations in the West Pasture Old Slough prior to its confluence with Fish Hatchery Creek were below minimum standards of 5 mg/L approximately 16 percent of the time, with levels dropping below 2 mg/L 5 percent of the time and below 0.5 mg/L less than 1 percent of the time.

Fish Hatchery flows directly through the West Pasture, eventually merging with the West Pasture Old Slough, before flowing out of the Giacomini Ranch into the Undiked Marsh. In 2006, the Giacominis diverted Fish Hatchery Creek to run through the West Pasture Old Slough to improve drainage of some of the pastures. Mean dissolved oxygen concentrations were similar between the two waterways: 9.13 mg/L for Fish Hatchery Creek and 9.2 mg/L for West Pasture Old Slough. However, there was more variability in oxygen levels in the West Pasture Old Slough (± 4.6 SD) than in Fish Hatchery Creek (± 2.8 SD). This is also evident in the 5th and 95th percentile estimates. For Fish Hatchery Creek, they ranged from 4.8 to 13.4 mg/L, while for the West Pasture Old Slough, they ranged from 2.6 to 17.8 mg/L. Similar patterns were observed in the percent saturation, with average values of 99.3 ± 34.2 (SD) % for Fish Hatchery Creek and 101.7 ± 63.0 (SD) % for West Pasture Old Slough. The 5th and 95th percentile estimates for percent saturation were 59.9 and 156.8 % for Fish Hatchery Creek and 20.7 and 203.3 % for the West Pasture Old Slough.

Most of the values below 5 mg/L recorded in West Pasture waterways occurred in bottom waters, but two locations often had surface water oxygen levels below 5 mg/L – one was at the "headwaters" of the West Pasture Old Slough, where surface and groundwaters from an adjacent parcel flow into a drainage ditch, and the other is midway along Fish Hatchery Creek in the West Pasture. Hypoxia occurred in the latter even prior to Fish Hatchery Creek's diversion in 2006.

Both of these sections of channel are relatively narrow and shallow.

Most of these events occurred in the spring or summer, when oxygen concentrations might be affected by a combination of nutrient loading, increased temperature, decreased flow conditions, and, consequently, an increase in primary productivity that could create rapid diel variation in oxygen levels. The West Pasture has been less intensively managed than the East Pasture in terms of grazing, but the upper portions of the creek flow through residential areas of Inverness Park, which may affect the quality of water flowing into the pasture through non-point source run-off from irrigation of landscaped areas, leaking septic systems, and other factors, thereby leading to nutrient loading even during the dry season.

As with Tomasini Creek, occasionally, reversed patterns of oxygen levels occurred in the West Pasture Old Slough such that oxygen levels were higher in bottom than surface waters. This phenomenon occurred much more frequently in the West Pasture Old Slough than in Tomasini Creek and was typically found in the downstream portion of the diked slough near the confluence with Fish Hatchery Creek. The degree of variation in oxygen levels during these sampling periods was high enough to rule out small-scale sampling error as the cause. For example, in October 2002, oxygen levels in surface waters averaged 9.06 mg/L, while those of the bottom waters exceeded 20 mg/L. In May 2003, oxygen concentrations in surface waters averaged 10.35 mg/L, while those of bottom waters again exceeded 20 mg/L. Generally, however, the degree of variation was less dramatic, with oxygen levels of bottom exceeding those of surface waters by approximately 1.35 to 2.38 mg/L.

As discussed earlier, there are several possible explanations for this phenomenon, one of which is that cold freshwater has the potential to carry more oxygen than warm freshwater. Interestingly, during several occasions on which bottom water oxygen levels exceeded those of surface waters, bottom waters were actually warmer than surface waters: cold water is typically denser and, therefore, sinks to the bottom due to density differences. Oxygen supplies may also be subsidized by tidal inflow, which is more likely to flow along the bottom of creeks due to higher osmotic concentrations and subsequent density-based stratification. All of these areas receive muted tidal inflow.

PH: Fish Hatchery Creek exceeded the maximum pH standard established in the Basin Plan during less than 2 percent of the sampling periods. Conversely, pHs in the West Pasture Old Slough dropped below the minimum standard of 6.5 approximately 6 percent of the time and exceeded the maximum standard of 8.5 slightly more than 1 percent of the time.

The geometric mean pH averaged 7.70 ± 0.42 (SD) for Fish Hatchery Creek and 7.44 ± 0.62 (SD) for the West Pasture Old Slough. The 5th and 95th percentile estimates were 7 and 8.3 for Fish Hatchery Creek and 6.44 and 8.47 for the West Pasture Old Slough. Baseline pH appeared higher in areas that are either tidal or tidally influenced, as tidal waters tend to be more alkaline (~ 7.8), and in the upstream portions of Fish Hatchery Creek that flows off the Inverness Ridge (~7.8 – 8.1), which may be related to the underlying chemistry that exists from weathering of this granite-dominated geologic formation. Typically, granitic substrates tend to drive pH down (Smedley 1991), but there may be something unique to the chemistry of this particular geologic formation that conversely drives pH up.

Temperature: Fish Hatchery Creek appears to support steelhead trout, although the size and migratory status of this population is unknown. Temperatures averaged 15.92 ± 5.41 (SD) degrees Centigrade for Fish Hatchery Creek and 16.19 ± 5.39 (SD) degrees Centigrade for West Pasture Old Slough. The 5th and 95th percentile estimates were also similar for the two principal waterways in the West Pasture – 8.49 and 25.92 for Fish Hatchery Creek and 7.9 and 25.85 for West Pasture Old Slough.

In general, temperatures varied seasonally, with the warmest temperatures in the summer. During the spring and summer, temperatures exceeded both the lethal (25 degrees Centigrade) and suboptimal limit (22 degrees Centigrade) for salmonids. Temperatures in the West Pasture Old Slough exceeded these limits during approximately 14 percent and 28 percent of the sampling periods, respectively. Exceedances were slightly lower in Fish Hatchery Creek, with temperatures above the lethal limit during approximately 6 percent of the sampling periods and above the suboptimal limit during approximately 17 percent of the sampling perids. However, at least one of the sampling locations at the upstream end of Fish Hatchery Creek consistently has cooler water temperatures than any of the other sampling locations, with average temperatures of 12.25 ± 2.23 (SD) degrees Centigrade. This area is just upstream of the Project Area and receives cool waters from the upper portions of the Fish Hatchery Creek subwatershed and is shaded by riparian habitat. Within this reach, temperatures never exceeded 22 degrees Centigrade and were typically below 15.4 degrees Centigrade, the 95th percentile for this sampling area.

West Pasture – 1906 Drainage, Freshwater Marsh, and Other Water Bodies

Dissolved Oxygen: Fish Hatchery Creek and the West Pasture Old Slough are the primary drainages in the West Pasture, but several smaller drainages flow into the western side of the West Pasture, including the 1906 Drainage, which flows into the West Pasture Freshwater Marsh. In addition, some former tidal sloughs often pond seasonally, creating low-lying panes or flats. Many of the small drainages are highly seasonal in nature and only convey water into the pasture during the winter. There are several perennial drainages that flow into the northern portion of the West Pasture. These drainages feed the large freshwater marsh that has established on the pasture's western perimeter adjacent to Sir Francis Drake Boulevard. The largest of these drainages is the 1906 Drainage that actually flows through the backyard of one of the private properties on the east side of Sir Francis Drake Boulevard and into the West Pasture, ending abruptly at the southern terminus of the West Pasture Freshwater Marsh.

As might be expected, oxygen concentrations within the 1906 Drainage are consistently higher than that of the marsh, where water residence time is long due to the depressional basin nature of the marsh and little opportunities exists for exchange with other water bodies. Average oxygen concentrations ranged from 9.22 ± 2.51 (SD) mg/L in the 1906 Drainage to 7.25 ± 4.66 (SD) mg/L in one of the open water areas in the West Pasture Freshwater Marsh. Variation in the 5th and 95th percentile values was higher in the Freshwater Marsh, with percentiles estimated as 0.93 and 14.85 mg/L for the Freshwater Marsh compared to 4.11 and 12.47 mg/L for the 1906 Drainage. In terms of oxygen saturation, percent oxygen averaged 87.58 ± 22.95 (SD) % in the 1906 Drainage compared to 68.53 ± 41.47 (SD) % in the West Pasture Freshwater Marsh. Similar to oxygen concentrations, there was greater variation in the 5th and 95 percentile estimates in the West Pasture Freshwater Marsh (12.98 and 127.04%) than in the 1906 Drainage (41.09 and 116.54%). Consistent with these patterns in oxygen levels, the percentage of sampling periods in which concentrations were below the minimum standards established in the Basin Plan (5 mg/L) was higher in the West Pasture Freshwater Marsh than in the 1906 Drainage. Oxygen levels were below 5 mg/L during 29 percent of the sampling periods in the West Pasture Freshwater Marsh compared to 7.3 percent of the sampling periods in the 1906 Drainage. Concentrations fell below 2 mg/L, the threshold for hypoxia, during 15 percent of the sampling periods in the West Pasture Freshwater Marsh compared to only 3 percent of the sampling periods in the 1906 Drainage. There were no recorded values below 0.5 mg/L, the threshold for anoxia.

Continuous water quality monitoring in the West Pasture Freshwater Marsh was conducted in two more vegetated portions of the marsh within the center of the basin during spring of 2004. Oxygen levels showed sharp diurnal variation throughout the deployment period. On March 19, 2004, oxygen levels climbed to 19.22 mg/L by mid-afternoon, only to crash to 0.59 mg/L during the middle of the next night (Appendix D6). During the months of April and May 2004, the diurnal swing in oxygen levels was not quite as sharp, with the upper range reaching between 8 and 13 mg/L and the lower range consistently falling between 0.25 and 1.25 mg/L. To some degree, the sharp swings in oxygen during March appeared to correspond with a period of tidal intrusion into the marsh, with salinities climbing to between 6 and 9 ppt during late March and then slowly falling to between 1.5 and 2.5 ppt during April and May. When diked, tidal intrusion into the marsh only occurred during periods of extreme tides, when tidal water levels within the diked portion of Fish Hatchery Creek consistently reached the upper limit of the muted tidal range – approximately 5.25 feet NAVD88. Tides may have replenished depleted oxygen levels in marsh waters or subsidized primary productivity in some way that resulted in an increase in oxygen production. However, this pattern in oxygen levels may be accounted for by other factors such as precipitation and/or surge in groundwater or surface inflow into the marsh.

During the 2.5-month deployment period, oxygen concentrations and saturation averaged 3.34 ± 3.81 (SD) mg/L and 43.84 ± 50.64 (SD) %, respectively, with 5th and 95th percentile estimates of 0.07 and 10.47 mg/L for concentration and 0.9 and 146.8 % for saturation. In both instances, the average appears to have been heavily influenced by some of the spikes in oxygen, as median values for concentration and saturation were considerably lower -- 1.25 mg/L and 14.6 %. Based on this data, oxygen levels in the center of the marsh fell below minimum standards established by the Basin Plan of 5 mg/L during approximately 71 percent of the time. Concentrations dropped into hypoxic levels (<2 mg/L) approximately 56 percent of the time and anoxic levels (<0.5 mg/L) 24 percent of the time. The sharp variation in mean oxygen concentrations and exceedance of Basin Plan standards between the data presented here and the data presented earlier for the West Pasture Freshwater Marsh probably relates primarily to the location of sampling. The sampling point for discrete water quality sampling is located on the perimeter of the marsh within a small channel that receives direct inflow from groundwater, small perennial drainages, and, on occasion, tidal intrusion. Conversely, the continuous water quality sampling instrument was placed in the center of the marsh, where residence time was much higher and exchange, much lower.

Other impounded areas within the West Pasture also suffered from low oxygen levels. A shallowly flooded flat that developed within a former tidal slough that converted into a swale feature had only slightly higher mean oxygen concentrations (4.08 ± 6.03 (SD) mg/L), with widely divergent 5th and 95 percentile estimates of 0.081 and 20 mg/L. Median concentrations dropped to 1.51 mg/L. In terms of saturation levels, percent saturation averaged 51.76 ± 88.47 (SD) %, with the 5th and 95th percentile estimated at 1.1 and 235.6 %. Minimum oxygen concentrations established by the Basin Plan of 5 mg/L were exceeded during approximately 77 percent of the sampling periods, with levels dropping below hypoxia (<2 mg/L) and anoxia (<0.5 mg/L) during approximately 63 percent and 27 percent of the sampling periods, respectively.

PH: Similar to Fish Hatchery Creek, the 1906 Drainage had geometric mean pH concentrations that consistently exceeded circumneutral (~7). The pH averaged 7.66 ± 0.49 (SD), with 5th and 95 percentiles of 6.88 and 8.56. The pH exceeded Basin Plan standards of 8.5 during approximately 5 percent of the sampling periods, but, based on the median pH (7.7), these peaks in pH did not necessarily unduly influence the mean. As noted earlier, the pH of these waters is controlled to a large degree by the mineral composition of run-off, which is influenced by the largely granitic geologic substrate of the Inverness Ridge watershed. Often, granitic substrates are associated with lower pH values (Smedley 1991), but some mineral or group of minerals within this particular geologic formation may lead to surface run-off having higher pH values. Conversely, baseline pH appeared slightly depressed (~5.9 – 6.6) in locations primarily influenced by groundwater. Most of the low pHs in the West Pasture were recorded in upstream sampling locations of the West Pasture Old Slough, which is fed by groundwater from an adjacent parcel and surface run-off.

The pH of the West Pasture Freshwater Marsh channel on its western perimeter was slightly lower than that of its larger source creek, with pH averaging 7.23 ± 0.5 (SD). The 5th and 95th percentile values ranged from 6.64 to 8.13, with 5 percent of the readings falling below the Basin Standard of 6.5. During deployment of the continuous water quality monitoring instrument in spring 2004, pH in the center of the marsh averaged 7.02 ± 0.37 (SD), which was slightly lower than that of the perimeter (Appendix D6). This may result from the greater influence along the perimeter of higher pH run-off waters from the Inverness Ridge. Fewer values did not meet Basin Plan standards during this period, with 1 percent of the values exceeding the 8.5 maximum standard and another 1 percent falling below the 6.5 minimum standard.

The 5th and 95th percentiles for water pH in the center of the marsh were more closely grouped than that of perimeter waters with values of 6.60 and 7.65, but the deployment period did not include the summer, when primary productivity typically peaks, and pH rises. Interestingly, pH during deployment closely follows the trends of dissolved oxygen in that pH levels are actually highest in early March and sharply fluctuate on a diurnal basis (Appendix D6). For example, on March 20, pH climbed from 7.22 in the morning to 8.82 in the afternoon. As with oxygen, pH values and the range or amplitude of daily variation in values dropped with the decrease in water salinity. The range contracted from 6.35 to 7.35 during April, with pH variation limited on most days to between 6.5 and 6.9. During the month of May, pH values and the range of daily variation again increased, but still remained below that of late March. During May 2004, the pH generally ranged from 6.8 to 7.5, with some peaks recorded as high as 8.1.

The pH for the shallowly impounded muted tidal flat in the West Pasture was typically lower than other waters in the West Pasture, averaging 6.8 ± 0.79 (SD). More than 32 percent of the values recorded during discrete sampling were below 6.5, the minimum Basin Plan standard. There were no exceedances of the maximum standard (8.5). The 5th and 95th percentile estimates for pH in this area ranged from 5.69 to 7.9. Similar to the East Pasture drainage ditches, breakdown and decomposition of organic matter, along with potentially other biogeochemical processes related to drawdown during the summer and fall, may have reduced pH through production of humic and other types of acids. Because this feature was hydrologically isolated from channels and other water sources other than groundwater, there was minimal potential for these acids to be buffered or neutralized by carbonates and bicarbonates in stream and tidal waters.

Temperature: Salmonids have not necessarily been documented within the 1906 Drainage or the Freshwater Marsh in the West Pasture, but it is possible that they occurred in the upper watershed of the 1906 Drainage historically, particularly as this perennial drainage was once more directly connected to open water areas of Tomales Bay.

Waters within the 1906 Drainage and the small channel on the perimeter of the West Pasture Freshwater Marsh did not have temperatures that exceeded the lethal limit for salmonids. However, during at least 2 percent of the sampling periods, temperatures in the 1906 Drainage did exceed 22 degrees Centigrade, which is above the temperature at which salmonids can persist for extended periods. Temperatures averaged 13.54 ± 2.82 (SD) degrees Centigrade in the 1906 Drainage and 13.1 ± 4.05 (SD) degrees Centigrade on the western perimeter of the marsh. The 5th and 95th percentile values for the marsh and its principal source creek were 5.87 and 19.34 and 10.08 and 18.4 degrees Centigrade, respectively. While the upper range of temperature may have been generally slightly higher in the marsh's perimeter channel, the slightly lower average temperature for this channel compared to the 1906 Drainage probably relates to the fact that the perimeter channel is densely shaded by riparian vegetation, while the 1906 Drainage is not shaded, at least in its lower reaches.

Temperatures appear to increase towards the center of the West Pasture Freshwater Marsh, as evident from the 2.5-month continuous water quality monitoring conducted in spring 2004 (Appendix D6). As with oxygen and pH, temperatures in the marsh center showed wide diurnal variation, particularly during late March, where values during the day peaked as high as 28.99 degrees Centigrade during the day and then dropped to 10.52 by the following morning (March 24-25, 2004; Appendix D6). In general, between mid-March and late May, temperatures rarely dropped below 10 degrees Centigrade and frequently exceeded 22 degrees Centigrade. Temperatures exceeded 22 degrees Centigrade approximately 24 percent of the time during this deployment period and exceeded what is considered the lethal limit for salmonids, 25 degrees

Centigrade, approximately 12 percent of the time. The sharps peaks in water temperature influenced the average temperature for this period, 18.42 ± 4.80 (SD) degrees Centigrade, with the median value being at least slightly lower, 17.61 degrees Centigrade. The 5^{th} and 95^{th} percentile values ranged from 11.63 degrees Centigrade to 27.12 degrees Centigrade.

Temperatures were generally slightly lower in the other impounded feature, the shallowly flooded flats in the northwestern corner of the West Pasture. Temperatures averaged 15.35 ± 5.06 (SD) degrees Centigrade, with a median temperature of 14.3 degrees Centigrade. The 5^{th} and 95^{th} percentiles were estimated at 9.44 and 24.25 degrees Centigrade. Temperatures exceeded the lethal limit for salmonids, 25 degrees Centigrade, during approximately 3 percent of the sampling periods, while temperatures exceeded 22 degrees Centigrade, the temperature at which salmonids can persist for extended periods of time, during approximately 17 percent of the sampling periods. Often, this feature was dry by the summer, which may have decreased its maximum temperature relative to other perennially impounded features.

Bear Valley Creek and Olema Marsh

Dissolved Oxygen: The monitoring record for Olema Marsh is shorter than for Giacomini Ranch, as monitoring was not initiated for this portion of the Project Area until summer 2004. From summer 2004 to summer 2006, oxygen levels in upstream and downstream portions of Bear Valley Creek averaged 5.84 ± 1.43 (SD) mg/L (Figure 14, Table 7). In this case, the median concentration (6.15 mg/L) was actually slightly higher than the mean, which shows the influence of some of the lower values recorded (Figure 14). The 5th and 95th percentile values were estimated at 2.95 and 7.70 mg/L. Oxygen concentrations fell below the minimum level established by Basin Standards (5 mg/L) during approximately 29 percent of the sampling periods, although levels never dropped below 2 mg/L, the threshold for hypoxia, or 0.5 mg/L, the threshold for anoxia (Table 7). In terms of percent saturation, oxygen content averaged 60.2 ± 18.0 (SD) %, with the 5th and 95th percentiles estimated as 31.4 and 91.0 %.

Bear Valley Creek flows through Olema Marsh to reach its confluence with Lagunitas Creek. Connectivity of this creek with Lagunitas, however, is hampered by the low outflow currently allowed from Olema Marsh due to loss of flow through one of two culverts and reduced outflow from the remaining culvert due to a berm in between the marsh and the culvert. This has led Olema Marsh to become a large freshwater pond that is getting larger every year based on estimates of a rise in water levels of 6 feet in the past decade (KHE 2006b).

Most of the lower oxygen levels occurred in late spring, summer, and sometimes in fall. Impoundment of waters within the marsh leads to long residence times and poor exchange, thereby increasing the potential during the late spring, summer, and early fall for eutrophic conditions to develop, which are often characterized by wide swings in oxygen levels between day and night. In addition, production of copious amounts of organic matter from decaying emergent vegetation can drive down oxygen levels through bacterial oxygen demand and respiration.

During individual sampling periods, oxygen concentrations were often lower in the downstream portion of Bear Valley Creek downstream of Olema Marsh than in the upstream portion, located in Bear Valley Marsh, although there were no statistically significant differences in means between the two sampling locations -- 5.82 ± 0.34 (SE) mg/L (downstream location) versus 5.90 ± 0.40 (SE) mg/L (upstream location; t-test, n=18, df=16, t=0.02, p=0.98). Low oxygen values recorded in downstream sampling locations appear to reflect conditions of the marsh more so than that of the sampling location, which occurs in a shaded portion of Bear Valley Creek that has consistently higher flow velocities and lower residence time than the marsh itself. The berm that constrains outflow of the marsh into this section of the creek may alter patterns of oxygen such that there is a delay between low levels in the marsh and outflow of low oxygen waters from the marsh. Ironically, while oxygen levels are often higher in the upstream sampling location during individual sampling periods, the upstream location is actually located in an open, marshy, and relatively impounded section of creek upstream of Bear Valley Road called Bear Valley Marsh.

PH: The geometric mean of pH for surface waters in upstream and downstream portions of Bear Valley Creek averaged approximately 7.02 ± 0.36 (SD; Figure 15, Table 7). The pH never exceeded the upper limit of 8.5 established by the Basin Plan standards or 9.0 established by the EPA for freshwater systems (Table 7). It fell below the lower limit of 6.5 only once or during less than 5 percent of the 20 sampling periods. The 5th and 95th percentile estimates for pH ranged from 6.5 to 7.71 (Table 7).

Temperature: Salmonids, principally steelhead or rainbow trout, occur in the upper portions of the Bear Valley Creek watershed, although the migratory status of these individuals is unknown. Coho have only been sighted once in recent times, however, this watershed is reputed to once have supported a thriving salmonid fishery. As with the Giacomini Ranch, this portion of Bear Valley Creek in Bear Valley and Olema Marshes would represent transitional habitat for salmonids moving upstream to spawn and downstream to outmigrate to the ocean.

Temperatures in creek waters averaged 14.50 ± 4.72 (SD) degrees Centigrade, although occasional spikes in temperature appear to have influenced the mean to some degree, as is evident from the lower median value of 12.9 degrees Centigrade (Figure 16, Table 7). The 5^{th} and 95^{th} percentiles were estimated at 10.03 and 24.00 degrees Centigrade (Table 7). Temperatures exceeded the lethal limit for salmonids, 25 degrees Centigrade, only once or during approximately 2 percent of the sampling periods, although temperatures reached 22 degrees Centigrade, the suboptimal limit, during approximately 12 percent of the sampling periods (Table 7).

Interestingly, average temperatures in the upstream sampling location that occurs in the open, marshy, and relatively impounded portion of Bear Valley Creek in Bear Valley Marsh (12.69 ± 0.60 (SE) degrees Centigrade) were lower than that of the downstream sampling location that occurs in a shaded section of Bear Valley Creek (15.15 ± 1.5 (SE) degrees Centigrade; t-test, n=20, df=18, t=-0.68, p=0.5). While the median temperature of upstream waters agreed relatively well with the average (12.5 vs. 12.69), the median temperature of downstream waters was estimated at 13.35 degrees Centigrade, suggesting that some occasional high temperatures are skewing the mean in this location. As with dissolved oxygen, the downstream sampling location appears to be more heavily influenced by the dynamics of Olema Marsh outflow than conditions of the sampling location itself, as temperatures would be expected to be considerably lower within this heavily shaded portion of the creek than in the open, marshy upstream sampling location.

Reference Areas

Undiked Marsh

Dissolved Oxygen: Oxygen levels in the Undiked Marsh north of the Giacomini Ranch averaged 8.39 ± 3.3 (SD) mg/L (Figure 14). The median concentration (7.75 mg/L) was slightly lower than the mean, which shows the influence of some of the higher or peak values recorded (Figure 14, Table 7). The 5th and 95th percentile values were estimated at 4.28 and 14.63 mg/L. Oxygen concentrations fell below the minimum level established by Basin Standards (5 mg/L) during approximately 10 percent of the sampling periods, with levels dropping below 2 mg/L, the threshold for hypoxia, approximately 2 percent of the time, but never dropping below 0.5 mg/L, the threshold for anoxia (Table 7). In terms of percent saturation, oxygen content averaged 97.0 ± 38.7 (SD) %, with the 5th and 95th percentiles estimated as 51.4 and 171.9%.

Almost all of the recorded anoxic and hypoxic oxygen values occurred in a marsh pond in the middle of the Undiked Marsh marshplain. This very shallow pond is fed by overbank flooding during higher high tide and winter flood events. Dense algal matting is often common in these ponds. The relatively infrequent exchange of waters in these ponds, coupled with strong oxygen demands from algal decay, probably lead to strong diel and tide-related patterns in oxygen, with levels decreasing overnight and during neap tide periods when pond waters are not replenished. The creeks themselves typically had oxygen levels exceeding 5 mg/L, even in bottom waters. In fact, there was very little stratification in creek waters, with bottom water oxygen levels only slightly lower than surface water oxygen concentrations.

PH: The geometric mean of pH for surface waters in the Undiked Marsh averaged approximately 7.47 ± 0.36 (SD; Figure 15, Table 7). The pH never exceeded the upper limit of 8.5 established by the Basin Plan standards and never fell below the lower limit of 6.5 (Table 7). The 5th and 95th percentile estimates for pH ranged from 6.94 to 8.15 (Table 7). Higher pH values (≥ 8) probably reflect peaks in primary productivity during the day by phytoplankton in creek waters, with corresponding increases in pH.

Temperature: The Undiked Marsh and other reference marshes probably represent transitional habitat for salmonids such as steelhead, coho, and chinook. These marshes would be areas where salmon would wait during higher than average flood flows before moving upstream in the watershed to spawn or spend time acclimating to marine conditions as outmigrating smolts.

Reflective of its downstream position in the watershed, temperatures in the Undiked Marsh averaged 17.32 ± 5.84 (SD) degrees Centigrade, although occasional spikes in temperature appear to have influenced the mean slightly, as is evident from the lower median value of 16.45 degrees Centigrade (Figure 16, Table 7). The 5^{th} and 95^{th} percentiles were estimated at 9.5 and 26.86 degrees Centigrade (Table 7). Temperatures exceeded the lethal limit for salmonids, 25 degrees Centigrade, during 7 percent of the sampling periods, and temperatures reached 22 degrees Centigrade, the suboptimal limit, during approximately 23 percent of the sampling periods (Table 7). While waters frequently reached temperatures considered supoptimal for salmonids, it is likely that most salmon were -- and are -- not present during these periods, because most of these higher temperatures occurred during mid-summer. Outmigration typically tapers off in June for the season.

Walker Creek Marsh

Dissolved Oxygen: Oxygen levels in Walker Creek Marsh averaged 9.21 ± 3.67 (SD) mg/L (Figure 14, Table 7). As with the Undiked Marsh and several other areas, the median concentration (8.56 mg/L) was slightly lower than the mean, which shows the influence of some of the higher or peak values recorded (Figure 14, Table 7). The 5th and 95th percentile values were estimated at 4.64 and 14.66 mg/L (Table 7). Oxygen concentrations fell below the minimum level established by Basin Standards (5 mg/L) during approximately 6 percent of the sampling periods, but never fell below 2 mg/L, the threshold for hypoxia, or 0.5 mg/L, the threshold for anoxia (Table 7). In terms of percent saturation, oxygen content averaged 110.9 ± 55.5 (SD) %, with the 5th and 95th percentiles estimated as 58.2 and 212.4%.

Oxygen levels dropped occasionally to anoxic levels during summer months, particularly in the smaller tidal channels. In general, surface and bottom oxygen concentrations were similar, suggesting that the shallow water in most of these sampling locations is pretty well-mixed. As noted in a few of the other sampling sites, bottom oxygen levels occasionally exceeded those of surface waters, but the degree of difference was not quite as marked (0.32 – 0.81 mg/L) as some of the other sites, where bottom levels often exceeded surface concentrations by as much as 1 – 5 mg/L. Again, as noted earlier, there are several possible explanations for this phenomenon, including temperature stratification of waters with denser, cold freshwater along the bottom carrying more oxygen than warm freshwater or salinity stratification with denser tidal waters subsidizing oxygen supplies on creek bottoms.

PH: The geometric mean of pH for surface waters in Walker Creek Marsh averaged approximately 7.63 ± 0.40 (SD; Figure 15, Table 7). The pH only once exceeded the upper limit of 8.5 established by the Basin Plan standards and never fell below the lower limit of 6.5 (Table 7). The 5th and 95th percentile estimates for pH ranged from 6.9 to 8.3 (Table 7). As with the Undiked Marsh and other sites, higher pH values (≥ 8) probably reflect peaks in primary productivity during the day by phytoplankton in creek waters, with corresponding increases in pH.

In comparison, during the LMER/BRIE study, pH was monitored in the mainstem of Walker Creek itself between 1987 and 1995. During this period, pH of creek waters averaged 7.73 ± 0.38 (SD), with the median being only slightly lower (7.64; LMER/BRIE data). The 5th and 95th percentile estimates for pH ranged from 7.3 to 8.3 (LMER/BRIE data). The pH exceeded the upper limit of 8.5 established by the Basin Plan standards during approximately 9 percent of the sampling events, but never fell below the lower limit of 6.5 (LMER/BRIE data).

Temperature: As with the Undiked Marsh, Walker Creek Marsh and other reference marshes probably represent transitional habitat for salmonids such as steelhead and coho for adults moving upstream in the watershed to spawn and for outmigrating smolts.

Reflective of its downstream position in the watershed, temperatures in Walker Creek Marsh averaged 16.92 ± 5.26 (SD) degrees Centigrade, although occasional spikes in temperature appear to have influenced the mean slightly, as is evident from the lower median value of 15.65 degrees Centigrade (Figure 16, Table 7). The 5th and 95th percentiles were estimated at 9.93 and 25.25 degrees Centigrade (Table 7). Temperatures exceeded the lethal limit for salmonids, 25 degrees Centigrade, during 6 percent of the sampling periods, and temperatures reached 22 degrees Centigrade, the suboptimal limit, during approximately 15 percent of the sampling periods (Table 7). While waters in this marsh and the Undiked Marsh frequently reached temperatures considered supoptimal for salmonids, it is likely that most of the salmon were -- and are -- not present during these periods, because most of the higher temperatures occur in mid-summer, and outmigration typically tapers off by June or early July.

During the LMER/BRIE study, temperatures in sections of Walker Creek directly upstream of the marsh averaged 15.38 ± 4.43 (SD) degrees Centigrade between 1987 and 1995, with the median being only slightly higher (15.5 degrees Centigrade) suggesting that a few very low temperatures skewed the mean somewhat (LMER/BRIE data). The 5th and 95th percentiles were slightly lower than those recorded for the marsh during our study – 8.17 and 22.8 degrees Centigrade, respectively (LMER/BRIE data). During this 8-year monitoring period, temperatures never exceeded suboptimal or lethal limits for salmonids (LMER/BRIE data).

Limantour Marsh

Dissolved Oxygen: Oxygen levels in Limantour Marsh averaged 8.47 ± 3.06 (SD) mg/L (Figure 14, Table 7). As with the Undiked Marsh and several other areas, the median concentration (8.17 mg/L) was slightly lower than the mean, which suggests that there only a very few supersaturated or peak values recorded at this sampling site (Figure 14, Table 7). The 5th and 95th percentile values were estimated at 4.33 and 13.33 mg/L (Table 7). Oxygen concentrations fell below the minimum level established by Basin Standards (5 mg/L) during approximately 8 percent of the sampling periods and below 2 mg/L, the threshold for hypoxia, during approximately 2 percent of the sampling period (Table 7). Levels never fell below 0.5 mg/L, the threshold for anoxia. In terms of percent saturation, oxygen content averaged 97.1 ± 30.5 (SD) %, with the 5th and 95th percentiles estimated as 55.7 and 154.2%.

Oxygen levels dropped frequently to anoxic and sometimes even hypoxic levels during summer months in both the larger main channels (Limantour Slough) and smaller tidal channels. As with the other tidal marshes, surface and bottom oxygen concentrations were similar, suggesting that the shallow water in most of these sampling locations is pretty well-mixed. In addition, bottom oxygen levels occasionally exceeded those of surface waters just as was discussed above for Walker Creek Marsh, but the degree of difference was not quite as marked (0.25 – 1.57 mg/L) as some of the other sites, where bottom levels often exceeded surface concentrations by as much as 1 – 5 mg/L.

PH: The geometric mean of pH for surface waters in Limantour Marsh averaged approximately 7.87 ± 0.52 (SD; Figure 15, Table 7). The pH only twice exceeded the upper limit of 8.5 established by the Basin Plan standards and never fell below the lower limit of 6.5 (Table 7). The 5th and 95th percentile estimates for pH ranged from 6.9 to 8.3 (Table 7). As with the Undiked Marsh and other sites, higher pH values (≥ 8) probably reflect peaks in primary productivity during the day by phytoplankton in creek waters, with corresponding increases in pH.

Temperature: As with other reference marshes, Limantour Marsh represents potential transitional habitat for salmonids such as steelhead for adults moving upstream in the watershed to spawn and outmigrating smolts.

Reflective of its downstream position in the watershed, temperatures in the Undiked Marsh averaged 17.46 ± 5.13 (SD) degrees Centigrade, although occasional spikes in temperature appear to have influenced the mean slightly, as is evident from the lower median value of 16.4 degrees Centigrade (Figure 16, Table 7). The 5th and 95th percentiles were estimated at 10.57 and 25.57 degrees Centigrade (Table 7) Temperatures exceeded the lethal limit for salmonids, 25 degrees Centigrade, during 7 percent of the sampling periods, and temperatures reached 22 degrees Centigrade, the suboptimal limit, during approximately 14 percent of the sampling periods (Table 7). While waters in the reference tidal marshes frequently reached temperatures considered supoptimal for salmonids, it is likely that most salmon were -- and are -- not present during these periods, because most of the higher temperatures occur in mid-summer, and outmigration tapers off in early summer. Also, the number of salmon present in this system during this period was constrained by the presence of a dam, which was removed in 2008.

Comparison Between Project Area and Reference Area

Dissolved Oxygen

Within the Project Area, most of the extremely low oxygen concentrations occurred in the East Pasture drainage ditches, where frequent ditching increased oxygen demand by filling ditch waters with vegetation material that was consumed by oxygen-dependent bacteria. This management practice, coupled with the relatively infrequent exchange or subsidy of ditch waters except during the winter or when irrigation was performed, typically kept oxygen levels below 5 mg/L and often below 2 mg/L. These same factors – copious amount of organic matter and infrequent exchange between the impounded marsh and Lagunitas Creek -- also contributed to consistently low levels of oxygen in Olema Marsh, although levels were not as low as the East Pasture. They also led median oxygen concentrations between subsampling areas within the Project Area to be significantly different despite proximity and general similarities in land management or (Kruskal-Wallis, n=796, df=4, H=177.12, p<0.001), with medians ranging from 4.55 mg/L in the East Pasture to 8.64 mg/L in Lagunitas Creek. Median oxygen levels for the other subsampling areas – excluding upstream sampling sites – were 8.5 mg/L for the West Pasture, 7.91 mg/L for Tomasini Creek, and 5.63 mg/L for Olema Marsh. These numbers are not necessarily similar to earlier numbers, because they do not include upstream sampling sites.

The effect of these low oxygen levels in the East Pasture and Olema Marsh were evident in the significant differences in median oxygen concentrations between the Project Area (7.58 mg/L) and those of the Reference Areas (8.32 mg/L) and Upstream Areas (9.51 mg/L; Kruskal-Wallis, n=1256, df=2, H=38.61, p<0.001; Figure 14, Table 7). Means ranged from 7.30 ± 3.83 (SD) mg/L in the Project Area to 8.56 ± 3.13 (SD) mg/L in Reference Areas (Figure 14, Table 7).

In general, Reference Areas had very similar average oxygen concentrations (ANOVA, n=310, df=2, F=1.94, p=0.15), with medians ranging from 7.89 mg/L in the Undiked Marsh to 8.59 mg/L at Walker Creek Marsh (Figure 14, Table 7). Means were not that dissimilar, ranging from 8.39 ± 0.33 (SE) mg/L in the Undiked Marsh to 9.21 ± 0.35 (SE) mg/L at Walker Creek Marsh (Table 7). Within reference marshes, oxygen concentrations were somewhat variable – coefficient of variation was 0.37 – although not nearly as variable as Study Areas within the Project Area. (CVs below 0.2 are considered to have low variability).

The 5th and 95th percentile for reference marshes were estimated at 4.15 and 15.20 mg/L, respectively (Table 7). Approximately 23 percent of oxygen values in the Project Area actually either fell below or exceeded these percentiles, so 77 percent of the concentrations in the Project Area, then, actually fell within the range of natural variability for this parameter. Of these exceedances, approximately 21 percent of the 23 percent that exceeded the natural variability range were comprised of levels that fell below the 5th percentile of concentrations recorded in references marshes. The East Pasture drainage ditches accounted for a majority of these lower oxygen values --- approximately 16 percent of the 23 percent. The effect of the East Pasture is evident in the 5th and 95th percentiles for the Project Area, which were estimated at 0.44 and 13.20 mg/L, respectively (Table 7). In fact, approximately 54 percent of the values from the East Pasture fell outside the natural range of variability.

Approximately 8 percent of the oxygen concentrations recorded in reference marshes fell below 5 mg/L, the Basin Plan standard, and another 1.2 percent fell below 2 mg/L, the threshold for hypoxia (Table 7). There were no instances in which oxygen levels fell below 0.5 mg/L. In contrast, in the Project Area, oxygen concentrations fell below the Basin Plan standard during 25 percent of the sampling periods and the hypoxic threshold during approximately 12.2 percent of the sampling periods, with 5.4 percent of the values plummeting to below 0.5 mg/L, the threshold for anoxia (Table 7). More than 66 percent of the levels measured in the Project Area even prior to restoration exceeded the lowest 16.7 percent of values recorded in the reference wetlands (>5.9 mg/L), which means that, in general, the Project Area met the 50 percent requirement set as part of progress criteria (Table 7). However, only 32 percent of the levels measured in the East Pasture exceeded the lowest 16.7 percent of values, so the East Pasture would not have met progress criteria.

Oxygen concentrations in Upstream Areas fell between those of the Project Area and Reference Marshes, with 14 percent of the values recorded falling below 5 mg/L and 4 percent falling below 2 mg/L (Table 7). Only two values fell below 0.5 mg/L. The 5^{th} and 95^{th} percentiles for Upstream Areas were estimated as 2.36 and 12.42 mg/L, respectively, which, again, falls in between those estimated for the Reference Area and Project Area (Table 7).

pH

The pH conditions did not appear to differ significantly between Study Areas (Kruskal-Wallis, n= 1218, df=2, H=5.09, P=0.08). The geometric means for pH were estimated as 7.60 in the Project Area, 7.62 in the Reference Area, and 7.63 in Upstream Areas (Figure 15, Table 7). Within the Project Area, however, median pH did appear to differ significantly between subsampling areas that excluded upstream sampling sites (Kruskal-Wallis, n=769, df=4, H=46.85, p<0.001). Low within-site variance leading to significant differences between seemingly similar median pH values (range=7.5 in East Pasture to 7.79 in Project Area portion of Lagunitas Creek), although the median Olema Marsh pH fell considerably below this range (6.9). Mean pH also differed seemingly between reference marshes (ANOVA, n=204, df=2, F=21.21, p<0.001), although the range of means was relatively tight from the standpoint of most biological organisms (7.47 in the Undiked Marsh to 7.88 at Limantour Marsh), which suggests that low within-site variance enabled detection of relatively small differences in means (Table 7).

This low variance is reflected in the small coefficient of variation (0.06), where CVs below 0.2 are considered to have low variability. The 5th and 95th percentile for reference marshes were estimated at 7 and 8.4, respectively (Table 7). Only 17 percent of pH values in the Project Area actually either fell below or exceeded these percentiles, so 83 percent of the values recorded in the Project Area, then, actually fell within the range of natural variability for this parameter (Table 7). Of these exceedances, 13 percent came from pHs that were lower than 7.0. The 5th and 95th percentiles for the Project Area were 6.60 and 8.40. Some of the factors contributing to the higher percentage of low pHs could be the fact that many of the groundwater-fed drainages in the West Pasture consistently had lower pH (~5.9 – 6.6) in contrast to those fed primarily by surface flows such as Fish Hatchery or Tomasini Creek, which had slightly elevated pHs (~7.8 to 8.1). Also, water pHs with more acidic values (~5.9 - 6.4) were typically found in drainage ditches and shallow seasonally flooded areas due probably to breakdown of organic matter after ditching or seasonal vegetation die-off and subsequent production of humic acids or other acids related to biogeochemical processes.

Approximately 11 percent of the pHs recorded in reference marshes exceeded 8.5, the upper Basin Plan limit, while pH never fell below 6.5 (Table 7). In comparison, in the Project Area, pH fell below 6.5 during approximately 2 percent of the sampling periods and exceeded 8.5 approximately 3 percent of the time (Table 7). More than 83 percent of the values measured in the Project Area even prior to restoration fell below the highest 16.7 percent of values recorded in the reference wetlands (<8), which exceeds the 50 percent requirement established as part of progress criteria (Table 7). While low pH can negatively affect aquatic organisms and has implications for nutrient cycling, high pHs can possibly increase the potential for the production of toxic unionized ammonia when temperatures are high and ammonia is present in sufficient quantities.

In Upstream Areas, approximately 1 percent of the values recorded fell below 6.5, and approximately 2.6 percent exceeded 8.5 (Table 7). The 5th and 95th percentiles for Upstream Areas were 6.90 and 8.44, respectively, which, again, falls very close to those estimated for the Reference Marshes and Project Area (Table 7).

Temperature

Significant differences occurred between median temperatures of the different Study Areas (Kruskal-Wallis, n=1234, df=2, H=50.04, p<0.001), with Upstream Areas having, not surprisingly, the lowest median (12.65 degrees Centigrade) and Reference Areas, the highest (17.30 degrees Centigrade; Figure 16, Table 7). This same pattern was replicated with average temperatures, which were estimated at 15.9 degrees Centigrade for the Project Area, 17.2 degrees Centigrade for Reference Areas, and 13.5 degrees Centigrade for Upstream Areas (Table 7). Slightly lower median and mean temperatures in the Project Area (median=15.1 degrees Centigrade) probably resulted from higher inflows of freshwater from adjacent creeks, small drainages, and groundwater, which tends to be cooler than tidal waters.

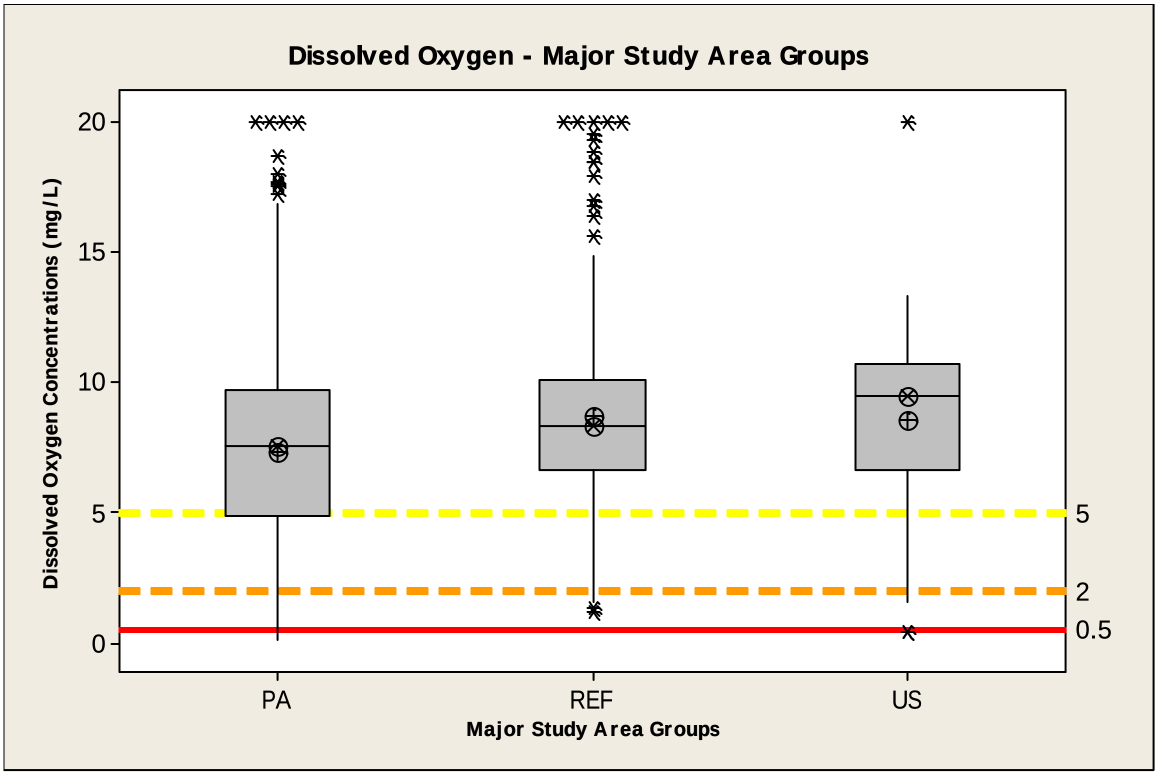
Temperature differences within the Project Area excluding upstream sites were not considered statistically different (Kruskal-Wallis, n=778, df=4, H=8.39, p=0.08), with medians ranging from 13.3 to 13.8 degrees Centigrade for Tomasini Creek and Olema Marsh, respectively; 14.4 degrees Centigrade for the Project Area portion of Lagunitas Creek, and 15.3 to 15.4 degrees Centigrade for the East and West Pastures, respectively.

Within reference marshes, temperatures did not differ significantly (ANOVA, n=309, df=2, F=0.29, p=0.751), although they remained somewhat variable, as evidenced by the coefficient of variation, which was 0.31 (Table 7). (CVs below 0.2 are considered to have low variability). Median temperatures were remarkably similar, ranging tightly between 17.3 degree Centigrade for the Undiked Marsh and Walker Creek Marsh and 17.4 degree Centigrade for Limantour Marsh (Figure 16, Table 7). There was slightly more disparity between means, but even these did not vary greatly, ranging from 16.9 ± 0.5 (SE) degrees Centigrade for Walker Creek Marsh and 17.5 ± 0.5 (SE) degrees Centigrade for Limantour Marsh (Figure 16, Table 7).

The 5th and 95th percentile for reference marshes were estimated at 9.75 and 27 degrees Centigrade, respectively (Table 7). Interestingly, only 11 percent of the temperatures in the Project Area actually either fell below or exceeded these percentiles, so 89 percent of the temperatures in the Project Area, then, fell within the range of natural variability for this parameter, even prior to restoration (Table 7). Of these exceedances, approximately 9 percent of the 11 percent were comprised of temperatures that fell below the 5th percentile of temperatures recorded in references marshes, which would not be considered problematic from an ecological standpoint. In fact, the 5th and 95th percentiles for the Project Area were 8.7 and 24.9 degrees Centigrade, so the range remained actually comparable to that found in reference marshes or was even slightly lower than those wetlands even prior to restoration (Table 7).

Approximately 6.7 percent of the temperatures recorded in reference marshes exceeded the lethal limit of 25 degrees Centigrade, and another 17.8 percent exceeded 22 degrees Centigrade, the suboptimal limit (Table 7). Comparatively, in the Project Area, temperatures exceeded the lethal limit during 5 percent of the sampling periods and exceeded the suboptimal limit during approximately 15 percent of the sampling periods (Table 7). The fact that there were fewer exceedances of temperature thresholds in the Project Area than in reference marshes despite diking and low to non-existent exchange with outside water bodies probably results from the fact that the Giacomini Ranch has a higher number of small drainages and groundwater inflow areas that provide cool freshwater to lower ambient temperatures in creeks, ditched sloughs, drainage ditches, and other exposed water features. Approximately 88 percent of the temperatures measured in the Project Area prior to restoration fell below the highest 16.7 percent of values recorded in the reference wetlands (23.1 degrees Centigrade) even prior to restoration, which exceeds the 50 percent requirement established as part of progress criteria (Table 7).

Moving upstream, temperatures, not surprisingly, cool even further. Only 3 percent of temperatures recorded in Upstream Areas exceeded 22 degrees Centigrade, with less than 1 percent exceeding the lethal limit of 25 degrees Centigrade (Table 7). The 5th and 95th percentiles for Upstream Areas were estimated at 8.8 and 20.8 degrees Centigrade, respectively (Table 7). Certainly, prior to restoration, these Upstream Areas are the ones that have held the most value historically for salmonids, so temperatures in these areas are particularly critical.



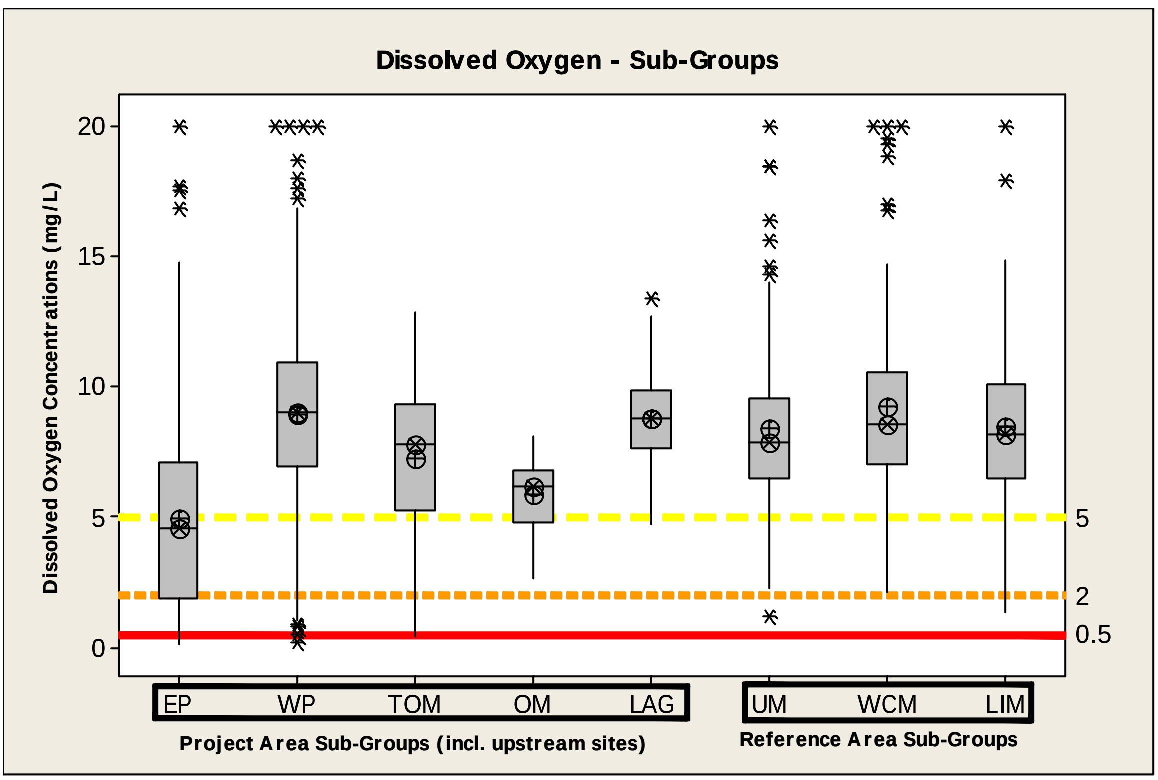
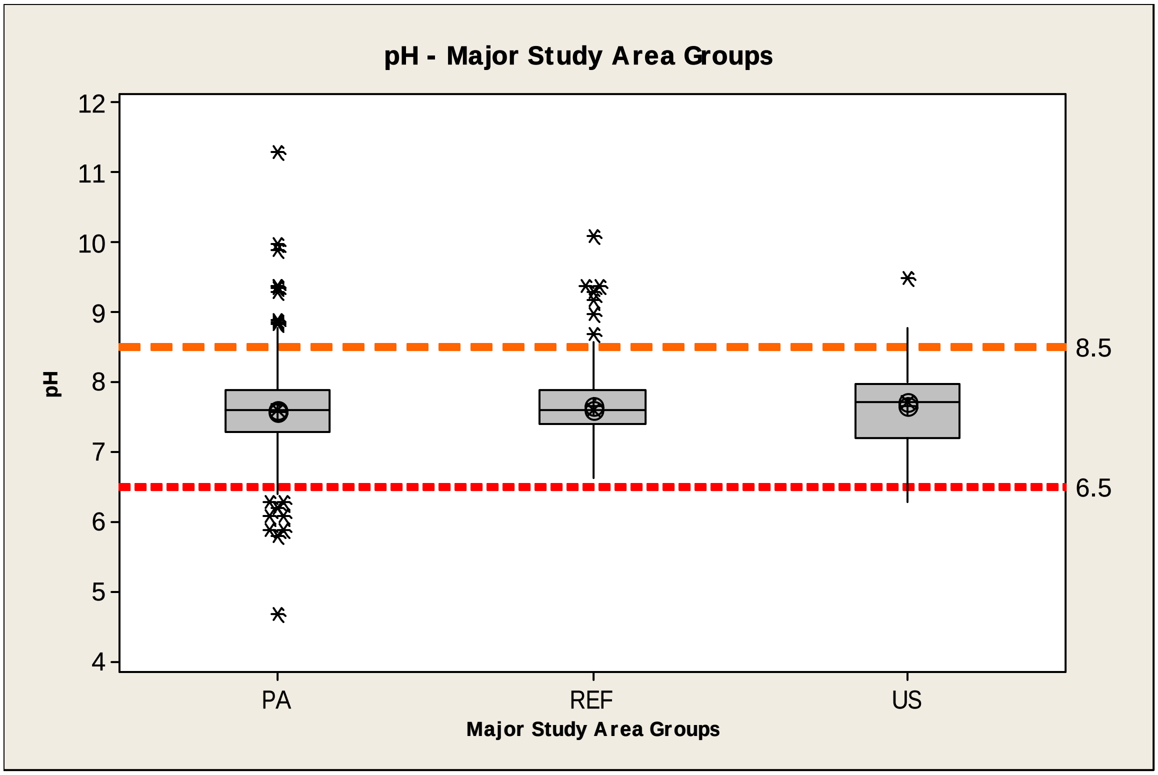


FIGURE 14. Dissolved oxygen in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



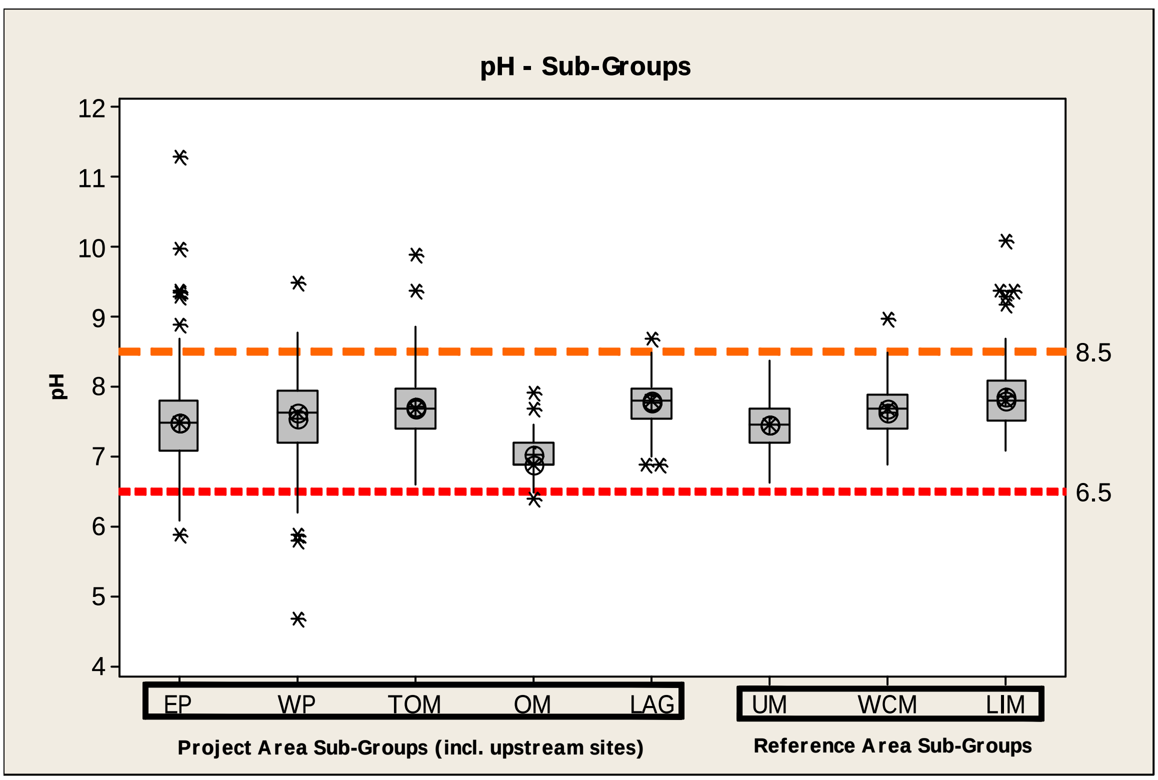
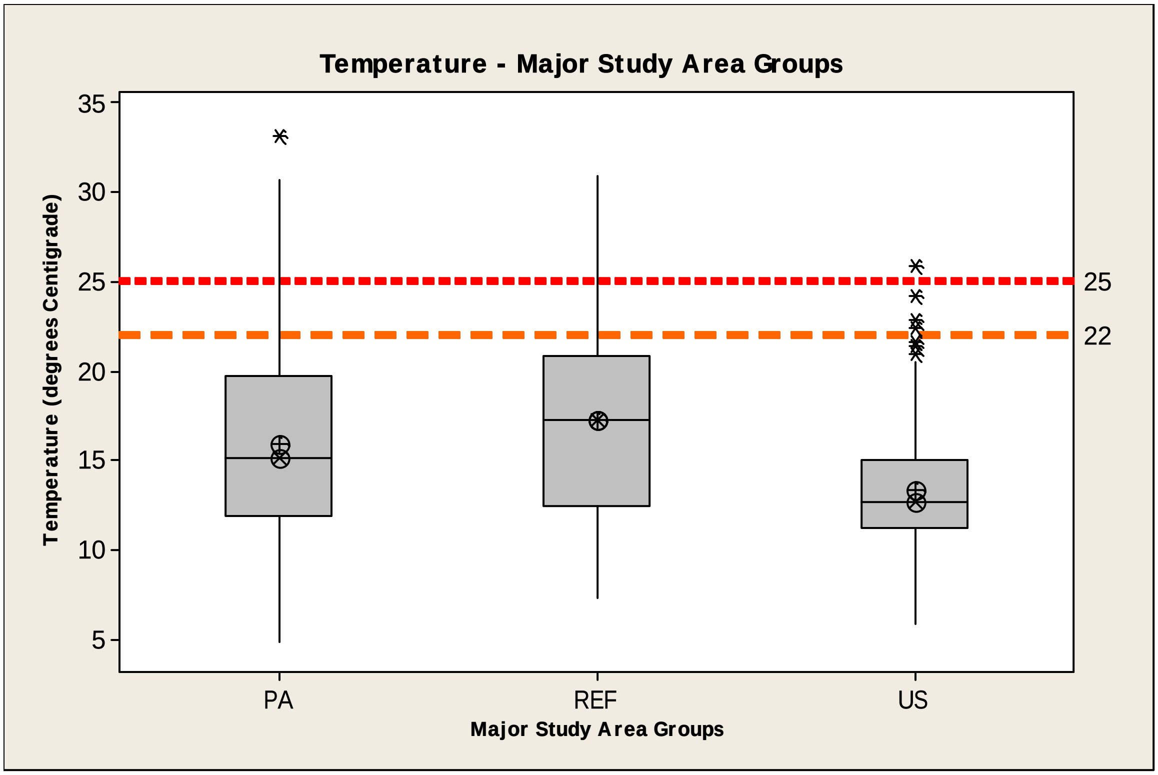


FIGURE 15. pH in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



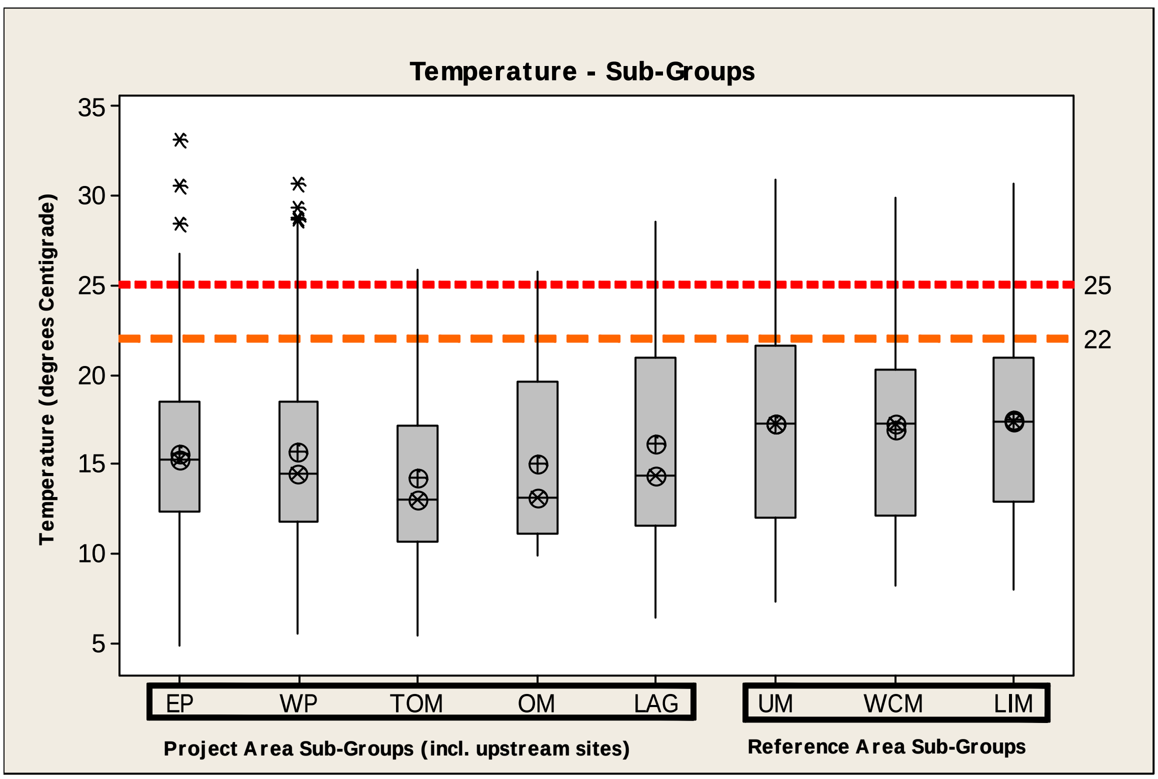


FIGURE 16. Temperature in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.

TABLE 7. Summary data for water quality field parameters – Giacomini Wetland Restoration Project pre-restoration water quality monitoring. Major Study Area Groups include Project Area (PA), Reference Areas (REF), and Upstream Areas (US). Project Area sub-groups in this chart include upstream sampling sites that are broken out as US in other analyses.

	Major Study Area Groups					Project Area Sub-Groups (including upstream sites)						Reference Area Sub-Groups		
	PA	*Range*	REF	US		EP	WP	TOM	LAG	OM		UM	WCM	LIM
Dissolved Oxygen (mg/L)														
Mean 7.	30		8.56	8.3		4.9	8.9	7.28	8.7	5.83		8	9.21.	47
SD 3.83			3.13	3.15		3.86	3.60	2.90	1.71	1.43		3.30	3.67	3.06
Median 7.58			8.32	9.51		4.56	9.00	7.78	8.77	6.15		7.75	8.56	8.17
<5 mg/L (%)	25		8	14		56	14	22	<1	29		10	6	8
<2 mg/L (%)	12.2		1.2	4		31	6	4	<1	0		2	0	2
<0.5 mg/L (%)	5.4		0	2		14	2	2	<1<	0		0	0	0
5th 0.44		77%	4.15	2.36		0.17	1.55	2.4	5.9	2.95		4.28	4.64	4.33
95th 13.20			15.20	12.42		11.1	15.05	11.9	11.8	7.70		14.63	14.66	13.33
16.7th		66%	5.9											
83.3rd														
CV 0.37														
pH														
Geometric Mean	7.60		7.66	7.63		7.48	7.57	7.70	7.80	7.02		7.47	7.63	7.87
SD 0.56			0.46	0.53		0.62	0.56	0.52	0.30	0.36		0.36	0.40	0.52
< 6.5 (%)	2		0	1		3	3	0	0	<5		0	0	0
> 8.5 (%)	3		11	3		7	2	3	<1<	0		0	3	6
5th 6.6		83%	7	6.9		6.6	6.6	6.9	7.3	6.5		6.9	6.9	6.9
95th 8.4			8.4	8.4		8.4	8.3	8.5	8.3	7.7		8.2	8.3	8.3
16.7th		83%												
83.3rd			8											
CV			0.06											
Temperature (°C)														
Mean 15.7			16.8	13.5		15.4	15.5	14.2	16.2	14.5		17.3	16.9	17.5
SD 5.2			5.3	3.7		4.7	5.2	4.9	5.5	4.7		5.8	5.3	5.1
Median 15.1			17.3	12.7		15.2	14.4	13.1	14.3	12.9		16.5	15.7	16.4
>25 °C (%)	5		7	1		3	6	3	6	6		7	6	7
>22 °C (%)	15		18	3		7	15	11	20	12		23	15	14
5th 8.7		89%	9.8	8.8		8.2	8.6	8.7	9.2	10.0		9.5	9.9	10.6
95th 24.9			27.0	20.8		23.8	25.7	23.0	25.4	24.0		26.9	25.3	25.6
16.7th		88%												
83.3rd			23.1											
CV			0.31											

Nutrients In the Watershed and Project Area

Nutrients are vital to most life, both plant and animal. They make plants and algae grow and, in the form of food, sustain animal life. However, in excessive amounts, nutrients can prove problematic to estuarine health. They can encourage over-proliferation of algae that result in wide swings in oxygen levels of waters during the day, often with dire consequences to aquatic life. Surges in primary productivity during the day can inadvertently increase concentrations of nutrients that are actually toxic to fish and other animals. By boosting pH, over-production of oxygen in eutrophic waters by algae, plankton, and plants increases the relative proportion of the toxic form of ammonia (unionized ammonia) present in waters with moderate to high levels of ionized ammonia. Conversely, when oxygen in waters is low, an intermediary form of nitrogen, nitrites, can occur that can cause asphyxia in humans and wildlife by binding to hemoglobin and reducing oxygen transport. The oxidized form, nitrates, can also impact human health when present in drinking water in excessive amounts by causing "blue baby" syndrome, where the bloodstream of infants is literally stripped of oxygen-carrying potential, thereby inducing asphyxiation of tissues.

Because of these impacts, the USEPA, RWQCB, and other agencies have established some standards or guidelines to address excessive nutrient concentrations or eutrophication in drinking, point source discharge, or receiving waters. The RWQCB originally intended to prepare TMDLs for nutrients, but this set of TMDLs is not scheduled for preparation during the near future (RWQCB 2007).

For nitrates, the USEPA has established 10 mg/L as nitrate-N (or 44 mg/L as NO3-) as the human consumption limit for drinking water supplies, but, for receiving waters, a much lower threshold -- 1 mg/L – has been advocated as the level above which nitrates are likely to exacerbate eutrophication and not maintain at least moderate aquatic diversity in estuaries (NOAA/USEPA 1988, Table 1). Even lower levels – 0.1 mg/L – are needed to promote maximum aquatic diversity in estuaries (NOAA/USEPA 1988, Table 1). In addition to nitrate standards, the USEPA has also established a threshold of 1 mg/L for nitrites as N (or 3.3 mg/L of nitrites as NO2-) for drinking water (Table 1). The RWQCB typically encourages levels of 0.5 mg/L for nitrates in receiving waters (Table 1).

There are no individual Basin Plan standards for nitrates, nitrites, phosphates, or ammonia (RWQCB 1995), but the RWQCB has established objectives for unionized ammonia (Table 1). In waters with elevated pH, temperature, and/or salinity, ionized ammonia converts to unionized ammonia, which the RWQCB considers toxic to aquatic organisms in levels exceeding 0.16 mg/L or when the annual median exceeds 0.025 (RWQCB 1995, Table 1). The EPA has also established specific saltwater standards of 0.233 mg/L for acute one-hour exposure and 0.035 mg/L for chronic exposure (four-day average; USEPA 1989)

For phosphates, the Basin Plan objectives focus on the linkage between high concentrations of phosphates and growth -- and sometimes overgrowth -- of algae. No specific concentration-based objectives are presented in the Basin Plan (1995), however, the recommended concentration of phosphorous to prevent algal blooms within estuaries is 0.01 to 0.1 mg/L, with lower levels promoting "maximum aquatic diversity" (NOAA/EPA 1988, Table 1). In freshwater systems, the USEPA stipulates that streams and rivers flowing into lakes should not have phosphates that exceed 0.05 mg/L to minimize algal growth, while those not flowing into lakes or reservoirs should not have levels that exceed 0.1 mg/L (USEPA 1986).

Tomales Bay

As discussed earlier, Tomales Bay has been subjected to intensive study on water quality, bay water mixing, and nutrient dynamics through the National Science Foundation and LMER/BRIE programs (Kimmerer et al. 1993; Chambers et al. 1994a; Joye and Hollibaugh 1995; Smith et al. 1996; Smith and Hollibaugh 1997a; Largier et al. 1997; Freifelder et al. 1998 and others). This large data set provides an excellent understanding into the complex nutrient cycling found in shallow, Mediterranean-climate estuaries such as Tomales Bay, particularly during summer months (TBWC 2003).

Nutrient dynamics within Tomales Bay are driven by both oceanic and terrestrial forces. Tomales Bay has been characterized by LMER researchers as a net heterotrophic estuary in that the rates of organic carbon loading from external sources (and subsequent conversion to inorganic nutrients) strongly exceeds those of inorganic nitrogen loading from external sources. Ecosystem respiration or conversion of organic matter generated by non-estuarine sources to inorganic nutrients exceeds external supply of inorganic nutrients or internal production of inorganic nutrients by about 10 percent (Smith and Hollibaugh 1993, 1997a, 1998; Smith et al. 1991). While most of the inorganic nutrients produced from organic matter exported into the estuary is eventually either lost to the atmosphere or recycled internally, dissolved inorganic phosphorous is exported to the ocean and constitutes the primary "product" produced by the Bay that is directly available to external ecosystems (Smith and Hollibaugh 1997b). Organic matter inputs into Tomales Bay come from terrestrial sources (50 percent) and the ocean (50 percent; Smith and Hollibaugh 1997b).

As might be expected, research has shown that the external supply of organic carbon -- and subsequently inorganic nutrients -- to Tomales Bay varies over seasonal and inter-annual time scales (Chambers 2000, Lewis et al. 2001). Terrestrial sources consist of organic matter, as well as sediment-bound and suspended forms of inorganic nutrients, from the surrounding watershed that flow into the Bay, typically during high rainfall periods. Most of this organic matter and inorganic nutrients enter the Bay through surface flows of its largest tributaries: as described earlier, Lagunitas Creek and its tributaries account for approximately two-thirds of the surface water freshwater inflow to the Bay, while Walker Creek and other small drainages account for the remaining one-third (Fischer et al. 1996). During the winter, groundwater also contributes to nutrient loading, although it represents only 20 percent of the load generated by streamflow (Oberdorfer et al. 1990). During the summer, however, groundwater discharge into the Bay may contribute about as much nutrient loading as does streamflow (Oberdorfer et al. 1990).

As with pathogens, the primary source or sources of inorganic nutrients delivered in terrestrial inputs to the Bay currently remains a controversial subject. The most probable sources remain dairies and beef cattle operations, leaking or poorly constructed septic systems, domesticated animals such as horses, boat bilge systems, and non-point source run-off from communities. Because of their prominent status within this largely rural watershed and concentrated number of cattle, dairies and ranches have received the most scrutiny. The Chambers at al. (1994) paper correlated "dairy runoff from pasture lands" in the watershed of one of the two study marshes with consistently high dissolved ammonium and phosphate in downstream marsh waters.

However, three recent studies suggest that nutrient loading from animal agriculture may not be as high as previously indicated, particularly loading from pastures (RWQCB 1995; Lewis et al. 2001 *in* TBWC 2002, Smith et al. 1996). Studies conducted in the upstream portions of the Lagunitas Creek by the Park Service found that nutrients, nitrites, and unionized ammonia did not appear to be problematic, at least in the upper portions of the watershed (Ketcham 2001). Nearly all of the samples collected from the larger stream systems and most of the tributary samples were below commercial laboratory method detection limits (Ketcham 2001). An overall decrease in agricultural activities within the Tomales Bay watershed may be the reason that export of at least particulate forms of nitrogen and phosphorous to the Bay has declined and reached steady-state conditions (Smith et al. 1996).

Oceanic sources of organic matter and inorganic nutrients come from upwelling or funneling of ocean-derived organic matter in offshore currents. The most intensive upwelling occurs during the summer, in response to strong, often persistent northwesterly winds (Smith and Hollibaugh

1997b). Upwelling elevates the concentration of particulate organic matter in the coastal waters, which is then delivered to the bay by tides and particle settling (Smith and Hollibaugh 1997b). Direct inorganic nutrient delivery from coastal upwelling in the Pacific Ocean is not of major importance to Tomales Bay, but may be important indirectly by affecting nutrient dynamics or cycling within the bay (Smith and Hollibaugh 1997b).

The importance of inorganic nutrient delivery from watershed sources is also reduced during the summer, but still remains a factor due to the high number of perennial drainages in this system. Some of the inorganic nutrients delivered to the Bay may originate from fringing and deltaic marshes on the perimeter of Tomales Bay. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that these systems act as sources of inorganic nitrogen and phosphorous to the Bay during the summer, probably due to internal metabolism/breakdown of organic matter (Chambers et al. 1994b). However, the relatively small acreage of intertidal wetlands in Tomales Bay probably reduces the importance of these marshes as sources of inorganic nutrients during the summer, thereby maintaining the estuary's heterotrophic status during low-rainfall periods.

Internal sources of organic matter or inorganic nutrients to Tomales Bay are primarily represented by phytoplankton, macroalgae, and aquatic organisms through excretion and decay. Algae represent important components of the estuarine food web, as well as sensitive indicators of ecosystem health. Dramatic increases in dissolved or particulate nutrients, combined with warm temperatures and stagnant water conditions, stimulate algal growth, resulting sometimes in excessive abundance of algae that are called algal blooms. Besides being sometimes unsightly, algal blooms play havoc with ecosystems by causing massive swings in dissolved oxygen content of waters through over-production of oxygen during the day and depletion at night through uptake or even algal die-off. Die-offs of algae can also boost nutrient concentrations through recycling or breakdown of organic matter into inorganic nutrients by bacteria. In addition, excreted material from large concentrations of consumers such as bivalves, waterfowl, shorebirds, and even mammals such as seals can noticeably affect localized nutrient concentrations, primarily through increases in ammonia (Judah 2000).

Despite its water quality problems, Tomales Bay has not been characterized as an eutrophic estuary (Cole 1989; Chambers 2000; Lewis et al. 2001), although it was listed as such in a recent evaluation of the nation's estuaries as highly "susceptible" due to nitrogen loading or other factors (Bricker et al. 2007). In fact, information from past sampling efforts in the Bay suggests that nutrients may be relatively low in Tomales Bay, at least relative to other agricultural and urbanized estuaries. To date, most of the 12 water quality studies conducted in the watershed and Bay have emphasized total and fecal coliform measurements and not nutrient levels (TBWC 2002). There are a few long-term or more intensive synoptic programs that have evaluated nutrient status. The LMER/BRIE program conducted sampling every two to three months in the Bay from its mouth to just north of the Giacomini Ranch between 1985 and 1996 with sampling usually in January, March, May, July, September, and November (LMER/BRIE data). It also conducted some sampling in the upper portions of the Lagunitas and Walker Creek watersheds (LMER/BRIE data). CDFG conducted a 10-year sampling program of 20 stations along the southern and eastern margins of Tomales Bay between 1991-2001(Rugg 2000, Rugg 2002).

During the LMER/BRIE monitoring period, dissolved nitrate(NO3-) concentrations in the Bay averaged 0.28 ± 0.37 (SD) mg/L, with mean total dissolved phosphates (PO4-), ammonium (NH4+), and total ammonia (NH3) concentrations estimated at 0.20 ± 0.09 (SD) mg/L, 0.02 ± 0.02 (SD) mg/L, and 0.04 ± 0.01 (SD) mg/L respectively (LMER/BRIE data). Particulate nitrogen during this period averaged 0.11 ± 0.08 (SD) mg/L, while particulate phosphorous averaged 0.02 ± 0.01 (SD) mg/L (LMER/BRIE data). These numbers fall well within nitrate standards established by the USEPA for promotion of at least moderate aquatic diversity and estuarine health (NOAA/USEPA 1988). Concentrations of total phosphorous –- all forms of phosphorous – were not available, but total dissolved phosphates also fell below the total phosphorous standards established by the USEPA for moderate, if not maximum, aquatic diversity (NOAA/USEPA 1988).

During the CDFG studies, total ammonia and unionized remained low at all stations, with only exceedance of unionized ammonia criteria (Rugg 2000, Rugg 2002).

In comparison, recent sampling in Suisun Bay, the estuarine transition zone for San Francisco Bay located east of Marin County, and the central portion of San Francisco Bay consistently shows much more elevated levels of dissolved nutrients. Nitrate concentrations (as NO3-) ranged from 3.41 ± 0.75 (SD) mg/L to 4.30 ± 0.44 (SD) mg/L for Suisun during spring and summer, respectively, while, in central San Francisco Bay, they are slightly lower, but still range from 1.77 ± 0.44 (SD) mg/L to 2.70 ± 0.53 (SD) mg/L (converted from original *u*mol units; Wilkerson et al. 2006). Dissolved phosphorous and ammonia concentrations in both portions of the Bay-Delta system were much lower, with the highest averages ranging from 0.08 ± 0.02 (SD) mg/L (phosphorous) to 0.23 ± 0.27 (SD) mg/L (ammonia as NH3) for the Central Bay and 0.1± 0.01 (SD) mg/L (phosphorous) to 0.39 ± 0.35 (SD) mg/L (ammonia as NH3) for Suisun (Wilkerson et al. 2006). These numbers do not necessarily violate Basin Plan or USEPA standards for discharge or receiving waters, but they do appear to exceed the thresholds established by the USEPA for healthy estuaries and maximum to even moderate aquatic diversity, which range from 0.01 mg/L (phosphorous) to 1 mg/L (nitrates).

While results from LMER/BRIE studies strongly suggest that nutrients are not an issue in this watershed, these studies had some limitations that may preclude drawing definitive conclusions. First, in general, most of the the studies – and corresponding data analysis – focused specifically on nutrient status (e.g., heterotrophic vs. autotrophic) of Tomales Bay and relationship of the estuary to nearshore waters through upwelling, biogeochemical reactions related to the products of primary production and respiration, and hydrodynamics of the estuary.

For this reason, much of the data analysis strictly assessed dissolved sources of carbon and nutrients or nutrients that are freely transported in solution, even though data on particulate nutrients was collected during sampling efforts. Many nutrients, contaminants, and pathogens, however, are principally transported in water as bound or sorbed to sediment particles, particularly where erosion rates and sediment yields are high (Walling et al. 1997). Estimates of sediment-bound nutrients vary widely, but, in general, phosphorous appears to be transported bound to sediment more than nitrogen (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). Most inorganic nitrogen is transported as soluble nitrate, however, ammonium ions and organic nitrogen are often carried on sediment or organic matter. Estimates of sediment-bound nitrogen transport range as high as 51-57 percent in some systems (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). A few studies conducted under the LMER program did assess particulate nutrient dynamics and even evaluated data from the wet season, including storm events (Chambers et al. 1995, Smith et al. 1996), but these studies represented the minority. Interestingly, Smith and colleagues noted in their study that, “suspended load transport represents the major net removal of C (carbon), N (nitrogen), and P (phosphorous) from the watershed” -- and, therefore, the largest source of nutrients delivered to the Bay (Smith et al. 1996).

In addition to focusing principally on dissolved nutrients, analyses also concentrated on summer and fall sampling events, even though sampling was conducted year-round. The dry-season data better fit the needs of the study in that, during the dry season, when water exchange is slow, nutrient dynamics reflect internal chemical reactions, with the Bay essentially acting as a closed "incubation chamber" in which the whole-system chemical reactions can be assessed (Smith and Hollibaugh 1997b).

Even when the entire dataset is summarized – as has been done above -- the results are also somewhat compromised by the fact that, during most of the study period (1985-1993), rainfall and run-off totaled approximately 25 percent and 55 percent, respectively, below the estimated mean values since 1880 (Fischer et al. 1996 *in* Smith et al. 1996). This corresponds exactly to the sampling period analyzed by Smith and colleagues in their study. Drought conditions did abate during the second half of the study in 1994-1995, with rainfall approximately 20 percent above average (MMWD, unpub. data *in* Smith and Hollibaugh 1997b), but these data were not analyzed as part of the study by Smith and colleagues (1996), which also looked at upstream nutrient concentrations and loading by Lagunitas and Walker Creek subwatersheds. In general, drought conditions would generate less loading of nutrients to downstream portions of the estuary by systems such as Lagunitas and Walker Creeks. They would particularly affect mobilization of particulate forms of phosphorous and nitrogen, which are usually almost exclusively exported during large storm and run-off events. This would suggest that results from the LMER/BRIE study may underestimate to some degree nutrient levels within Tomales Bay, particularly wet season levels and particulate nutrients. Smith and colleagues noted that particulate nutrients remained the major source of nutrients exported from the watershed even during dry years, despite the fact that concentrations of particulate nutrients were more strongly dependent on flow than dissolved nutrients (Smith et al. 1996).

In general, then, despite the extensive LMER/BRIE program, there are still large gaps potentially in our understanding of the long-term interannual and intraannual patterns of nutrients in the Bay and export from the upper watershed, particularly during wetter climatic cycles or during storm events. In addition, the fate of nutrients exported during the wet season once delivered to the Bay is not entirely understood, some of which is dependent on fluvial transport and estuarine circulation processes.

Tides, temperature, salinity, and freshwater inflow rates affect nutrient, as well as water, circulation patterns in Tomales Bay. During the winter, spring, and early summer, the substantial volume of freshwater inflows to the Bay results in a considerable exchange of organic matter and inorganic nutrients between the inner and middle portions of the Bay and the outer Bay and ocean. However, as freshwater flows decrease into the summer and fall, circulation mechanisms shift from salinity-driven to temperature-driven gradients, which results in weaker exchange of waters – and carbon and nutrients -- between at least the northernmost portions of the inner (or middle) Bay and the outer Bay-Pacific Ocean (Harcourt-Baldwin 2003). This shift in circulation pattern increases water residence time and potential persistence of nutrients within the central and inner portions of the Bay from several days during the winter to more than a month (Smith and Hollibaugh 1997b). As noted earlier, during the summer and periods of low run-off, water in the northern 3.73 miles of the bay exchanges with nearshore coastal water on each tidal cycle, while water in the southern 8.7 miles of the bay remains for approximately 120 days (Harcourt-Baldwin 2003).

In the “inner” inner or southernmost portions of the Bay, absence of a strong salinity or temperature gradient with the middle and outer portions during the summer can effectively eliminate exchange of waters between these regions (Hearn and Largier 1997, Largier et al. 1997). This phenomenon, which is accompanied by hypersaline conditions, apparently causes a buildup in dissolved inorganic phosphorous, as well as severe depletion of dissolved inorganic nitrogen (Largier et al. 1997). During this period, the Bay is effectively a closed "incubation chamber" (Smith and Hollibaugh 1997b). Dissolved phosphorus and carbon are released to the water by internal reactions: over time, some of the dissolved carbon released escapes to the atmosphere, but the dissolved phosphorus simply accumulates in the water column (Smith and Hollibaugh 1997b). Dissolved nitrogen is also released by decomposition reactions, but the nitrogen is subsequently stripped to the limits of analytical detection by the process of denitrification (Smith and Hollibaugh 1997b). Understandably, hypersaline systems “are very susceptible to pollution as even small loadings during the hypersaline phase may be recycled and accumulate, rather than being flushed from the system” (Largier et al. 1997).

Nutrient circulation patterns are not only tied to water circulation patterns, but sediment transport processes. With a large proportion of inorganic and organic nutrients transported to Tomales Bay during the winter potentially sorbed to sediment, sediment transport processes, primarily suspended sediment processes, largely govern circulation patterns of particulate nutrients and determine which downstream areas become “sinks.” Within fluvially dominated portions of the watershed, sediment transport and particulate nutrient dynamics are determined by stream energy and associated patterns within stream reaches of sediment deposition and transport. Once waters reach the estuary, estuarine-related processes become more important in influencing sediment and nutrient dynamics. These include factors that affect patterns of sediment deposition and/or resuspension such as bathymetry, tidal currents, and salinity-related estuarine circulation patterns that often lead to formation of areas known as Estuarine Turbidity Maximum (ETM), where sediment deposition is at a maximum. In addition to the effect that salinity has on circulation of estuarine waters and longitudinal gradients and currents, salinity can also play a direct role in determining patterns of sediment and sediment-bound nutrient deposition through flocculation or aggregation of river-borne sediments caused by the increased electrostatic charge present at the landward edge of the "salt wedge" (Arthur and Ball 1979). In addition, salinity can also drive conversion of particulate nutrients and pollutants to dissolved phases and vice versa by affecting the ionic environment and thereby inducing processes such as sorbtion, desorbtion, precipitation, and biological uptake (Sikes 2008).

Project Area

Lagunitas Creek

In general, the portion of Lagunitas Creek in the Project Area is separated from the Giacomini Ranch by levees, which minimize – if not eliminate -- interaction between the creek and dairy-influenced waters on the ranch. However, other ranches occur upstream of the Giacomini Ranch along Lagunitas Creek and along tributaries to Lagunitas, all of which could potentially increase nutrient loading in the creek. In addition, rural residential developments exist along some of the tributaries, as well, which could potentially affect creek waters through septic leaking, fertilization of gardens, and other land use practices. Nutrient dynamics are also complicated by the presence of dams upstream that regulate flow, including peak or storm flows, when runoff from adjacent lands often increases nutrient loading to tributaries and the mainstem of Lagunitas Creek.

Nitrates: In the portion of Lagunitas Creek that flows through the leveed Giacomini Ranch, estimated nitrate concentrations averaged 0.92 ± 0.54 (SD) mg/L, with the median also being 0.92 mg/L (Figure 18, Table 8). As was discussed, this average and others for nutrients and pathogens were calculated using statistical procedures to estimate values that were below the laboratory detection limits (Helsel 2005). The 10^{th} and 95^{th} percentiles for nitrates were estimated at 0.20 and 1.90 mg/L, respectively (Table 8). All of the levels recorded in the Project Area portion of Lagunitas Creek exceeded the threshold established by the USEPA for maximum (0.1 mg/L) aquatic diversity and estuary health, while half of the samples (50 percent) fell below the standards for (1 mg/L) moderate aquatic diversity in estuaries. None of the samples exceeded USEPA standards for drinking water (10 mg/L as nitrate-N or 44 mg/L as NO3-). There was no exceedance of standards for nitrites.

Nitrate concentrations in the creek were seemingly lower than were recorded during the LMER/BRIE study between 1987 and 1995. Nitrate concentrations (as NO3-) averaged 1.21 ± 1.31 (SD) mg/L at the upstream sampling site near the USGS gage station and even much lower (0.15 ± 0.27 (SD) mg/L) at the downstream sampling site during the five to eight years of monitoring (LMER/BRIE data). Medians ranged from 0.69 mg/L to 0.02 mg/L, respectively. The fact that the average concentrations were higher, but the median levels were lower during the LMER/BRIE study period suggests that either his study captured potentially more spikes or pulses during storm events, even though it was conducted during a drought period, or it may reflect an actual decrease in average nitrate concentrations or at least mobilization during pulse or wet season events.

During our study, nitrate concentrations in the Project Area portion of Lagunitas Creek did not show an exceptionally strong seasonal pattern, although a few lower concentration samples did occur in the summer. In previous studies conducted by LMER/BRIE on areas of Lagunitas Creek slightly upstream of the Project Area at the Gallagher Ranch stream gage, nitrates followed a more complex pattern in which, at streamflow rates below 50,000 cubic meters or 1.77 million cubic feet, nitrate concentrations increased sharply with flow, but, at higher flow rates, concentrations changed little (Smith et al. 1996). The same held true for Walker Creek (Smith et al. 1996). Based on streamflow records, during that period, streamflow below 50,000 cubic meters occurred almost 300 days per year, yet accounted for only 20 percent of the total annual flow (Smith et al. 1996). The high flow regime accounts for most of the transport of nitrates, with concentrations not showing a linear relationship with flow rates (Smith et al. 1996).

This premise is supported by results of this study, which showed a weak relationship of nitrate concentrations at the upsteam Lagunitas Creek sampling site at the Green Bridge with flow (MLE Regression, $p=0.065$, model $0.01>p>0.001$, model $R^2=0.30$), but a very strong linear relationship between nitrate loading and flow (MLE Regression, $p<0.0001$, model $p<<0.0001$, model $R^2=0.99$; Figure 17). Nitrate concentrations did appear to show some relationship with recent rainfall totals (MLE Regression, $p=0.016$, $R^2=0.10$), although no clear patterns emerged from visual analysis of the data, and variables related to streamflow and rainfall combined to only explain 30 percent of the variability in the nitrate concentration data.

As might be expected, despite high concentrations in several sampling locations in the Project Area, the highest instantaneous loading rates for nitrates – or total volume of nitrates discharged at a single point in time based on stream discharge and capacity -- came from Lagunitas Creek (mg/s). Estimated instantaneous loading rates averaged 10.11 ± 39.46 (SD) mg/s for Lagunitas Creek, but this average was skewed dramatically by loading during storm events, as evident by the estimated median loading rate of 0.66 mg/s (Figure 20). During an April 2006 storm, instantaneous loading rates of nitrates in Lagunitas Creek reached as high as approximately 220 mg/s. In comparison, the highest instantaneous loading rates recorded for some of the other smaller creeks, drainages, and seeps ranged from only 1.23 mg/s for the 1906 Drainage to 29.6 mg/s for Tomasini Creek, with most sampling sites having peak instantaneous loads averaging well below 3 mg/s (0.019-2.93 mg/s).

Patterns of loading of nitrates and other nutrients and pollutants from Lagunitas Creek are incredibly complicated due in large part to regulation of a large portion of the upper part of the watershed. Typically, downstream streamflow would increase once the surrounding watershed soils are saturated and run-off increases, however, during the early part of the season, most of the flow is trapped behind dams in the upper part of the watershed. In response to reservoir management, downstream flow often shows peaks and drops that do not necessarily correspond to rainfall or run-off patterns or cumulative rainfall volume during a storm. In addition to reducing total flow volume downstream, these dams undoubtedly also trap some portion of the nutrient load, particularly those carried in suspension as particulate nutrients or nutrients adhered to organic or inorganic matter. Once reservoirs reach close to capacity, which usually occurs after there has been sufficient rainfall to fill reservoirs, more stormwater is allowed to exit the spillway and flow downstream.

Ultimately, reservoir management may affect patterns of loading in Lagunitas Creek such that increases in rainfall or run-off may not necessarily correlate with the highest concentrations or rates of loading of nutrients and pollutants downstream as they might in unregulated watersheds. This appears to be the case with fecal coliform loading (see Fecal Coliform section for more discussion). However, for nitrates, as Figure 17 indicates, a strong relationship appears to exist between streamflow and nitrate loading, regardless of the dynamics associated with trapping of flows and pollutants and patterns in precipitation. This may suggest that nitrates, which are soluble, are more readily mobilized than some of the other nutrients and pollutants and are not always mobilized strictly by run-off events. In a study of agricultural watersheds on the East Coast of the US, stream baseflow during the dry season was found to actually account for 25- to 37 percent of nitrate loading (Vanni et al. 2001).

Nitrate concentrations did not consistently show any decrease between the upstream sampling location at the Green Bridge and the downstream sampling location at the Giacomini Ranch North Levee (MLE Regression, n=40, df=1, Chi-Square=1.16, $p>0.20$). Nitrate concentrations averaged an estimated 0.96 ± 0.58 (SD) mg/L at the upstream site and 0.87 ± 0.52 (SD) mg/L at the downstream site, with medians very similar or equivalent – 1.0 mg/L and 0.87 mg/L, respectively. Loading also showed no statistically significant differences between upstream and downstream locations, although both the arithmetic mean and medians were seemingly lower at the downstream site (4.0 ± 9.5 (SD) mg/s and 0.65 mg/s) than at the upstream site (14.5 ± 48.8 (SD) mg/s and 1.47 mg/s). As evident from the standard deviations, high variance in the data due to storm event sampling may have reduced power of the test. Also, the levees may have acted to funnel flows and increase streamflow velocities and decrease potential for settling of nutrients and pollutants in flow.

Ammonia: Overall, total ammonia concentrations in Lagunitas Creek between 2002 and spring 2006 were generally either non-detect or low (<0.26 mg/L; Figure 20). During approximately 75 percent of the sampling periods, total ammonia concentrations fell below minimum detection limits for commercial laboratory analysis (< 0.2 mg/L).

Median ammonia concentrations in upstream and downstream portions of Lagunitas Creek were estimated at <0.001 mg/L (Figure 21, Table 8). Conversely, estimated mean concentrations were much higher – 0.35 ± 2.05 (SD) mg/L (Figure 21, Table 8). As is evident from the large standard deviation, this mean was skewed by one instance when total ammonia levels climbed to as high as 13 mg/L. This occurred in April 2003 after a potential discharge of flood waters from the pasture. During this period, unionized ammonia likely exceeded the maximum general limit for most estuarine waters of 0.16 mg/L (RWQCB 1995). Because oxygen levels were generally good in creek waters, these sporadic pulses of ammonia did not seemingly reflect a biogeochemical limitation on ammonia conversion but rather some very proximate discharges of ammonia into the creek from cattle, wildlife, and other point and non-point sources.

Estimated average ammonia levels between 1987 and 1995 as sampled under the LMER/BRIE program were much lower than those reported in this study. At both the upstream sampling site near the USGS gage station and downsteam sampling site near the Giacomini Ranch North Levee, total mean ammonia ranged from 0.04 ± 0.01(SD) mg/L at the downstream sampling site to 0.03 ± 0.01(SD) mg/L at the upstream sampling site, with median values equivalent. Because our analysis relies on estimation of values below detection limits whereas the LMER/BRIE program probably employed analytical techniques with lower detection limits, a direct comparison of these differences may not be appropriate.

During our study, estimated loading rates for ammonia in upstream and downstream sections of Lagunitas Creek averaged 0.056 ± 0.172 (SD) mg/s. This estimate actually does not include the exceptionally high value from April 2003, as current was not recorded that day. For the upstream portion near the Green Bridge, peak loading rates during sampling events ranged from 0.44 to 0.09 mg/s, while at the downstream end, peak loading rates were estimated at 0.37 to 0.12 mg/s.

Phosphates: Concentrations of total dissolved phosphates in the Project Area portion of Lagunitas Creek were typically at or below detection limit (0.10 – 0.20 mg/L) for a majority of the monitoring events (Figure 22). Approximately 74 percent of the samples fell below the minimum detection limit for the commercial laboratory (Figure 22), however, due to interference from salts, the detection limit during this period varied widely from as low as 0.05 mg/L to as high as 15 mg/L. For most sampling events, however, the detection limit was 0.2 mg/L.

Phosphate concentrations for Lagunitas Creek averaged an estimated 0.12 ± 0.11 (SD) mg/L, with high values apparently skewing the mean upwards to some degree as is evident from the median (0.07 mg/L; Figure 23, Table 8). (For the purposes of this analysis, the highest minimum detection limit values were discarded.) All of the uncensored values exceeded the USEPA standards for maximum aquatic diversity in estuaries (0.01 mg/L), while only one sample or 10 percent of the uncensored values fell below the threshold for moderate aquatic diversity (0.1 mg/L,Table 8). As with ammonia, higher phosphate concentrations point to upstream sources of phosphates, including leaking septic systems, ranch and dairy waste, and other point and non-point source discharges, as well as subsidies from tidal exchange.

Total dissolved phosphates recorded at upstream and downstream portions of Lagunitas Creek during the LMER/BRIE study between 1987 and 1995 were actually similar to levels recorded in our study. Phosphate concentrations (as $PO4^-$) averaged 0.12 ± 0.05 (SD) mg/L at the upstream site near the USGS gage and 0.24 ± 0.11 (SD) mg/L at the downstream site near the Giacomini Ranch North Levee. Medians were similar, ranging from 0.11 mg/L upstream and 0.19 mg/L downstream. The downstream sampling site may have higher levels of phosphates due to its closer proximity to tidal sources. While medians between the two almost consecutive decades seem similar, a direct comparison may not be appropriate due to the estimation methods used in our study.

As with nitrates, during our study, the highest loading rates for total dissolved phosphates in the Project Area – or the highest volumes of phosphates relative to stream discharge – came from Lagunitas Creek, with loading reaching as high as 2.51 mg/s in Lagunitas Creek and maximum values for other creek and drainages in the Project Area being no higher than 0.66 mg/s. (Walker Creek, however, had some peak loading events in which phosphates exceeded 3.0 mg/s in October 2003 and late April 2006.) In Lagunitas Creek, phosphates loading averaged an estimated 0.19 ± 0.58 mg/s, with median loading estimated at 0.03 mg/s during these sampling events.

Particulate Nutrients: With the exception perhaps of total ammonia, most of these analyses in this sampling program focused on dissolved nutrients. (Recent sampling efforts have been adjusted to incorporate analytes that will illustrate the contribution of particulate, as well as dissolved, nutrients to nutrient dynamics in the Project Area.) As was discussed above under Tomales Bay, the LMER/BRIE research did expand their sampling efforts to include suspended and particulate nutrients in Tomales Bay, as well as in upstream areas of Lagunitas Creek and Walker Creek (LMER/BRIE data). Between the summers of 1987 and 1995, water samples were collected from the section of creek adjacent to the Gallagher Ranch gage station.

During this period, particulate nitrogen averaged 0.09 ± 0.08 (SD) mg/L in upstream areas of Lagunitas Creek, with the median being 0.06 mg/L (LMER/BRIE data). Because of temporal autocorrelation issues, multiple consecutive days of sampling were averaged, but peak particulate nitrogen, which would be expected to increase dramatically in response to rainfall events, reached as high as approximately 14 mg/L, probably during a storm event. Particulate phosphorous averaged 0.01 ± 0.01 (SD) mg/L, with the median value being equivalent (0.01 mg/L, LMER/BRIE data). Peak values for particulate phosphorous did not exeed 0.02 mg/L (LMER/BRIE data). In contrast with trends in Tomales Bay, particulate levels were generally lower than nitrate and ammonia levels, which is somewhat unexpected given that particulate loading should be higher closer to its source in the upper portions of the watershed. Unlike nitrates, particulate nutrient concentrations showed strong dependence on flow rates (Smith et al. 1996). As discussed earlier, based on their research, Smith and colleagues felt that particulate transport was the dominant pathway by which nitrogen and phosphorous were removed from the watershed and transported downstream (Smith et al. 1996).

Giacomini Ranch

Based on results from four years of monitoring within the Giacomini Ranch and adjacent undiked reference marshes, water quality appears to be relatively resilient despite more than 70 years of nutrient input from cattle. In general, between 2001 and spring 2006, waters within the Giacomini Ranch did not appear to be eutrophic. With a few exceptions, parameters such as nitrates only occasionally exceeded Basin Plan or EPA water quality objectives. There were generally low to moderate concentrations of nutrients, even in drainage ditches, with the exception of seasonal or sporadic pulses. The "hotspot" in terms of highest nutrient concentrations or most frequent detections was, unsurprisingly, the Giacomini Ranch East Pasture, which supported the active dairy herds and was more heavily managed in terms of irrigation, manure spreading, filling, haying, and other agricultural practices.

Nitrates: Nitrates appear to be the most abundant nutrient in the Project Area. It almost always exceeded commercial laboratory detection limits. Nitrate concentrations between 2001 and spring 2006 were generally moderate (between 0.4 and 1.6 mg/L), except in certain portions of the East Pasture, the more heavily managed pasture area. Nitrate concentrations averaged an estimated 7.25 ± 12.95 (SD) mg/L in East Pasture, 1.44 ± 2.73 (SD) mg/L in Tomasini Creek, and 1.14 ± 1.00 (SD) mg/L in the West Pasture (Figure 18, Table 8). The mean for the East Pasture was heavily skewed by high values during some of the sampling events, as the median was 1.3 mg/L (Figure 18, Table 8). Means for Tomasini and the West Pasture were also slightly skewed by high values, with medians estimated at 0.88 and 0.92, respectively (Figure 18, Table 8).

Because of these occasional pulses, approximately 7percent of the nitrate samples collected from the East Pasture exceeded 44 mg/L – the NO3- equivalent to the 10mg/L nitrate-N EPA standard for human consumption -- with all of these exceedances coming from a ditch at the base of the Dairy Mesa (Table 8). This ditch receives a substantial amount of groundwater from the Point Reyes Mesa. This groundwater is probably influenced by adjacent septic systems of residential developments on the Mesa, as well as non-point source stormwater run-off during the winter from a ditch that runs adjacent to one of the Giacomini Ranch's former calf lots and then flows downslope into the ditch.

Nitrate concentrations consistently (>100 percent of the time) exceeded USEPA objectives for promoting maximum aquatic diversity in estuaries (0.1 mg/L) and regularly exceeded thresholds established for moderate aquatic diversity, with anywhere from 43 percent (West Pasture) to 52 percent (East Pasture) of the concentrations recorded exceeding 1.0 mg/L (Table 8).

Fall and winter concentrations were highest, with pulses often observed during October and January rainfall events, although, sometimes, levels were high in spring and summer, as well.

Based on monitoring data, average nitrate concentrations in the East Pasture were potentially higher than in many other dairies in the Seashore, although nitrates often ranged between 1.5 and 11 mg/L in some of the creeks adjacent to other dairies (Ketcham 2001). Sampling on dairies had just initiated at the time the 2001 report was issued, so data on dairies and nutrient concentrations were limited: also, means were calculated using different procedures to estimate values below laboratory detection limits. In a study on other agricultural operations in Tomales Bay, nitrate concentrations in dairy facilities ranged from approximately 3 mg/L for pastures and stockpiles to a peak of 25 mg/L for waste management systems (Lewis et al. 2001). These operations often greatly elevated nutrient concentrations in downstream reaches of creeks (mean = 3.61 ± 0.40 (SE) mg/L) relative to upstream areas where pasture grazing and even manure pasture applications might be conducted (mean = 1.77 ± 0.36 (SE) mg/L; Lewis et al. 2001). Despite this, no statistically significant differences were observed between dairy facility, upstream, and downstream areas in terms of nitrate loading (Lewis et al. 2001).

Within the Project Area, the highest nitrate loading rates for some of the creeks, drainages, and seeps in the Giacomini Ranch ranged between 1.23 mg/s for 1906 Drainage, 2.93 mg/s for Fish Hatchery Creek, and 29.60 mg/s for Tomasini Creek.

For the West Pasture as a whole, which incorporates Fish Hatchery Creek and the 1906 Drainage, nitrate loading averaged an estimated 0.13 ± 0.43 (SD) mg/s, with the median being even lower at 0.009 mg/s (Figure 19). In the West Pasture, loading and concentrations did actually appear to drop between upstream sampling locations outside the Project Area and in the Project Area itself. Average nitrate concentrations dropped from 1.52 ± 0.31 (SE) mg/L on Fish

Hatchery Creek at Sir Francis Drake Boulevard to 0.84 ± 0.16 (SE) mg/L on Fish Hatchery Creek midway through the West Pasture, which was less heavily grazed than the East Pasture (MLE Regression, n=36, df=1, Chi Square=13.47, 0.001>p>0.0001). In terms of loading, similar trends occurred, with average loads dropping from 0.43 ± 0.24 (SE) mg/s at the upstream Fish Hatchery Creek location to 0.04 ± 0.02 (SE) mg/s midway through the West Pasture (Wilcoxon Score, n=23, df=1, Chi-Square=6.24, p=0.012). Flood flows from Fish Hatchery Creek frequently overtop banks downstream of Sir Francis Drake Boulevard and sheetflow across the pasture, thereby probably leading to reductions in nitrates, although, occasionally, downstream concentrations and loading were higher, undoubtedly due to the influence of cattle grazing patterns. These results are interesting, because floodplain-wetland systems are typically least effective at trapping nitrates, with removal rates for some areas studied estimated at only between 1-17 percent (Seitzinger et al. 2002, Van der Lee et al. 2004).

Average concentrations of nitrates also appeared to drop from upstream to downstream along Tomasini Creek, although the overall gradient pattern was much less clear than with Fish Hatchery Creek, with levels sometimes higher downstream. Average nitrate concentrations dropped from 1.88 ± 0.91 (SE) mg/L on upstream Tomasini Creek at Mesa Road to 1.02 ± 0.15 (SE) mg/L on Tomasini adjacent to the Shallow Shorebird Habitat and south of Railroad Point (MLE Regression, n=37, df=1, Chi-Square=8.80, 0.01>p>0.001). Average loading rates also dropped in a downstream direction from 2.95 ± 2.67 (SE) mg/s at the upstream sampling site to 0.24 ± 0.12 (SE) mg/s at the downstream sampling site (MLE Regression, n=23, df=1, Chi-Square=33.73, p<0.0001). However, based on median rather than mean loading rates – which were highly skewed by one very large sample during a storm event -- loading actually appeared to increase in a downstream gradient, with a median loading rate of 0.02 mg/s at the upstream site and 0.07 mg/s at the downstream site. Nitrate loading for Tomasini Creek as a whole averaged 1.54 ± 6.15 (SD) mg/s, with the median being much lower (0.06 mg/s, Figure 19).

Unlike Fish Hatchery Creek, the decrease in nitrate concentrations on Tomasini Creek probably relates more to dilution than nutrient trapping, as the fairly substantial levees constrict overbank flooding during most high flow events to a narrow band or floodplain along the inboard of the levees. While concentrations decrease downstream, the volume of water must increase and thereby elevate loading rates relative to upstream areas. Hydrodynamic modeling has shown that a fairly substantial source of additional freshwater in the form of groundwater from Point Reyes Mesa contributes to creek baseflow downstream of Mesa Road (KHE 2006a). This groundwater not only dilutes nutrient concentrations and elevates loading rates by increasing water volume, but may also represent another source of nutrients and other pollutants to this system due to the presence of septic systems in the adjacent residential neighborhood. Methylene Blue Active Substances (MBAS) -- synthetic surfactants found in many types of laundry detergents as optical brighteners -- can be transported from septic system effluent into the ground water (Thurman et al. 1986) and was detected at least once in downstream creek waters.

Pump was used to drain waters from the ditches in the East Pasture when water levels were too high.

Technically, the East Pasture did not discharge to downstream water bodies because the levees and one-way tidegates maintained this pasture as non-tidal. The only loading that might have occurred was during flood flows when waters overtopped into the East Pasture and then flowed into Lagunitas Creek via the spillway and when waters were pumped from the ditches into Tomales Bay. Frequency of pumping during the study period is unknown, but, presumably, pumping typically occurred when water levels in the ditches threatened to overflow into adjacent pastures. To predict what nitrate loading might have been should the East Pasture have been at least muted tidal, estimates of potential loading were developed using average current for flow rates in the Undiked Marsh for similar-sized channels. This analysis was only done for nitrates, because they were consistently detected and represented the largest nutrient source in the East Pasture. Under this scenario, average loading rates under muted tidal conditions for East Pasture sites could have ranged from 0.1 mg/s to 1.15 mg/s for the East Pasture Old Slough.

Nitrites were almost always below the detection limit, although they were infrequently detected in the East Pasture, with at least one exceedance of USEPA objectives of 1.0 mg/L for human consumption.   Based on RWQCB standards, there were three exceedances of nitrite levels considered toxic to aquatic organisms (>0.5 mg/L), with all of these in the East Pasture ditches (Table 8). Again, conversion of nitrites to nitrates is dependent on oxygen levels and pH, with hypoxic conditions in East Pasture ditches undoubtedly affecting biogeochemical nutrient processes.

Ammonia: Overall, ammonia concentrations between 2002 and spring 2006 were generally not detectable by commercial laboratory standards (Figure 20). Approximately 84 percent of the samples fell below minimum detection limits, which generally averaged 0.2 mg/L, but were sometimes as high as 0.5 mg/L (Figure 20). The presence of higher concentrations of ammonia, which is often bound to sediment as ammonium when transported, typically can be traced to the recent or nearby presence of wildlife or livestock or use of ammonia fertilizers or poorly oxygenated conditions, as ammonia is quickly converted to nitrates under well-oxygenated conditions.

The well-oxygenated conditions within most of the Project Area appear to be quickly converting ammonia to nitrates, however, where oxygen levels were consistently or even sporadically low, ammonia was typically present, as was occasionally nitrites. These oxygen-driven pulses in ammonia did not necessarily coincide with any particular season, but may have been related more to timing of management practices such as ditch maintenance that was often accompanied by sharp drops in oxygen concentrations. Some of the areas with the highest ammonia concentrations included the Giacomini Ranch's East Pasture drainage ditches, the drainage ditch receiving groundwater and feedlot-influenced stormwater run-off from Point Reyes Station, and shallowly flooded flats in the West Pasture.

The East Pasture accounted for 48 percent of the sampling events in which ammonia was detected (Figure 20), and it also accounted for 70 percent of the highest ammonia concentrations recorded (>0.49 mg/L to 76 mg/L). The highest value (76 mg/L) was recorded in a drainage ditch in the southern portion of the East Pasture adjacent to a ranch road where cattle were frequently present. Estimated ammonia concentrations averaged 2.61 ± 10.69 (SD) mg/L, with the average being highly skewed by large pulses as is evident from the estimated median of 0.61 mg/L (Figure 21, Table 8). However, because of the levees, no loading of these occasionally ammonia-laden waters into Lagunitas Creek and the Bay would actually have occurred, except potentially during flood overflow or pumping situations.

Ammonia has also been frequently detected in other creeks adjacent to dairies in the Seashore, with ammonia above detection limit often half or more of the time (Ketcham 2001). When detected, ammonia concentrations ranged from as low as 0.5 mg/L to a high of 4.3 mg/L in creeks near operations such as A Ranch (Ketcham 2001).

High values also substantially influenced the estimated mean concentration of ammonia in the West Pasture. Total ammonia only exceeded detection limits on six occasions (Figure 20). Estimated ammonia concentrations averaged 0.14 ± 1.03 (SD) mg/L, with the median being much lower at 0.001 mg/L (Figure 21, Table 8). With the exception of one occasion when ammonia levels reached 9.50 mg/L in a hydrologically isolated shallowly flooded flat, ammonia typically never exceeded 0.51 mg/L in the West Pasture. In terms of downstream delivery during these periods, estimated loading rates averaged 0.0006 ± 0.0038 (SD) mg/s, with a peak value of 0.02

mg/s at Fish Hatchery Creek near Sir Francis Drake Boulevard. Fifty percent of the ammonia detections came from a small channel on the west side of the West Pasture Freshwater Marsh, which receives groundwater and drainage flow from the Inverness Ridge. Some of this is undoubtedly influenced by septic, as MBAS was detected in these waters during when sampled. Oxygen levels in this marsh and channel often show sharp diel patterns, with supersaturation during the day and hypoxia at night, and these diel oxygen patterns could be affecting biogeochemical nutrient processes.

Ammonia concentrations in Tomasini Creek were not as affected by outliers as the East and West Pastures (and the Project Area portion of Lagunitas Creek). Estimated ammonia concentrations averaged 0.07 ± 0.16 (SD) mg/L, with the median estimated as 0.02 mg/L (Figure 21, Table 8). When ammonia was present in Tomasini waters, concentrations never exceeded 0.98 mg/L. Estimated loading rates during these periods averaged 0.006 ± 0.027 (SD) mg/s. Peak loading during these sampling events ranged from 0.1 mg/s at the downstream Tomasini Creek sampling station just south of Railroad Point to 0.01 mg/s near Mesa Road. Four of the five sampling events in which ammonia was detected occurred in upstream Tomasini Creek during the summer and fall seasons, when surface flow in upper Tomasini Creek dries up, leaving isolated pools such as the one near Mesa Road where sharply fluctuating oxygen levels may affect biogeochemical nutrient processing.

Interestingly, despite occasional spikes in ammonia concentrations, only one sampling location exceeded the maximum concentration limit for unionized ammonia in estuarine waters of 0.16 mg/L. This occurred in the one East Pasture drainage ditch in which ammonia concentrations reached 76 mg/L, with the corresponding unionized ammonia concentrated estimated at 2.52 mg/L, well above Basin Plan standards. While ammonia was obviously detected in lower, but still relatively high, concentrations elsewhere, particularly in the East Pasture, temperature and/or pH did not climb high enough to encourage dissociation of ammonia into its unionized ion.

Phosphates: As with ammonia, total dissolved phosphate concentrations between 2002 and spring 2006 often fell below detection limits, with the exception of the Giacomini Ranch's East Pasture drainage ditches (Figure 22). The presence of phosphates in the surface waters may be directly attributed to human and agricultural activity impacting runoff into ditches and channels within the Giacomini Ranch (KHE 2006a).

Approximately 57 percent of the samples collected fell below the minimum detection limit, however, the detection limit varied widely during the study (0.05 – 15 mg/L) due to sample interference during processing. For this reason, during statistical analysis, data was censored at the highest detection limit, as is recommended for statistical procedures based on survival analysis techniques (Helsel 2005).

As noted above, measurable concentrations of phosphates were primarily detected in the Giacomini Ranch's East Pasture drainage ditches and ranged from 0.24–9.4 mg/l. Total dissolved phosphate concentrations in the East Pasture averaged an estimated 2.40 ± 2.24 (SD) mg/L (Figure 23, Table 8). Again, mean values were at somewhat skewed by pulses of phosphates, particularly in the East Pasture, which had median concentrations of 1.8 mg/L. The hypoxia to even anoxia that persisted in East Pasture ditch waters would actually encourage flux of phosphates from sediments into overlying waters. However, as noted with ammonia, because of the levees, phosphates could not have been transported downstream into Lagunitas Creek and the Bay, except potentially during flood overflow or pumping situations. Even if this area had been at least muted tidal (e.g., connected with a tidegate that limited inflow and outflow), estimates generated earlier for potential nitrate loading (see Nitrates) based on flow rates in adjacent undiked marshes suggest that the relatively small volume of water in East Pasture ditches would not have resulted in comparatively high loading rates.

In the study on other agricultural operations in Tomales Bay, phosphate concentrations often ranged between 1.66 mg/L for pastures to 43.54 mg/L for waste management systems, with the lowest levels found in and around gutters (0.23 mg/L; Lewis et al, 2001). Agricultural operations appeared to increase downstream phosphate levels in creeks (0.97 mg/L ± 0.12 (SE) mg/L) relative to upstream ones (0.29 mg/L ± 0.08 (SE) mg/L; Lewis et al. 2001). As with nitrates, there were no differences in loading rates between reaches of creek upstream or downstream of agricultural operations and even control creek reaches, although loading in downstream areas did appear higher than upstream ones during storm events (Lewis et al. 2001), perhaps suggesting that phosphates were mobilized during these run-off periods.

In comparison with the East Pasture and other heavily managed dairy areas, dissolved phosphate concentrations for the much less heavily managed West Pasture averaged 0.13 ± 0.14 (SD) mg/L, with the median being slightly less than half that (0.07 mg/L; Figure 23, Table 8). Estimated average concentrations in Tomasini were similar – 0.15 ± 0.12 (SD) mg/L – with a median of 0.11 mg/L (Figure 23, Table 8). Estimated average loading rates for phosphates ranged from 0.002 ± 0.013 (SD) mg/s for the West Pasture to 0.05 ± 0.15 (SD) mg/s for Tomasini Creek. Peak loading rates ranged from 0.01 mg/s for the West Pasture to 0.66 mg/s for Tomasini Creek. Again, as was discussed for nitrates and ammonia, both of these areas were influenced to some degree by on-site dairy operations, but they were also influenced by upstream or upslope land uses such as rural residential and other ranching operations that affect the quality of both surface water flow and groundwater flow into these subsampling areas.

Bear Valley Creek and Olema Marsh

As was noted earlier, water quality monitoring in Bear Valley Creek and Olema Marsh was not initiated by the Park Service until August 2004, so the amount of data available from which to draw a conclusion regarding nutrient conditions in Olema Marsh is more limited.

Nitrates: Nitrates never exceeded USEPA water quality objectives of 10 mg/L or 44 mg/L as NO_3^- for human consumption, but routinely (>71 percent of sampling events) exceeded levels recommended for preventing eutrophication in estuaries and maintaining moderate aquatic organism diversity (1.0 mg/L), ranging from 0.96 to 2.9 mg/L between August 2004 and April 2006 and averaging an estimated 1.44 ± 0.81 (SD) mg/L (Figure 18, Table 8).

Estimated average nitrate concentrations flowing into Olema Marsh (1.82 ± 0.28 (SE) mg/L) exceeded those flowing out of the marsh (1.06 ± 0.21 (SE) mg/L; MLE Regression, n=18, df=1, Chi-Square=5.65, $0.02>p>0.01$), which would suggest an upstream source for this nutrient. There was only once instance when concentrations were lower upstream than downstream, otherwise, they often differed by as much as 0.6 to 2.0 mg/L. Agricultural operations do exist upstream on tributaries to Bear Valley, but they are reduced in scope due to the fact that the Seashore now owns much of the land in this historically agricultural watershed. Some data from prior to this study show that one of those agriculturally influenced tributaries, Vedanta Creek, had lower nitrate concentrations (median = ~ 0.75 mg/L; Ketcham 2001). Within the park, the creek does run adjacent to a heavily used trail on which horses are allowed: during rainfall events, fecal matter undoubtedly runs off into the adjacent creek. Downstream of the park and other large private operations is a small rural residential development that may influence nutrient concentrations in groundwater inflow and surface waters from small drainages that flow off the Inverness Ridge.

Average nitrate loading rates also appeared higher upstream (1.23 ± 1.1 (SE) mg/s) than downstream (0.29 ± 0.12 (SE) mg/s; MLE Regression, n=18, df=1, Chi-Square=48.87, $p<0.0001$). Average loading rates for the Bear Valley Marsh outlet were skewed by a very high value of 10.07 mg/s. Estimated median loading rates were dramatically reversed, with medians estimated as 0.05 mg/s for the upstream area and 0.13 mg/s for downstream area, a reverse of the trend observed for concentrations. While, overall, loading was lower at the downstream site than the upstream site, nitrate loading rates showed no clear upstream-downstream pattern during all of the individual sampling events, although, in late April 2006, when loading was 10.07 mg/s at the upstream location, loading totaled only 0.14 mg/s at the downstream location. Loading rates for the upstream area may not be as accurate as those at the downstream location, because a very wide Bear Valley Marsh is abruptly funneled into two 6-foot culverts, and estimating flow volume is logistically difficult. Estimated average loading rates for Olema Marsh as a whole averaged 0.75 ± 2.35 (SE) mg/s), with a median of 0.12 mg/s (Figure 19).

Nitrites were generally not detected (<0.05 mg/L), except for one slightly elevated observation (0.07 mg/L) at the downstream location that did not exceed Basin Plan standards (1995).

Ammonia and Phosphates: Ammonia was not detected (detection limit < 0.2 mg/L), and total dissolved phosphates generally ranged from below detection standards (<0.2 mg/L) to 0.35 mg/L (Figures 20, 22, 23; Table 8). Total dissolved phosphate concentrations averaged 0.24 ± 0.06 (SD) mg/L, with the median being similar (0.23 mg/L; Figure 23, Table 8). As noted earlier, detection limits exceeded the USEPA recommendations for both maximum and moderate aquatic diversity in estuaries (0.01 – 0.1 mg/L), confounding our ability to accurately interpret this data. However, phosphates were detected 78 percent of the sampling events, even at these higher detection limits, so concentrations -- and loading -- would appear to be higher than in natural streamflow conditions (Figure 22).

Estimated loading rates for both the upstream and downstream sampling locations averaged 0.04 ± 0.08 (SD) mg/s, with median loading rates estimated at 0.001 mg/s. No clear upstream-downstream trend in phosphate concentrations was apparent, but loading often appeared to be higher at the downstream location, although these results may be impacted by inaccurate flow volume estimates for the upstream end, as discussed earlier. Slightly elevated concentrations of phosphates observed in Olema Marsh may result either from re-suspension of phosphates in sediments during anoxic periods, excretion by aquatic organisms, or influx from some outside source of phosphates such as leaking septic systems, fertilizers, or agricultural waste.

Reference Areas

Undiked Marsh

The Undiked Marsh is directly downstream of the Giacomini Ranch, but it has been cut off from this once contiguous marsh system by levees and tidegates that limit outflow from the ranch principally to Fish Hatchery Creek and Tomasini Creek and the mainstem of Lagunitas Creek. The marsh, however, is also affected by numerous small drainages and groundwater flow from the Inverness Ridge and tidal water from Tomales Bay: most of the interior channels would almost exclusively be affected by the latter, except during periods of flooding or extreme high tides. Nutrient dynamics in the Undiked Marsh, then, are driven not only by agricultural wastes from Giacomini Ranch and other ranches upstream on Lagunitas and Tomasini Creeks, but by non-point source run-off and septic systems of the adjacent rural residential development. Also, during times of low freshwater inflow and strong tides, nutrient levels may also be influenced by nutrient dynamics of Bay waters.

Nitrates: Nitrate concentrations in the Undiked Marsh averaged an estimated 0.89 ± 0.60 (SD) mg/L, with the median estimated as slightly lower (0.77 mg/L; Figure 18, Table 8). Peak concentrations ranged from 2.1 to 2.5 mg/L, with one of these higher values located at the outlet of smaller drainage that flows off the Inverness Ridge. The others occurred in a small tidal creek channel in the interior of the marsh. Many of the small drainages that flow into the Undiked Marsh come from the Inverness Ridge and may carry higher than natural loads of nitrates from fertilizers, septic system leaching, and other anthropogenic nitrogen sources.

No clear seasonal pattern occurred with nitrate concentrations, with levels sometimes high in summer, fall, and spring, as well as winter, samples. The 10^{th} and 95^{th} percentiles for nitrates were estimated at 0.21 and 2.10 mg/L, respectively (Table 8). Nitrates never exceeded human consumption limits of 10mg/L, but they frequently (42 percent of the time) exceeded USEPA standards of 1 mg/L for sustaining moderate aquatic diversity in estuaries and universally exceeded standards of 0.1 mg/L for promoting maximum diversity (Table 8).

Estimated average nitrate loading rates were relatively low (mean = 0.20 ± 0.37 (SD) mg/s), with the mean again skewed by several of those high values as is evident from the median (0.06 mg/s; Figure 19). Peak loading of 1.77 mg/s and 1.16 mg/s occurred in Fish Hatchery Creek immediately downstream of Giacomini Ranch in October and January 2004, respectively. Another high value (0.98 mg/s) occurred in a larger interior marsh channel (Fault Slough) in January 2005. Otherwise, most of the sampling sites had peak loading values below 0.25 mg/s.

Nitrites were almost always below the detection limit.

Ammonia: Ammonia was detected on only four occasions in the Undiked Marsh, the fewest number of any of the Reference Areas (Figure 20). When ammonia was present, concentrations always fell below 0.51 mg/L, with the estimated average for all sampling events being 0.09 ± 0.11 (SD) mg/L (Figure 21, Table 8). Estimated loading rates averaged 0.02 ± 0.13 (SD) mg/s. Ammonia was detected twice on a sampling site on Fish Hatchery Creek just downstream of the Giacomini Ranch and twice on a side channel very near this site. In addition to outflow from Giacomini Ranch, these sites are also highly influenced by drainage and groundwater flow from the adjacent moderately developed Inverness Ridge. Ammonia concentrations, temperature, and pH were seemingly never sufficiently high enough in combination during sampling events to promote formation of unionized ammonia, the toxic form of ammonia.

Phosphates: In the Undiked Marsh, concentrations of total dissolved phosphates fell below minimum commercial laboratory detection limits during 79 percent of the sampling events (Figure 22). While matrix interference in the laboratory resulted in multiple detection limits, samples in the Undiked Marsh were only subject to one – 0.2 mg/L. Phosphates showed no clear spatial or temporal trends, with peak concentrations of 0.38 mg/L occurring at one of the larger interior marsh channels (Fault Slough). Average phosphate concentrations were estimated at 0.16 ± 0.07 (SD) mg/L, with a similar median of 0.14 mg/L (Figure 23, Table 8).

Interestingly, concentrations did not show strong or consistent seasonality patterns, but higher values during wet months of the year were more apparent in loading data. Phosphate loading rates averaged an estimated 0.03 ± 0.10 (SD) mg/s, with median rates estimated as being well below 0.0001 mg/s. Peak phosphate loading values were recorded at a station on Fish Hatchery Creek downstream of Giacomini Ranch of 0.48 mg/s in October 2004 and 0.25 mg/s further downstream near Inverness in July 2006.

Walker Creek Marsh

As with the Undiked Marsh, Walker Creek Marsh is subject to many influences, including overbank flow from Walker Creek, which drains a largely agricultural subwatershed, as well as non-point source runoff and potentially leaking septic systems from the sparse number of rural residential areas and small towns scattered throughout this area. It is not as densely populated as the Lagunitas Creek watershed, but the percentage of land remaining in agriculture is higher.

Nitrates: Nitrate concentrations averaged an estimated 0.87 ± 0.78 (SD) mg/L, with a lower estimated median of 0.7 mg/L (Figure 18, Table 8). Peak concentrations ranged from 2.9 to 3.2 mg/L, with both of these values occurring on the mainstem of Walker Creek in late January in 2004 and 2005, respectively. Other high concentrations were recorded in a small tidal channel that lies directly adjacent to Tomales Bay, however, those occurred primarily during summer and fall sampling events. The 10th and 95th percentiles for nitrates were estimated at approximately 0.13 and less than 2.90mg/L, respectively (Table 8). Nitrates never exceeded human consumption limits of 10mg/L, but they frequently (40 percent of the time) exceeded USEPA standards of 1 mg/L for sustaining moderate aquatic diversity in estuaries and exceeded standards of 0.1 mg/L for promoting maximum diversity almost 100 percent of the time (Table 8).

As with Lagunitas Creek, nitrate levels (as NO3-) recorded during the LMER/BRIE study at a station just upstream of Walker Creek Marsh between 1987 and 1995 were generally higher, averaging 1.20 ± 1.62 (SD) mg/L, with a much lower median of 0.24 mg/L. The lower median suggests that sampling events did capture some nutrient pulse events. The differences in average nitrate concentrations between the two study periods could be due either to the LMER/BRIE study capturing more pulses, even though it was conducted during a drought period, or to an actual decrease in average nitrate concentrations or mobilization during wet season periods.

During our study, nitrate pulses during winter (or summer/fall) skewed average estimated nitrate loading rates (1.02 ± 1.86 (SD) mg/s), as is evident from the estimated median of 0.062 mg/s (Figure 19). Walker Creek recorded some of the highest estimated peak loading rates of 7.15, 5.71, 4.92, and 4.72 mg/s, with almost all of these associated with some type of rainfall-affected or wet season sampling event. Otherwise, peak loading rates on the smaller tidal channels ranged from between 0.39 mg/s to 0.62 mg/s.

Nitrites were detected in six of the samples, but concentrations only exceeded RWQCB standards of 0.5 mg/L once (2.5 mg/L) at the small tidal channel directly adjacent to Tomales Bay, with the rest falling below 0.17 mg/L.

Ammonia: Ammonia was detected in seven (7) of the samples from Walker Creek Marsh, the highest number of any of the Reference Areas (Figure 20). Peak ammonia concentrations ranged from 0.61 to 1 mg/L, with four samples detected between this range in small tidal channels either directly adjacent to Tomales Bay or at the landward edge of the marsh. Estimated ammonia concentrations averaged 0.15 ± 0.21 (SD) mg/L, with the median being only slightly lower (0.08 mg/L; Figure 21, Table 8). During the LMER/BRIE study a decade earlier, average ammonia levels (as NH3) were estimated as much lower (0.03 ± 0.01 (SD) mg/L), with an equivalent median of 0.02 mg/L. However, as has been discussed earlier under Lagunitas Creek, a direct comparison may not be appropriate due to the estimation methods used in our study. During our study, estimated average ammonia loading rates of 0.07 ± 0.34 (SD) mg/s were skewed considerably by one high loading value as is evident from the median being less than 0.001 mg/s. Loading rates of ammonia peaked at an estimated 1.89 mg/s on the mainstem of Walker Creek during an October 2003 sampling event.

Despite frequent detections, there was only once occasion, however, in which ammonia concentrations, temperature, and pH appeared sufficient to promote dissociation of ammonia into its toxic unionized form, but estimated levels (0.003 mg/L) fell well below Basin Plan standards of 0.16 mg/L.

Phosphates: Total dissolved phosphates were detected much more frequently in Walker Creek Marsh (61 percent of the sampling events) than in the Undiked Marsh (21 percent; Figure 22). However, concentrations typically fell below 0.55 mg/L, with only one peak value of 2 mg/L exceeding this, which occurred in the small tidal channel at the landward edge of the marsh. This station receives surface flow and probably groundwater flow from the adjacent uplands, which supports a small residential area, as well as agricultural operations further upslope.

This fairly tight range in phosphate levels is evident in the average concentrations, estimated at 0.26 ± 0.31 (SD) mg/L, with a median of 0.22 mg/L (Figure 23, Table 8). Interestingly, during the LMER/BRIE study, phosphate levels (as PO4-) appeared to be slightly higher, averaging 0.39 ±

0.16 (SD) mg/L, with a median of 0.37 mg/L (LMER/BRIE data). (In contrast, total dissolved phosphate concentrations averaged only 0.12 -0.24 mg/L at the two sampling stations in Lagunitas Creek.) As was noted for ammonia, a direct comparison may not be appropriate due to the estimation methods used in our study.

During our study, average phosphate loading was estimated at 0.33 ± 0.79 (SD) mg/s, with a much lower median of 0.007 mg/s. As with nitrates and ammonia, the mean for loading was highly influenced by peak values on Walker Creek ranging from 1.06 to 3.57 mg/s during some of spring and fall sampling events: the two highest loading rates (3.57 and 3.04 mg/s) occurred in October 2003 and late April 2006, respectively. Otherwise, loading rates on the smaller tidal channels never exceeded 0.27 mg/s on both the interior and exterior tidal channels.

Particulate Nutrients: During the LMER/BRIE study, some sampling was conducted of particulate nutrients. Particulate nitrogen averaged 0.10 ± 0.08 (SD) mg/L, with a median of 0.07 mg/L. Particulate phosphorous was considerably lower, averaging 0.04 ± 0.13 (SD) mg/L, with a median of 0.01 mg/L. As with some of the other nutrients, the moderately high standard deviations and lower medians suggest that sampling did capture some peak concentration and potentially loading events.

Limantour Marsh

In terms of nutrient inflow from the upper watershed, Limantour Marsh is among the least impacted of the Reference Areas, with all agricultural activities having ceased with purchase of this area by the park and only a few residences occurring on or around the perimeter. As with Bear Valley Creek, there is some potential impact from use of public access trails by equestrians and, during high tides, from waters flowing into the marsh from Drake's Estero, but, otherwise, this system in terms of nutrient input and cycling (e.g., wildlife, plant decomposition, even fire[1]) is remarkably natural for an area within the larger San Francisco Bay region. One unnatural factor that may have affected nutrient dynamics during this period, however, was the Muddy Hollow Pond directly upstream, a dam-controlled pond with a high-water outflow channel that, undoubtedly, functioned in terms of nutrient cycling much like an isolated lake or pond with oxygen levels potentially affecting types and fluxes of nutrients.

Nitrates: While Limantour is not subject to some of the nutrient influxes that marshes in Tomales Bay are, nitrate concentrations were remarkably similar. Nitrate concentrations averaged an estimated 0.82 ± 0.62 (SD) mg/L, with a slightly lower estimated median of 0.68 mg/L (Figure 18, Table 8). Peak nitrate concentrations of 2.6 mg/L were detected at the sampling station directly below the dam, with peak values of 2.1 mg/L recorded downstream of this area in the main marsh slough, as well as in a smaller interior tidal marsh channel. The 10^{th} and 95^{th} percentiles were roughly estimated at 0.2 mg/L and 2.1 mg/L, respectively (Table 8). Nitrate concentrations never exceeded USEPA human consumption limits of 10 mg/L or 44 mg/L as NO_3^-, but they did exceed USEPA standards of 1 mg/L for promoting at least moderate aquatic diversity in estuaries 31 percent of the time and standards of 0.1 mg/L associated with maximum aquatic diversity 100 percent of the time (Table 8).

Seasonal patterns in nitrates were unusual, with peak concentrations highest at all three sampling sites in August 2005 (2 to 2.6 mg/L), October 2002 (1.8 to 2.4 mg/L), and January 2003 (1.2 to 1.3 mg/L). The lack of a clear seasonal pattern may be at least partly due to the influences of the pond upstream.

This same lack of a seasonal trend was evident in nitrate loading rates. Nitrate loading averaged an estimated 0.31 ± 0.55 (SD) mg/s, with -- as happened in many other sampling areas -- the mean skewed by high values (est. median = 0.10 mg/s; Figure 19). Peak loading values of 3.02

[1] Limantour Marsh burned during the Mt. Vision Fire in 1996 all the way to the beach.

and 1.2 mg/s occurred in the main Limantour Slough in October in 2004 and 2005, respectively, with 1.03 mg/s estimated for the upstream portion of the slough immediately downstream of the dam in August 2005. Otherwise, loading rates typically fell below 0.71 mg/s.

Nitrites were detected in six samples, but concentrations never exceeded USEPA standards of 1 mg/L, with all values falling below 0.11 mg/L.

Ammonia: Ammonia was detected in five (5) samples from Limantour Marsh (Figure 20). Estimated ammonia concentrations never exceeded 0.66 mg/L, with concentrations averaging an estimated 0.16 ± 0.11 (SD) mg/L, with a slightly lower estimated median of 0.13 mg/L (Figure 21, Table 8). Eighty percent of the detections occurred in a small interior tidal channel that flows into the mainstem of Limantour Slough, with no clear seasonal trend apparent. Estimated average ammonia loading rates of 0.009 ± 0.052 (SD) mg/s were slightly skewed by high values, with the median being less than 0.001 mg/s. Loading rates of ammonia peaked at an estimated 0.25 mg/s at the upper Limantour Slough sampling site in October 2003.

Ammonia concentrations, temperature, and pH never appeared sufficient to promote dissociation of ammonia into its toxic unionized form.

Phosphates: As with Walker Creek Marsh (61 percent of the samples), total dissolved phosphates were much more frequently detected in Limantour Marsh (70 percent of the samples) than in the Undiked Marsh (21 percent; Figure 22). Concentrations typically fell below 0.50 mg/L, with concentrations averaging an estimated 0.37 ± 0.56 (SD) mg/L and the estimated median being 0.30 mg/L (Figure 23, Table 8). There was at least one large peak value of 3.6 mg/L in the upstream Limantour Slough sampling site in January 2004. The next highest peak levels of 0.79 and 0.75 mg/L occurred in the small interior tidal channel in April 2005 and 2004, respectively. As with nitrates and ammonia, no clear seasonal trends were apparent.

Average phosphate loading was estimated at 0.11 ± 0.23 (SD) mg/s, with a much lower estimated median of 0.005 mg/s. As with nitrates and ammonia, the mean for loading was highly influenced by peak values on the mainstem of Limantour Slough ranging from 0.77 to 0.90 mg/s in October 2003 and October 2005, respectively. Peak phosphate loading for the upstream Limantour Slough sampling area was estimated at 0.63 mg/s in January 2004, while that of the smaller interior tidal channel never exceeded 0.1 mg/s (October 2005).

Comparison Between Project Area and Reference Areas

Nitrates

Nitrates were the most prevalent nutrient recorded in the Study Areas. There were only a few times that nitrates were not detected, even at higher detection limits. Estimated nitrate concentrations differed between Study Areas (Wilcoxon Score, n=136, df=2, Chi-Square=14.24, p=0.001, Figure 18, Table 8). While estimated median concentrations for the Project Area (0.83 mg/L) were not statistically different from those of the Reference Areas (0.7 mg/L; Wilcoxon Score, df=1, Chi-Square=3.00, p=0.08), the power of the test – even a non-parametric test – may have been obscured by the large variance in the data as indicated by the difference between estimated medians and means, with the latter ranging from 3.22 ± 0.72 (SE) mg/L for the Project Area versus 0.86 ± 0.05 (SE) mg/L for Reference Areas.

As the earlier discussion indicated, this mean was substantially influenced by consistently high values in the more heavily managed East Pasture, which supported two active dairy herds, as well as being more actively managed in terms of irrigation, manure spreading, haying, land leveling, and other actions. Within the Project Area (excluding upstream sampling sites), estimated nitrate concentrations averaged 7.25 ± 12.94 (SD) mg/L for the East Pasture and then dropped to below 1.1 mg/L for the other sub-groups: 1.06 ± 0.62 (SD) mg/L for Olema Marsh;

1.02 ± 0.67 (SD) mg/L for Tomasini Creek; 0.87 ± 0.51 (SD) mg/L for Lagunitas Creek; and 0.75 ± 0.61 (SD) for the West Pasture. Estimated median concentrations differed significantly between these Project Area groups (Kruskal-Wallis, n=136, df=4, H=12.42, p=0.015). Because these numbers exclude upstream sampling sites, they may not correspond to numbers discussed earlier.

Conversely, estimated average nitrate concentrations did not vary between Reference Area marshes (0.82 ± 0.09 (SE) mg/L for Limantour; 0.87 ± 0.11 (SE) mg/L for Walker Creek Marsh, and 0.89 ± 0.08 (SE) mg/L for Undiked Marsh; MLE Regression, n=155, df=2, Chi-Square=-28.786, p>0.20, Figure 18, Table 8).

Estimated nitrate concentrations upstream of the Project Area (Upstream Areas; mean = 1.46 ± 0.08 (SE) mg/L) were also seemingly lower than the Project Area, but higher than Reference Areas (Wilcoxon Score, df=1, p<0.0001, Figure 18, Table 8). The 5^{th} and 95^{th} percentiles for nitrates levels in Reference Areas were estimated at 0.06 and 2.3 mg/L, respectively (Table 8). Despite the substantially higher average nitrate concentrations in the Project Area, approximately 84 percent of nitrate values fell within this range of natural variation in Reference Areas, which again points to the weight accorded to occasional spikes in nitrate levels or spatial hotspots (Table 8). Seventy-one (71) percent of Project Area samples fell below the highest 16.7 percent of nitrate levels recorded in the Reference Areas (1.5 mg/L), which exceeds the 50 percent threshold required to meet this progress criteria (Table 8). The coefficient of variation for nitrates was estimated 0.78, which suggests that there is high variability even with Reference Area concentrations.

In terms of Basin Plan standards, nitrates never exceeded USEPA water quality objectives of 10 mg/L as nitrate-N or 44 mg/L for NO_3^- for human consumption in the most of the Study Areas. However, in the East Pasture, approximately 7 percent of the nitrate samples collected exceeded 44 mg/L, with all of these exceedances coming from a ditch at the base of the Dairy Mesa (Table 8).

Approximately 31- to 71 percent of samples exceeded the USEPA recommended threshold for promotion of at least moderate aquatic diversity and ecosystem health in estuaries, with the Reference Area range (31 – 42 percent) only slightly lower than most of the Project subsampling areas (43-52 percent; Table 8). Olema Marsh had the highest number of exceedances at 71 percent. All of the sampling locations exceeded the USEPA objective for maximum aquatic diversity (0.1 mg/L) 100 percent of the time, with the one exception of Walker Creek Marsh (98 percent).

Nitrites were generally not detected (<0.05 mg/L), although they were infrequently detected in the East Pasture, with at least one exceedance of USEPA objectives of 1.0 mg/L for human consumption (Table 8). Based on RWQCB standards, there were three exceedances of nitrite levels considered toxic to aquatic organisms (>0.5 mg/L), with all of these in the East Pasture ditches. At Walker Creek, nitrites were detected in six of the samples, but concentrations only exceeded RWQCB standards of 0.5 mg/L once (2.5 mg/L). Similarly, at Limantour Marsh, nitrites were detected in six samples, but concentrations never exceeded USEPA standards of 1 mg/L, with all falling below 0.11 mg/L.

For most of the Project Area and Upstream Areas, concentrations of nitrates were highest in winter and fall sampling events, although there were occasionally spikes in spring or summer. However, there was no clear seasonal pattern in nitrate concentrations in Reference Areas, which may suggest that, during non-flood periods, inorganic nutrients are being regenerated “internally” from breakdown of organic matter within marshes. Smith et al. (1996) did find that nitrate concentrations varied sharply with flow below a certain streamflow threshold value of 50,000 m^3 (1.77 million cf^3 per day), which occurs almost 300 days per year, so concentrations should have dropped with decreases in streamflow during the summer and fall if nitrates were tied strictly to inputs from outside sources. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that these systems acted as sources of inorganic nitrogen and phosphorous to the Bay during the summer, probably due to breakdown of organic matter (Chambers et al. 1994b).

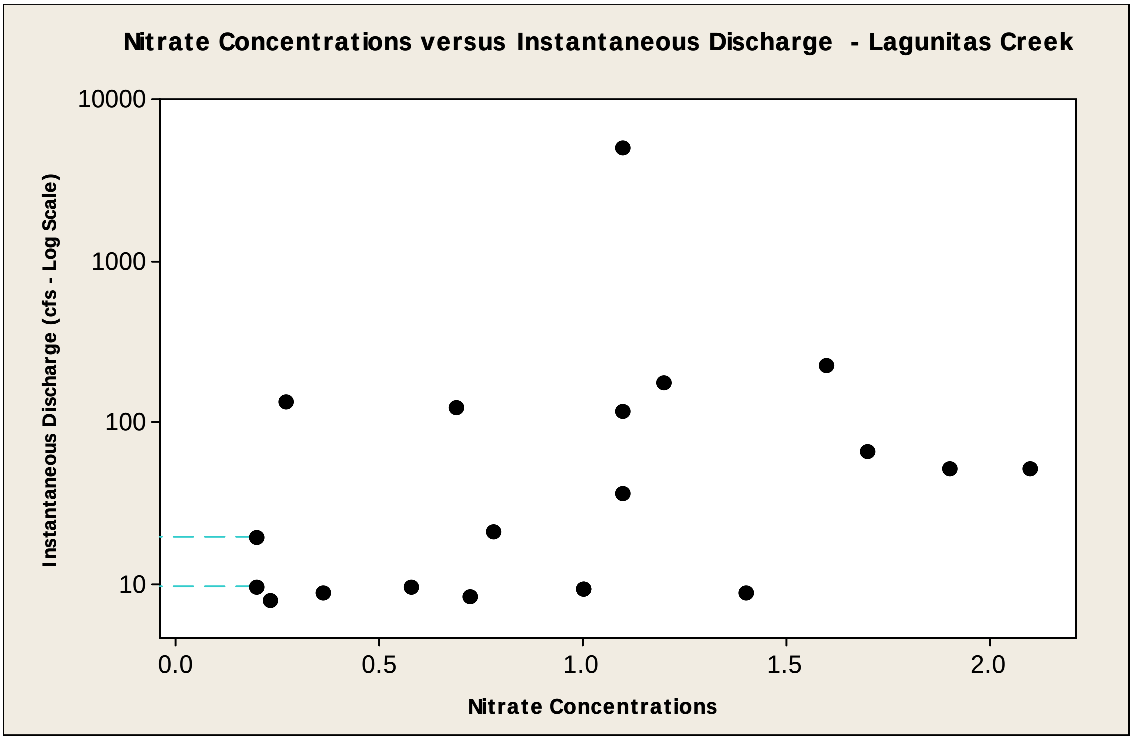
Nitrate loading numbers were more difficult to interpret. Estimated median loading rates did vary between Study Areas (Kruskal-Wallis, n=276, df=2, H=45.59, P<0.001, Figure 19). Loading rates for the Project Area (median=0 mg/s) were lower than Reference Areas (median=0.08 mg/s, Wilcoxon Score, p<0.001, Figure 19). Conversely, estimated average loading rates for the Project Area (est. mean=0.54 ± 0.35 (SE) mg/s) were slightly higher than Reference Areas (est. mean=0.51 ± 0.11 (SE) mg/s (Figure 19). The 10th and 95th percentiles for nitrate loading in Reference Areas were estimated at 0 and 3.09 mg/s, respectively, and all but two of the nitrate loading values fell into the range of natural variability for the Reference Areas. Approximately 89 percent of the estimated loading values in the Project Area fell below the highest 16.7 percent (0.63 mg/s) of rates in Reference Areas.

These numbers are affected by the fact that the East Pasture was leveed and, therefore, did not factor into the analysis of loading. Loading from the Project Area, then, comes from discharge of West Pasture waters through the muted two-way tidegate on Fish Hatchery Creek, Tomasini Creek waters through the muted tidal flashboard dam structure, and Bear Valley Creek/Olema Marsh waters through impaired hydraulic flowpath through the Levee Road culvert. In addition, the Project Area incorporates the portion of Lagunitas Creek that flows through the Giacomini Ranch, because the creek was also impacted by crossing of cattle from one pasture to the next, as well as by occasional discharges from the East Pasture. Of the Project Area sampling sites, the downstream Lagunitas Creek station at the North Levee had one of the highest estimated average loading rates of 3.98 ± 2.85 (SE) mg/s: the upstream Lagunitas Creek station has been incorporated for analysis purposes in Upstream Areas.

As was discussed, loading of nitrates and other nutrients from the East Pasture to Lagunitas Creek and Tomales Bay only occurred during moderate to large storm events, when the levee overtopped, and when waters were actively pumped by the Giacominis from the pasture into the creek. During the period of this study, pumping was not necessarily very frequent, but seemingly used to drawdown ditch water levels in the spring to dry out pastures. However, as noted previously, even if the East Pasture had been muted tidal, based on flow rates for similarly sized channels in the Undiked Marsh, the volume of water that these ditches and sloughs could have contributed to downstream flow would have limited loading rates to between 0.1 and 1.15 mg/s for the East Pasture Old Slough. The upper estimated loading rate represents approximately the 89th percentile of loading for Reference Area creeks.

In comparison, estimated nitrate loading from Upstream Areas (est. median =0.067 mg/s) was considerably higher than that of the Project Area (Wilcoxon Score, p<0.001, Figure 19). Estimated average loading values were even higher (4.22 ± 2.91 (SE) mg/s; Figure 19). Large variability in the Upstream Area data reduced power to detect differences between the Reference Areas and Upstream Areas despite the seemingly sizeable difference in means (Wilcoxon Score, p=0.76). This exceptionally high estimated average for loading rates in Upstream Areas is driven by storms occurring during some of the sampling events, which increased means for Lagunitas Creek and upstream areas of Bear Valley Creek.

Reservoir management undoubtedly affects concentrations and loading of nitrate and other nutrients and pollutants in Lagunitas Creek, but, based on our data, nitrate loading corresponded fairly well with instantaneous discharge or streamflow, regardless of the dynamics associated with flow capture and pollutants and precipitation patterns (Figure 17). This may suggest that nitrates, which are soluble, are more readily mobilized than some of the other nutrients and pollutants and are not always mobilized strictly by precipitation events of sufficient magnitude and duration to generate run-off. In a study of agricultural watersheds on the East Coast of the US, stream baseflow during the dry season was found to actually account for 25- to 37 percent of nitrate loading (Vanni et al. 2001). Conversely, with our data, concentrations showed only potentially a



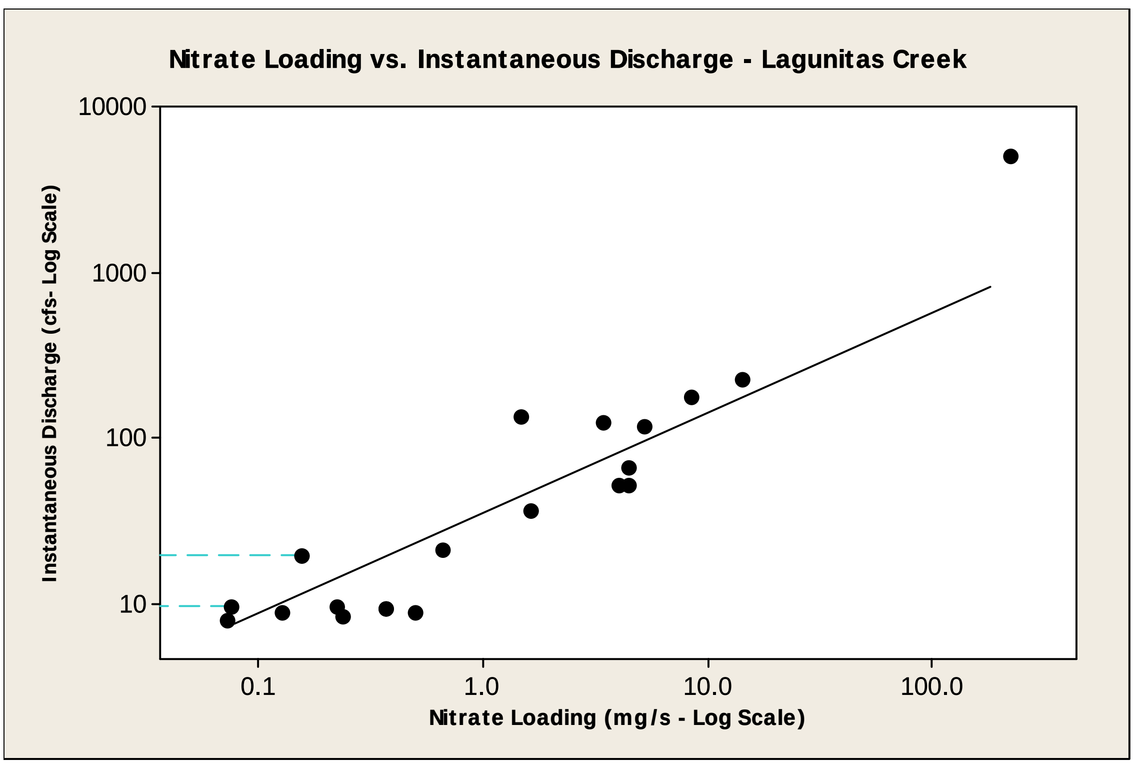


FIGURE 17. Estimated nitrate concentrations at the upstream sampling site on Lagunitas Creek versus instantaneous discharge (MLE Regression, $p=0.065$; Overall Model $0.01>p>0.001$, $R^2=0.30$; top) and instantaneous nitrate loading at the upstream sampling site on Lagunitas Creek rates versus instantaneous discharge (MLE Regression, $p<0.001$; Model $p<<0.0001$, $R^2=0.99$; bottom). Blue dashed lines indicate estimated values based on censored data techniques.

weak relationship with streamflow. These results support earlier findings by Smith et al. (1996), who concluded that the high flow regime accounts for most of the transport of nitrates in Lagunitas Creek, with concentrations not showing a linear relationship with flow rates. Nitrate concentrations increase sharply with flow to a certain level after which point increased flow corresponds with little change in concentrations (Smith et al. 1996).

In addition, Reference Area means were also highly influenced by high estimated average loading rates for Walker Creek at the downstream end of Walker Creek Marsh: Walker Creek represents the second largest subwatershed in Tomales Bay in terms of annual streamflow (Fischer et al. 1996). Nitrate loading averaged an estimated 1.02 ± 0.31 (SE) mg/s at Walker Creek Marsh, compared to 0.31 ± 0.10 (SE) mg/s for Limantour Marsh and 0.20 ± 0.06 (SE) mg/s for the Undiked Marsh. Despite this disparity in means, estimated median loading rates did not differ between Reference Areas (Kruskal-Wallis, $n=108$, $df=2$, $H=2.13$, $p=0.34$, Figure 19). These seemingly disjunct results attest to the importance – and flashy nature – of storm events on pollutant loading to downstream waters.

Some reductions of nitrates did occur even within diked portions of the Project Area. Both mean estimated nitrate concentrations and instantaneous loading showed statistically significant reductions between upstream and downstream locations in Fish Hatchery Creek in the West Pasture, Tomasini Creek, and Olema Marsh/Bear Valley Creek. In some instances, such as loading at Tomasini Creek and Olema Marsh/Bear Valley, estimated median loading rates were actually either equivalent or reversed between upstream –downstream sampling locations, but, overall, mean values may better reflect filtering during larger streamflow and loading events. In general, Fish Hatchery Creek remained connected to a large floodplain, because it was not directly leveed, but rather leveed off from Lagunitas Creek at the edge of the West Pasture. Nitrates are believed to be one of the nutrients that are least effectively trapped by floodplains as they are entirely in solution and are often trapped better in systems with longer retention times, with estimated rates of floodplain retention varying between 1 – 17 percent (Seitzinger et al. 2002, Van der Lee et al. 2004).

Unlike Fish Hatchery Creek, the decrease in nitrate concentrations, if not necessarily loading, on Tomasini Creek probably relates more to trapping of nutrients in the channel itself or dilution than nutrient trapping, as the fairly substantial levees constrict overbank flooding during most high flow events to a narrow band or floodplain along the inboard of the levees. Concentrations may be diluted at downstream locations by tidal inflow and copious groundwater inflow from the Point Reyes Mesa. While tidal and groundwater inflows decrease concentrations at the downstream location, they increase the volume of water and, therefore, may increase loading rates. In addition, groundwater may also be a source of nutrients and other pollutants due to the presence of septic systems in the adjacent residential neighborhood.

In contrast to these other creeks, nitrate concentrations and loading in Lagunitas Creek did not consistently show any decrease between the upstream sampling location at the Green Bridge and the downstream sampling location at the Giacomini Ranch North Levee, although both the arithmetic mean and medians for loading were seemingly lower at the downstream site (4.0 mg/s and 0.65 mg/s) than at the upstream site (14.5 mg/s and 1.47 mg/s). High variance in the data from storm sampling and other large loading events may have reduced power of the test. In addition, levees may have reduced the the potential for in-channel deposition or filtration by the small amount of outboard marshplain present by increasing flood flow velocities and, thereby, reducing potential for retention. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that, in some marshes with well-developed channels, short water residence times resulting from channelization of short-duration, high-intensity flows may decouple these systems from the nutrient pathway during the winter, reducing their effectiveness in filtering contaminants (Chambers et al. 1994b).

Ammonia

Ammonia patterns are difficult to analyze due to the high number of values that fell below commercial laboratory detection limits. Overall, there was apparently no statistically significant differences in the number of detections between Study Areas (Chi Square, n=320, df=2, Chi-Square=2.70, p=0.26, Figure 20). However, of the 64 detections of ammonia during the study, more than 47 percent of them occurred in the East Pasture, a substantial – and statistically significant – difference from the other Project and Reference Area subsampling areas that accounted for no more than 11 percent of the detections (WCM; Chi Square, n=99, df=4, Chi-Square=13.4, p=0.009, Figure 20). Estimated concentrations appeared to be substantially higher in the Project Area (mean = 1.26 ± 0.58 (SE) mg/L) than in the Reference Areas (mean = 0.23 ± 0.01 (SE) mg/L; Wilcoxon, p<0.001) or the Upstream Areas (mean = 0.22 ± 0.01 (SE) mg/L; Wilcoxon, p<0.001; Wilcoxon Score, n=320, df=2, Chi-Square=22.46, p<0.001, Figure 21).

As with nitrates, frequent detections or spikes in East Pasture waters again appeared to drive higher average ammonia concentrations in the Project Area overall (Wilcoxon Score, n=99, df=4, Chi-Square=55.28, p<0.001, Figure 21). Within the Project Area, estimated ammonia concentrations in the East Pasture averaged 2.61 ± 1.51 (SE) mg/L, which differed significantly from values estimated for the West Pasture (0.45 ± 0.24 (SE) mg/L) and Tomasini Creek (0.20 ± 0.01 (SE) mg/L; Wilcoxon Score, p<0.001): these numbers do not include upstream sites incorporated for analyses purposes into Upstream Areas and so may not correspond exactly with numbers discussed earlier. Estimated means were substantially higher than medians due to the influence of occasional ammonia pulses, with medians ranging from 0.61 mg/L in the East Pasture to less than 0.001 mg/L for Lagunitas Creek. Some of the areas with the highest ammonia concentrations included the Giacomini Ranch's East Pasture drainage ditches, the drainage ditch receiving groundwater and feedlot-influenced stormwater run-off from Point Reyes Station, and shallowly flooded flats in the West Pasture. A few spikes also occurred in the downstream portion of Lagunitas Creek, with levels once totaling 13 mg/L: estimated concentrations at this downstream sampling site averaged 0.68 ± 0.65 (SE) mg/L, which differed significantly from the East Pasture (Wilcoxon Score, p=0.001). Ammonia was not detected in Olema Marsh.

Within the Project Area, ammonia was more frequently detected during sampling events in fall, summer, and spring than in winter, with only 23 percent of ammonia detections occurring during the winter sampling periods. During the winter, the water column would have higher levels of oxygen due to higher streamflow, lower water residence time, and less diel variability in oxygen due to primary productivity cycles, so inputs of ammonia and other forms of nitrogen into the system are more likely to be quickly converted to nitrates. Ammonia concentrations were typically highest in waters with lower oxygen (or pH) levels and appeared more related to timing of management practices such as ditch maintenance or low oxygen levels than timing of storm inflows or run-off. Many of these management practices such as ditch maintenance increased organic matter available for mineral decomposition, while others such as diking and ditching limited hydrologic connectivity and caused strong variability in oxygen levels that strongly affected nutrient chemistry.

Interestingly, despite occasional spikes in ammonia concentrations, only a few sampling locations exceeded the maximum concentration limit for unionized ammonia in estuarine waters of 0.16 mg/L. One event occurred in the one East Pasture drainage ditch in which ammonia concentrations reached 76 mg/L, with the corresponding unionized ammonia concentrated estimated at 2.52 mg/L, well above Basin Plan standards. In addition, unionized ammonia likely exceeded this limit in Lagunitas Creek in April 2003, when total ammonia levels climbed to as high as 13 mg/L. While ammonia was obviously detected in lower, but still relatively high, concentrations elsewhere, particularly in the East Pasture, temperature and/or pH did not climb high enough to encourage dissociation of ammonia into its unionized ion.

Within Reference Areas, there were no statistically significant differences in estimated average ammonia concentrations (Wilcoxon Score, n=155, df=2, Chi-Square=0.75, p=0.69) or in the frequency of ammonia being detected (Chi Square Test, n=138, df=2, Chi-Square=0.04, p=0.98, Figures 20-21). Approximately 27 percent of the Project Area samples exceeded the highest estimated 12 percent of ammonia values in the Reference Areas (0.20 mg/L -- typically the MDL), with more than 50 percent of the sampling events falling below this progress criterion threshold. Approximately 24 percent exceeded the estimated 95th percentile of values in the Reference Areas (0.48 mg/L). Coefficient of variation (CV) was estimated at 0.52, well above the 0.2 threshold for low variability.

The Project Area (est. mean = 0.007 ± 0.005 (SE) mg/s) and Upstream Area (est. mean = 0.009 ± 0.007 (SE) mg/s) had seemingly lower estimated average loading rates than Reference Areas (0.034 ± 0.0.020 (SE) mg/s, but medians were not statistically different (Wilcoxon Score, n=276, df=2, Chi-Square=3.68, p=0.159). The Reference Area mean was highly influenced by an estimated loading value of 1.89 mg/s for the mainstem of Walker Creek adjacent to the marsh in October 2003. However, despite this, estimated loading rates did not appear to differ significantly between Walker Creek Marsh (est. mean=0.068± 0.058 (SE) mg/s) and the Undiked Marsh (est. mean=0.024 ± 0.020 (SE) mg/s) and Limantour Marsh (0.009 ± 0.009 (SE) mg/s; Wilcoxon Score, n=108, df=2, Chi-Square=0.47, p=0.791).

Conversely, the Project Area mean reflects the fact that the East Pasture was considered to have no loading potential during sampling events, as it was entirely leveed and only interacted with Lagunitas Creek during extreme flooding events and periods when pumping from the pasture was conducted. However, as the earlier discussion regarding nitrate loading indicated, even with tidal connection, these areas may have still have contributed little to downstream loads. Olema Marsh also had very minimal loading potential as ammonia was never detected. Within the Project Area, estimated loading rates did differ between subsampling areas (Wilcoxon Score, n=92, df=4, Chi-Square=10.58, p=0.032), with downstream Lagunitas Creek having the highest loads (0.08 ± 0.06 (SE) mg/s), followed by Tomasini Creek (0.01 ± 0.01 (SE) mg/s) and the West Pasture (0.0002 ± 0.0002 (SE) mg/s). These values exclude upstream sampling sites and may not correspond to numbers discussed earlier. Approximately 10 percent of the Project Area ammonia loading rates exceeded the highest 16.7 percent of values in the Reference Areas (0.002 mg/s), with 90 percent falling below, much higher than the 50 percent progress criteria threshold. Approximately 99 percent fall within the range of natural variability exhibited in Reference Areas, with the 95th percentile estimated at 0.15 mg/s.

Phosphates

Estimated phosphate concentrations in the Project Area (mean = 0.99 ± 0.16 (SE) mg/L) significantly exceeded that of the Reference Area wetlands (mean = 0.23 ± 0.03 (SE) mg/L; Wilcoxon Score, n=346, df=2, p<0.001, Figure 23, Table 8). The estimated Project Area concentrations were higher than that of both the Reference Areas and Upstream Areas (mean = 0.12 ± 0.01 (SE) mg/L; Wilcoxon Score, p=0.001, Figure 23, Table 8). Phosphates were not detected in approximately 57 percent of the sampled waters, although detection limits sometimes varied widely (range = 0.05 to 15 mg/L) due to matrix interference from salts in the waters. Significant differences occurred between the frequency of detection between Study Areas (Chi Square Test, n=183, df=2, Chi-Square=9.29, p=0.010), with the number of detections disproportionately higher in the Project Area than in the other areas (Figure 22).

The East Pasture largely accounted for the disproportionate number of samples in which phosphates were detected (26 percent; Chi-Square Test, n=51, df=4, Chi-Square=25.47, p<0.001, Figure 22). It also accounted for 76 percent of the values recorded in the upper end of the detection range (0.79 – 9.4 mg/L), with detections in other subsampling areas typically falling below 0.79 mg/L. Within the Project Area, estimated phosphate concentrations in the East Pasture were estimated to average 2.40 ± 0.33 (SE) mg/L, which was significantly higher (Wilcoxon Score, p≤ 0.001) than the means of 0.15 ± 0.03 (SE) mg/L for the West Pasture, 0.16 ± 0.02 (SE) mg/L for Tomasini Creek, 0.16 ± 0.02 (SE) mg/L for the Project Area portion of

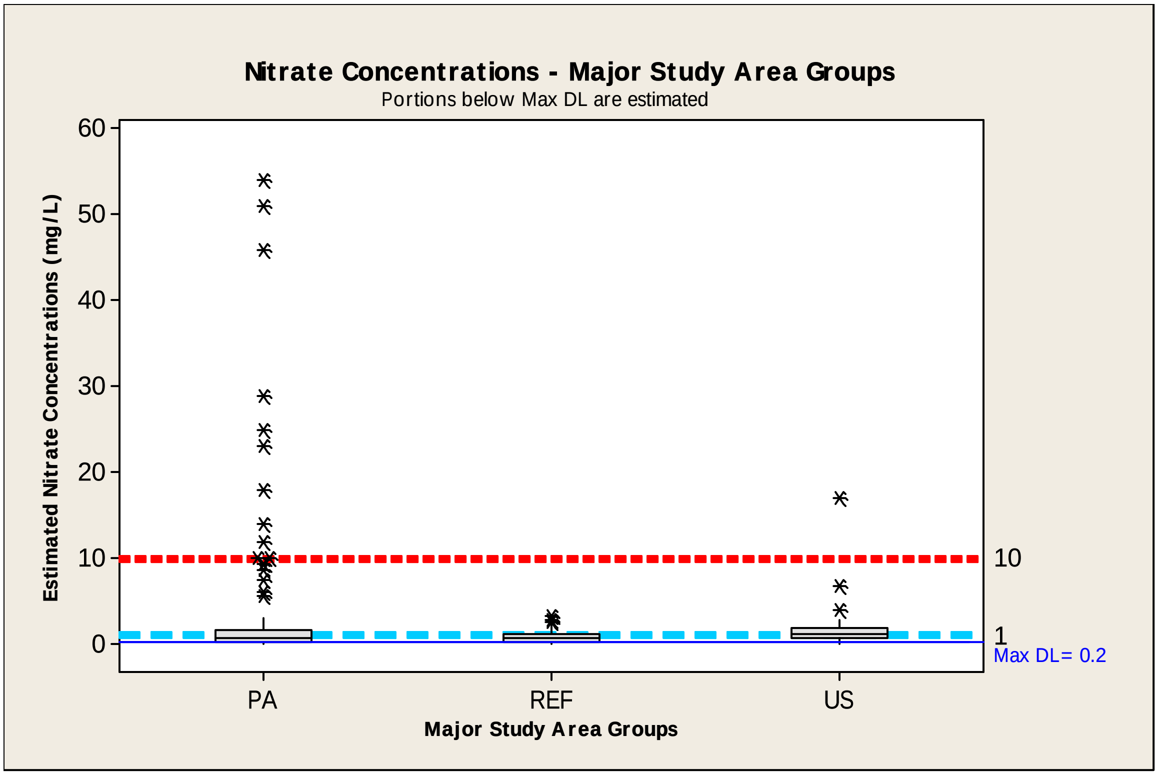
Lagunitas Creek, and 0.24 ± 0.02 (SE) mg/L for Olema Marsh (Wilcoxon Score, n=124, df=4, Chi-Square=102.51, p<0.001). These numbers may not correspond with numbers present earlier, because they exclude upstream sampling sites.

Within Reference Areas, estimated average concentrations of phosphates were lower in the Undiked Marsh (0.16 ± 0.01 (SE) mg/L; Wilcoxon Score, p<0.001) than in either Walker Creek Marsh (0.26 ± 0.05 (SE) mg/L) or Limantour Marsh (0.37 ± 0.09 (SE) mg/L; Wilcoxon Score, n=136, df=2, Chi-Square=22.81, p<0.001, Figure 23, Table 8). Approximately 37 percent of the Project Area samples were higher than the highest 16.7 percent of phosphate values in the Reference Areas (0.35 mg/L), which did not exceed the progress criterion threshold of 50 percent: 32 percent were higher than the 95^{th} percentile of values (0.55 mg/L) in the Reference Areas (Table 8). The coefficient of variation for phosphate concentrations was 0.61, suggesting that variability within Reference Areas is high.

Interestingly, while the Project Area had lower estimated average loading rates (0.03 ± 0.01 (SE) mg/s) because of being largely diked, the Reference Areas actually had higher estimated average loading rates (0.15 ± 0.05 (SE) mg/s) than Upstream Areas (0.06 ± 0.04 (SE) mg/s; Wilcoxon Score, p=0.002), which had roughly equivalent rates to the Project Area (Wilcoxon Score, p=0.82; Overall Wilcoxon Score, n=275, df=2, Chi-Square=23.34, p<0.001). The Reference Area mean was skewed by some high loading values estimated for the mainstem of Walker Creek (range = 3.04 to 3.57 mg/s), which drove up the Walker Creek mean (0.33 ± 0.13 (SE) mg/s) relative to the other means for Limantour Marsh (0.11 ± 0.04 (SE) mg/s) and the Undiked Marsh (0.03 ± 0.02 (SE) mg/s; Wilcoxon Score, n=108, df=2, Chi-Square=12.72, p=0.002).

Most of the estimated means for the other subsampling areas (e.g., Tomasini Creek, Olema Marsh) were close to those recorded in the Undiked Marsh (0.03 mg/s) or even lower -- 0.001 ± 0.001 (SE) mg/s for the West Pasture and no loading in the East Pasture. The Project Area portion of Lagunitas Creek appeared to have the second highest estimated mean loading rate (0.20 ± 0.12 (SE) mg/s) behind Walker Creek Marsh and followed by Limantour Marsh. The Lagunitas Creek estimated mean was strongly influenced by very high loading rates during a January 2006 sampling event of 4.03 mg/s.

As with ammonia, phosphate cycling within the Study Areas does not appear to be strictly tied to inflow from upstream sources. While concentrations were sometimes high during storm events – as was observed in Walker Creek and Lagunitas Creek -- they also showed peaks during spring and fall. As discussed above, these spring and fall peaks probably resulted from recirculation of phosphates from sediments into overlying waters when the upper sediment and bottom water layers became anoxic due to low oxygen levels the soil-water interface, which can happen when respiration rates increase substantially. Phosphate concentrations were highest in the Project Area and, specifically, in the East Pasture due to not only the proximity to sources such as cattle and septic-influenced groundwater, but also due to agricultural management regimes that caused oxygen levels within ditch waters to frequently be low. Low oxygen levels also probably accounted for the higher estimated average concentrations for Olema Marsh and for the higher estimated average concentration and loading rates for many of the Reference Areas such as Limantour and Walker Creek marshes. Also, higher phosphate levels may have been driven by increased proximity to the Bay and ocean. In general, phosphates are more prevalent in marine environments than in terrestrial ones and are not considered a limiting nutrient factor for estuarine macrophytes or plankton unlike upland species (Day et al. 1989, Mitsch and Gosselink 2000).



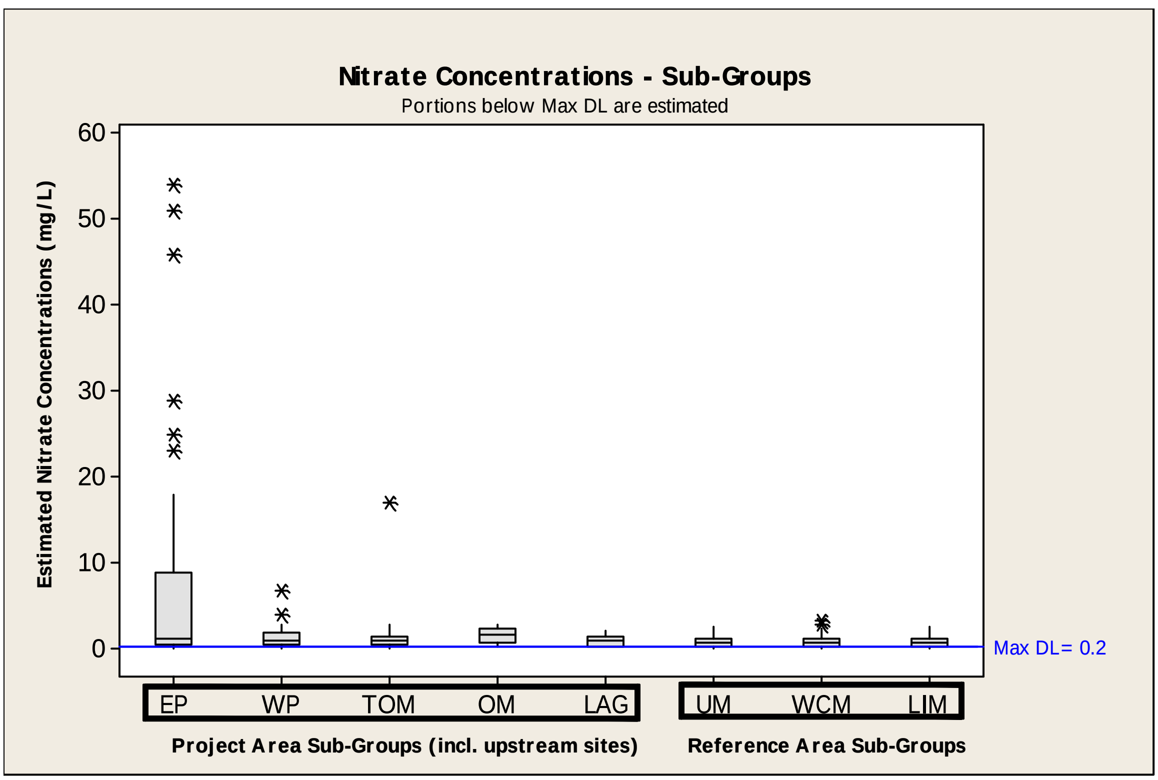
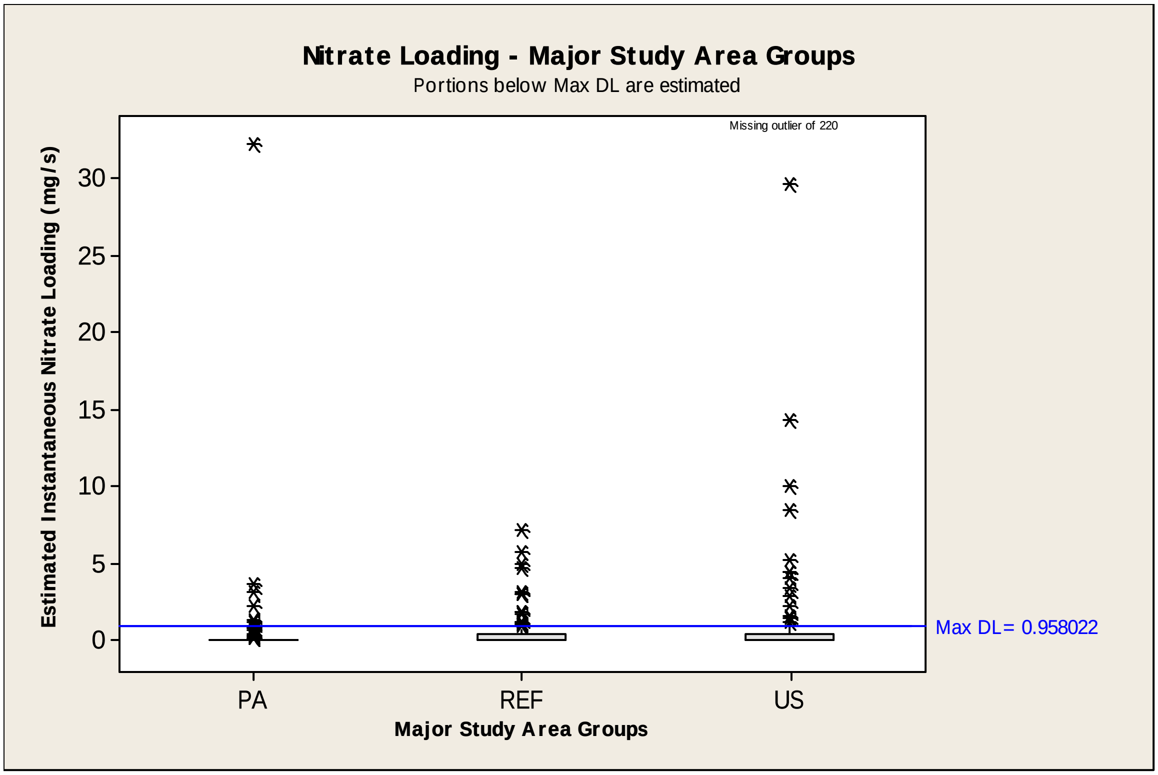


Figure 18. Estimated nitrate concentrations in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10^{th} and 90^{th} percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



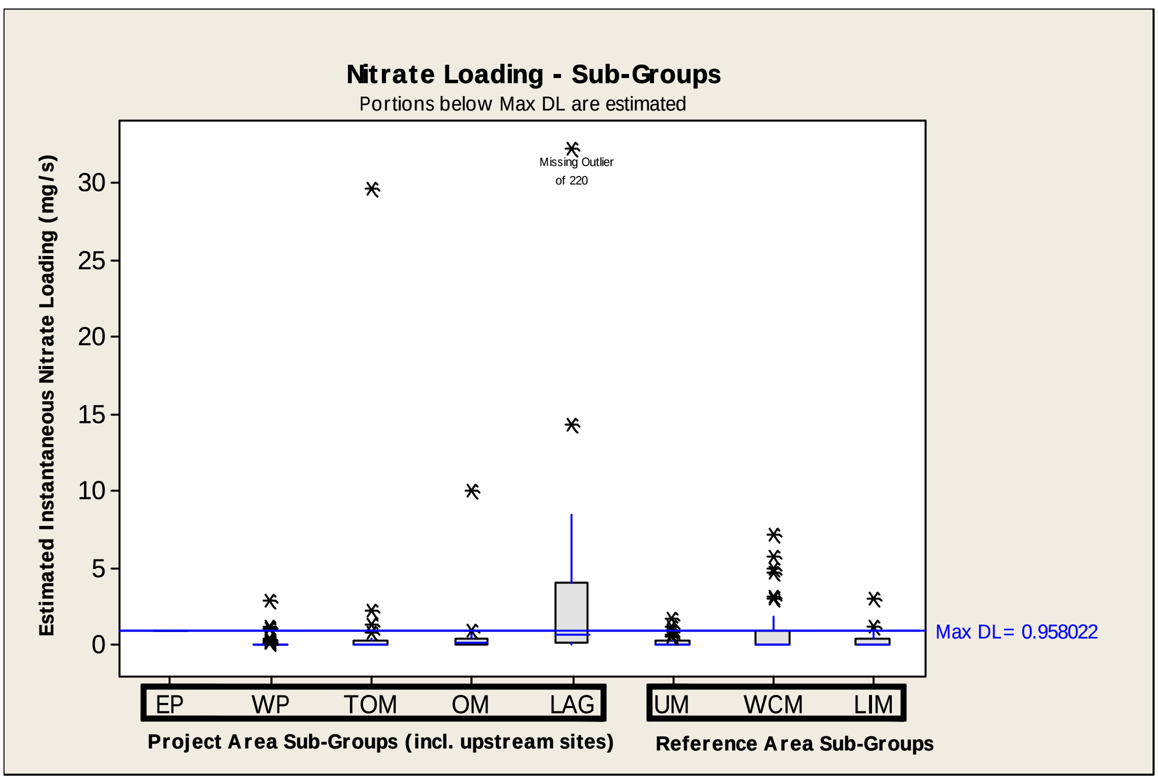
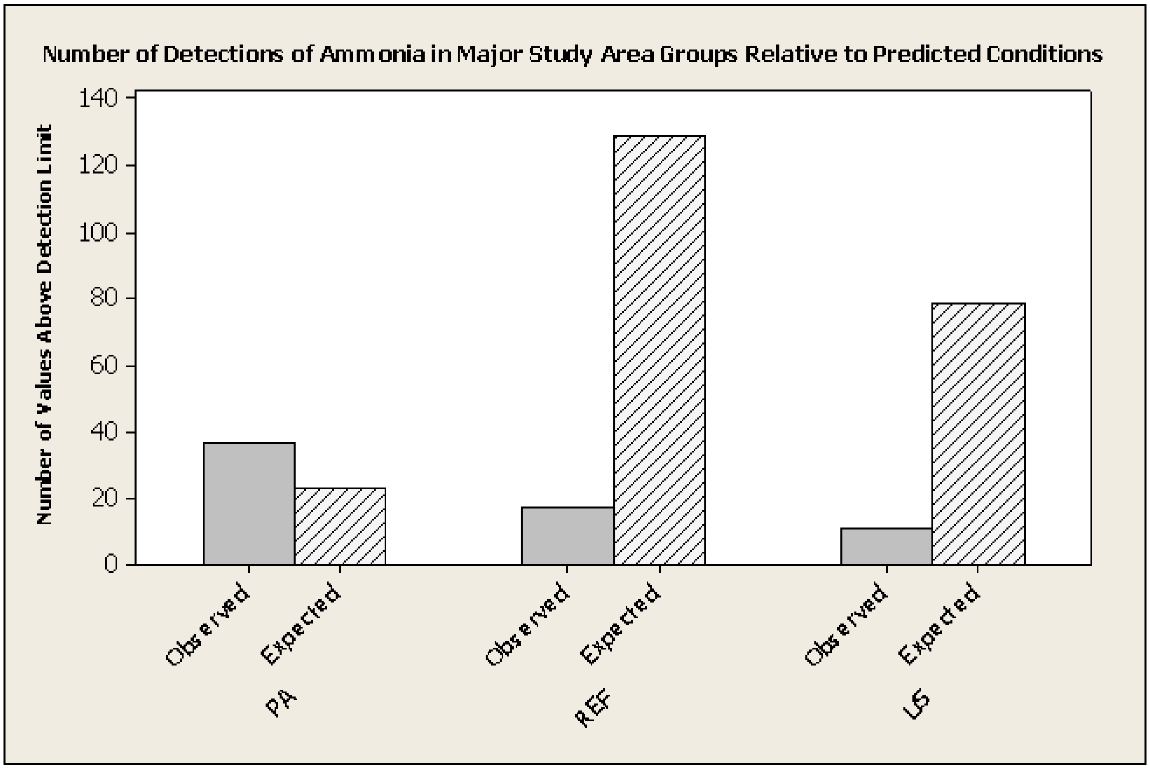


FIGURE 19. Estimated instantaneous nitrate loading in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10^{th} and 90^{th} percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



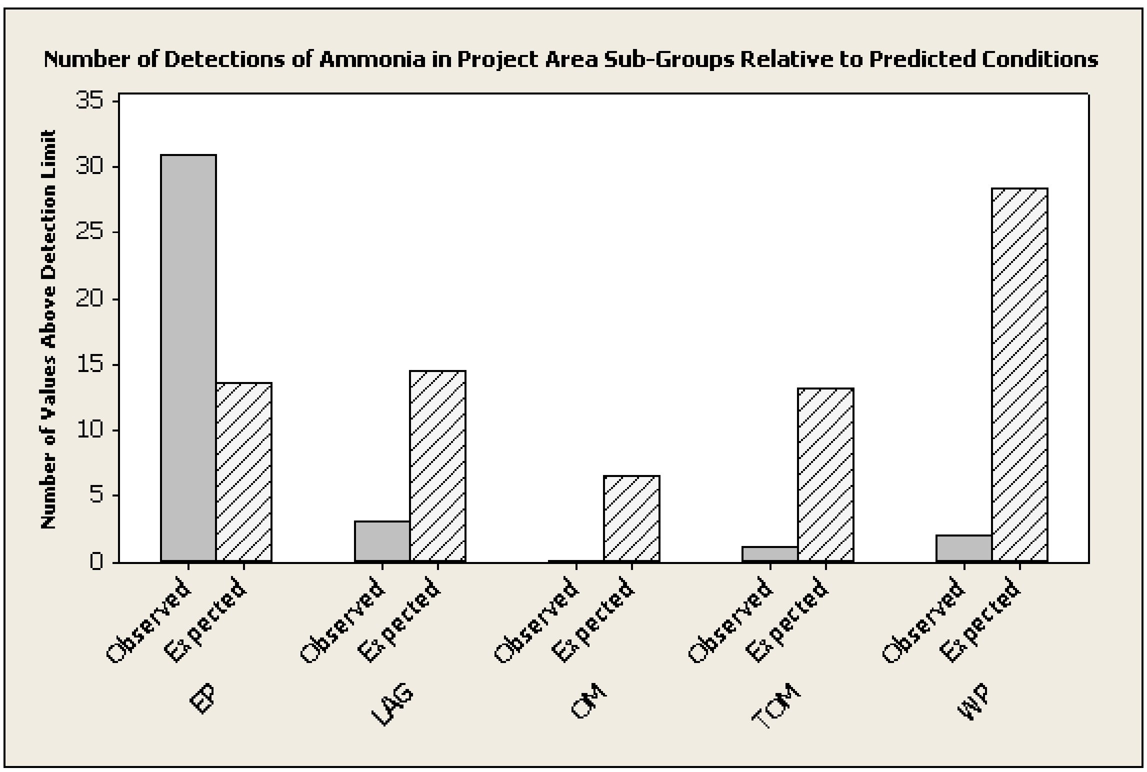
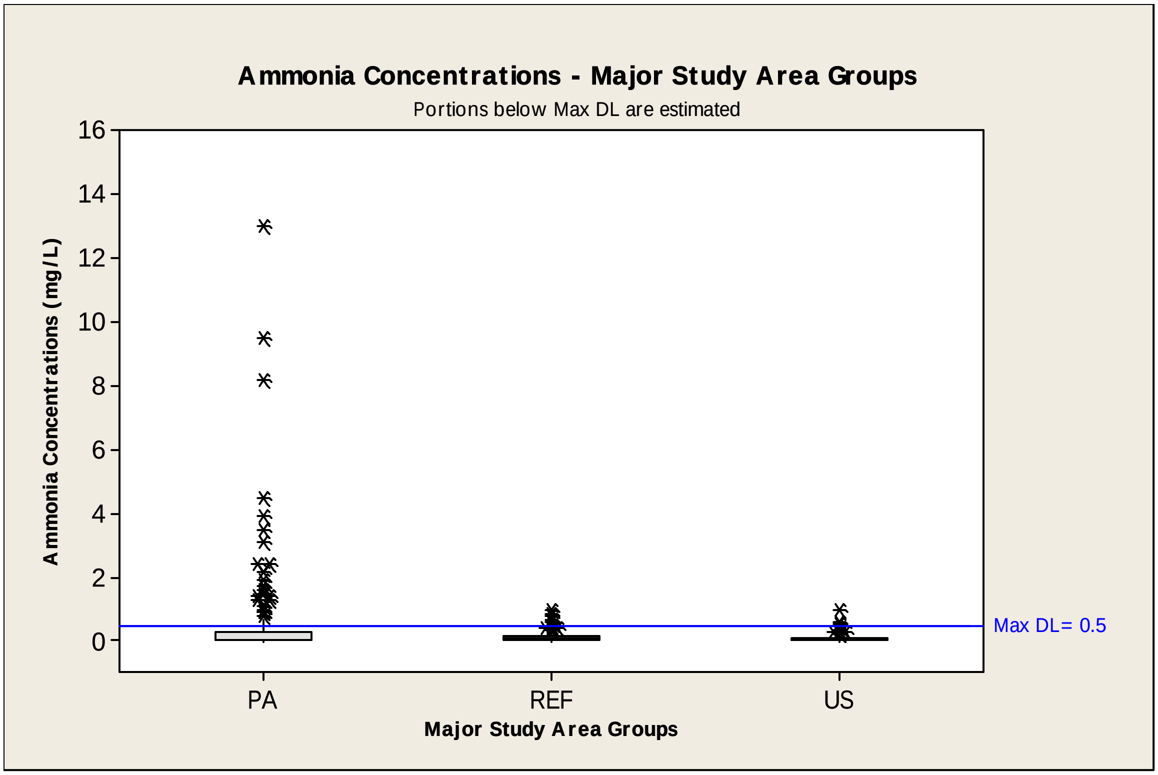


FIGURE 20. Number of total ammonia detections in the Major Study Area Groups and Sub-Groups. Detections refer to values that were above the commercial laboratory detection limit. Expected refers to numbers predicted based on equal probability.



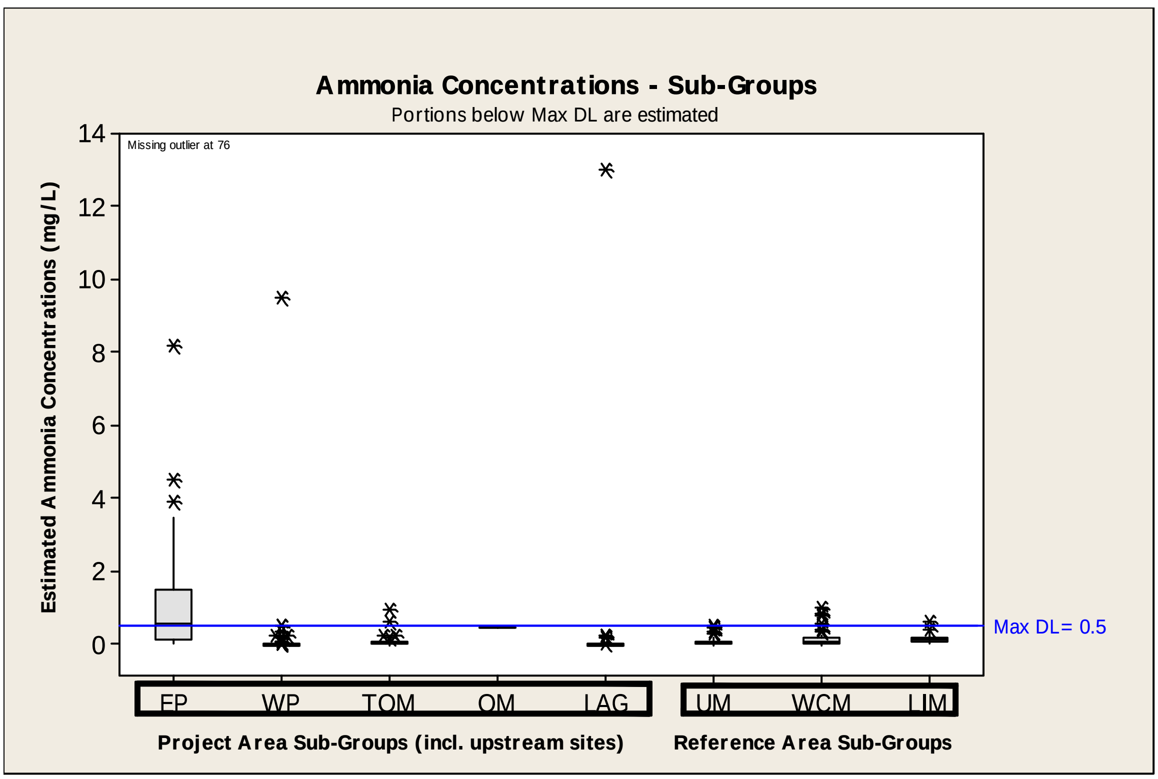


FIGURE 21. Estimated total ammonia concentrations in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10^{th} and 90^{th} percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.

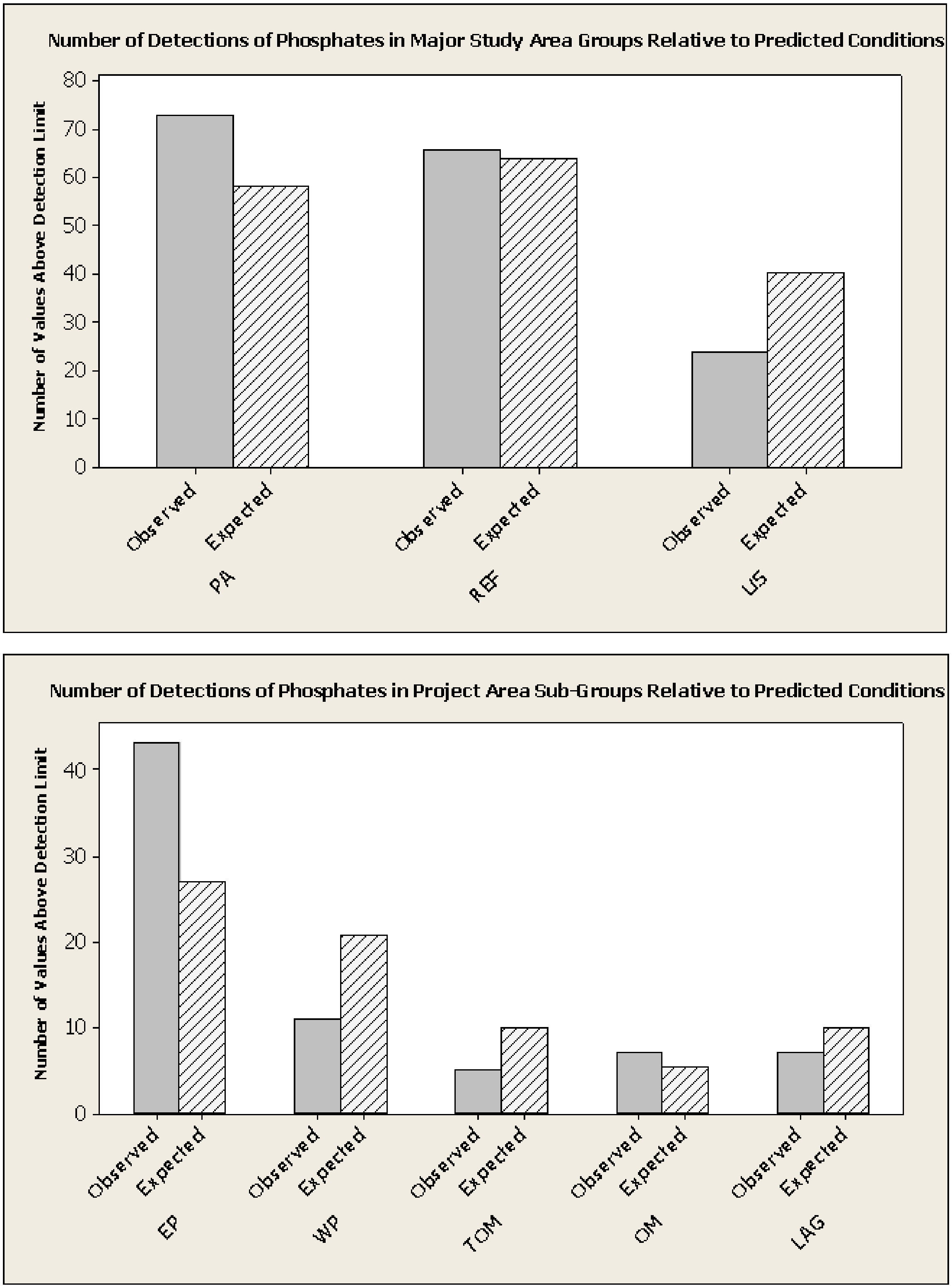
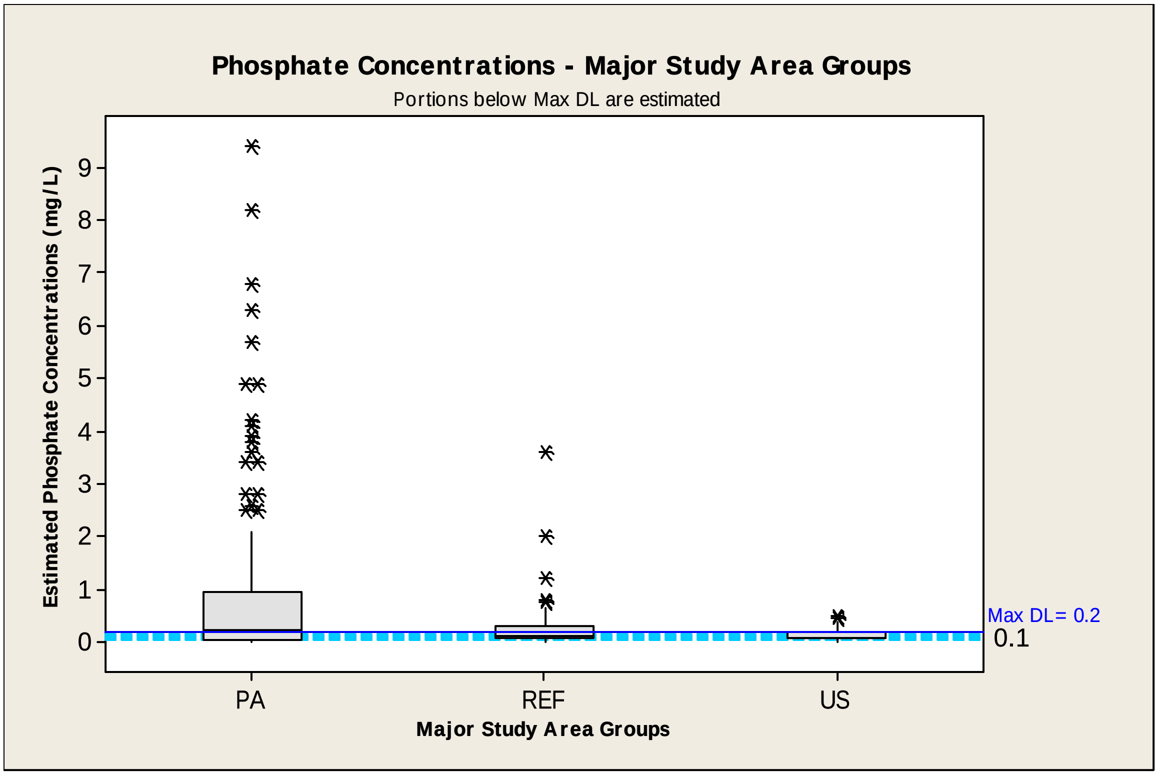


FIGURE 22. Number of total dissolved phosphate detections in the Major Study Area Groups and Sub-Groups. Detections refer to values that were above the commercial laboratory detection limit. Expected refers to numbers predicted based on equal probability.



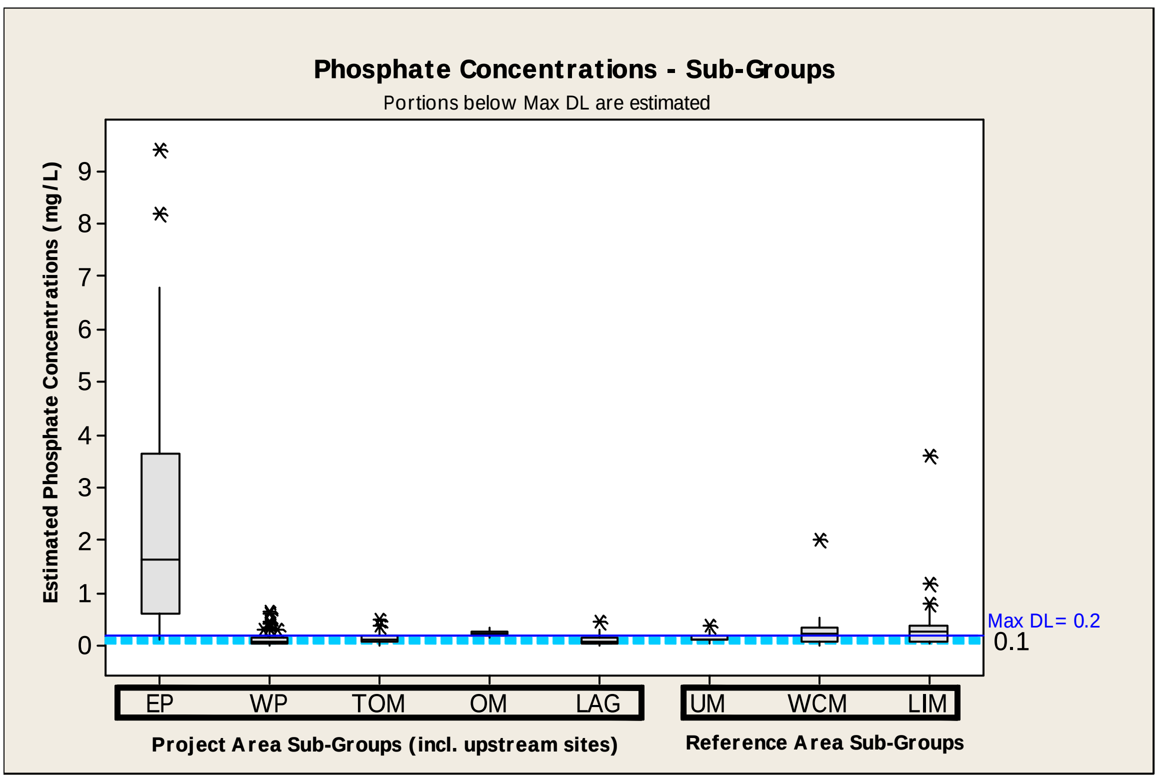


FIGURE 23. Estimated total dissolved phosphate concentrations in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10^{th} and 90^{th} percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.

TABLE 8. Summary data for nutrient concentrations – Giacomini Wetland Restoration Project pre-restoration water quality monitoring. Major Study Area Groups include Project Area (PA), Reference Areas (REF), and Upstream Areas (US). Project Area sub-groups in this chart include upstream sampling sites that are broken out as US in other analyses. Summary data are estimated using survival analysis statistical techniques recommended by Helsel (2005) for censored or non-detect data.

	Major Study Area Groups				Project Area Sub-Groups (including upstream sites)					Reference Area Sub-Groups		
	PA	*Range*	REF	US	EP	WP	TOM	LAG	OM	UM	WCM	LIM
Nitrates (mg/L)												
Mean 3.22			0.86	1.46	7.25	1.14	1.44	0.92	1.44	0.89	0.87	0.82
SD 8.40			0.67	1.89	12.95	1.00	2.73	0.54	0.81	0.60	0.78	0.62
Median 0.83			0.70	1.10	1.3	0.92	0.88	0.92	1.60	0.77	0.70	0.68
USEPA: >10 mg/L (%)[1] 2			0	0	7	0	0	0	0	0	0	0
USEPA: > 1 mg/L (%)	40		34	52	52	43	46	50	71	42	40	31
USEPA: > 0.1 mg/L (%)	100		100	100	100	100	100	100	100	100	98	100
USEPA: Nitrites > 1 mg/L (%)[2] <1			<<1	0	1	0	0	0	0	0	2	0
RWQCB: Nitrites >0.5 mg/L (%)	2		0	0	5	0	0	0	0	0	2	0
5^{th} <0.21		↕84%	0.06	<0.21	<0.24	<0.21	<0.37	<0.23	0.24	<0.21	<0.15	<0.26
95^{th} 23.0			2.30	2.90	51.0	2.70	2.80	1.9	2.90	2.10	≤2.90	2.1
83.3rd		↓71%	1.50									
CV 0.78												
Total Ammonia (mg/L)												
Mean 1.26			0.23	0.22	2.61	0.14	0.07	0.35	ND	0.09	0.15	0.16
SD 6.73			0.12	0.10	10.7	1.03	0.16	2.05		0.11	0.21	0.11
Median	*NE*		*NE*	*NE*	0.61	0.001	0.02	0.001		0.05	0.08	0.13
RWQCB: Union. Amm >0.16 mg/L (# of events)	2X		0 0		1X	0 0		1X		0	0	0
5^{th}	*NE*	↕76%	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*		*NE*	*NE*	*NE*
95^{th} 3.50			0.48	0.36	4.50	0.28	0. 27	0.26		0.38	0.79	0.37
83.3rd		↓73%	<0.2									
CV 0.52												
Total Dissolved Phosphates (mg/L)												
Mean 0.99			0.23	0.12	2.40	0.13	0.15	0.12	0.24	0.16	0.26	0.37
SD 1.75			0.38	0.12	2.24	0.14	0.12	0.11	0.06	0.07	0.31	0.56
Median 0.23			0.08	*NE*	1.8	0.07	0.11	0.07	0.23	0.14	0.22	0.30
5^{th}	*NE*	↕68%	*NE*	*NE*	<0.24	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
95^{th} 5.70			0.55	0.37	9.20	0.44	0.40	0.31	0.35	0.26	0.55	1.20
83.3rd		↓63%	0.35									
CV 0.61												

NE=non-estimatable

[1] *10 mg/L as NO3-as N is equivalent to 44 mg/L as NO3-*

[2] *1 mg/L as NO2-as N is equivalent to 3.3 mg/L as NO2-*

Fecal Coliform in the Watershed and Project Area

For decades, fecal coliform has been used as an indicator for the presence of pathogenic bacteria that could negatively affect human and wildlife health. Pathogenic bacteria are typically transmitted through human and animal feces, which enter streams and other water bodies either directly through cattle being in creeks or boats discharging sewage or indirectly through leaking septic systems or sewage treatment facilities.

In many ways, pathogens are considered one of the primary problems facing the Tomales Bay watershed. While the exact sources and magnitude of these contributions remains in dispute, pathogens in Tomales Bay undoubtedly result from agricultural operations, leaking septic systems, direct discharge from boat waters into the Bay, recreational use of the Bay, and discharge associated with other livestock operations.

During the last few decades, poor water quality in Tomales Bay has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak. The 1998 virus infestation of Tomales Bay oysters affected 171 people and was determined to be from human fecal origin: Shellfish harvested at the time that the contaminated oysters were collected met both the water and shellfish fecalcoliform standards (Smith 2003). In 2000, four cases of food borne illnesses associated with *Vibrio parahaemolyticus* – a naturally occurring bacterium common in coastal waters during the summer -- prompted DHS to issue warnings to consumers against eating raw or undercooked oysters (Commandatore 2000 *in* Smith 2003).

Even prior to these incidents, Tomales Bay had been listed as “threatened” under the state’s Shellfish Protection Act in 1994. In addition, the Bay was later listed as impaired under Section 303(d) of the CWA due to pathogens for several reasons, including the fact that water quality standards are commonly exceeded for an estimated 90 days a year, which results in closure of shellfish harvesting during that period (Taberski 2000 *in* Smith 2003).

Under the Basin Plan, a number of water quality objectives were developed to protect beneficial uses, with standards for fecal coliform ranging from a median of less than 14 mpn/100 ml for five samples collected over a 30-day period for shellfish harvesting to means of less than 2,000 mpn/100 ml over 30 days for non-contact water recreation (Basin Plan 1995; Table 1). Recently, the RWQCB developed TMDL or maximum daily load limits for pathogens as part of a series of TMDLs scheduled to be issued for Tomales Bay over the next few years. TMDLS focus on conditions in the receiving water body rather than the individual point (and non-point) sources. For Tomales Bay, the median fecal coliform concentration is required to be less than 14 mpn/100 ml, with a 90^{th} percentile less than 43 mpn/100 ml (Ghodrati and Tuden 2005). The log of the mean for Lagunitas Creek, Olema Creek, and Walker Creeks must fall below 200 mpn/100 ml, with the 90^{th} percentile below 400 mpn/100 ml (Ghodrati and Tuden 2005). The TMDL load allocation on Lagunitas Creek at the Green Bridge (LAG1; Appendix A1) must have a log mean of less than 95 mpn/100 ml.

As Smith (2003) pointed out, incidences of human pathogens contaminating Tomales Bay oysters during times when coliform standards were met brings into question the validity of fecal coliform as the sole indicator of safe conditions for harvesting. The most common fecal indicators are the total coliform bacteria, fecal coliform bacteria, and *E. coli* (Simmons 2008). Total coliform bacteria are many times not feces specific and include many bacteria that are not derived from human or animal waste sources (Kadlec and Knight 1996). Fecal coliform bacteria are a subset of the total coliform bacteria that can grow at elevated temperature (44.5°C); these tend to be more feces specific because they grow only at elevated temperatures similar to that found in warm-blooded mammals (Simmons 2008), but they come from many other mammals other than humans and livestock and do include some free-living bacteria (Kadlec and Knight 1996). *E. coli* are a specific subset of the fecal coliform bacteria, tend to be very feces specific, and are the most indicative of fecal contamination of water (Simmons 2008). However, there are sometimes problems with this bacterial indicator because it may be more easily inactivated in the environment than the pathogens of concern (Simmons 2008). Because of this, another group of fecal bacteria, the *enterococci* spp., have been suggested for use in some cases, most specifically for measuring the quality of estuarine and marine waters for bathing water quality (Simmons 2008).

Because of the problems with total and fecal coliform, many managers and researchers have started using these other, reputedly more accurate indicators of pathogenic activity such as *E. coli* and *enterococcus*, which would be more likely to be associated with health problems in humans and wildlife than coliforms. However, the Basin Plan, TMDL, and other standards are still tied to fecal coliform. Until the parameter to which standards are applied is changed, most groups sampling water quality, particularly for compliance purposes, will continue to focus on fecal and total coliform.

Tomales Bay

Because of the potential impact that bacteria have on shellfish production, research and monitoring for pathogens has been more extensive than that for nutrients. As early as 1967, the Pacific Marine Station and NMWD found that Tomales Bay had fecal coliform levels that were high during the winter runoff periods (Smith et al. 1971 *in* TBWC 2002). Since then, several intensive studies on bacteriological water quality of the Bay and its tributaries have been conducted over the past 28 years, which were summarized in the Staff Report for the pathogen TMDL (Ghodrati and Tuden 2005). These studies include:

- A 1974 shellfish and water quality study by the California Department of Health and Human Services (DHS);
- A shoreline and watershed water quality survey carried out in 1976-1977 and 1977-1978 by the RWQCB;
- A sanitary survey conducted by DHS;
- A pilot study conducted by DHS in the winter of 1994–95 to test sampling methods and locations for the 1995–96 study;
- A RWQCB-funded study conducted in 1995–96 by DHS and the RWQCB, under the auspices of the Tomales Bay Shellfish Technical Advisory Committeee (TBSTAC); and
- A second RWQCB-funded study conducted in 2001 by the RWQCB and TBSTAC with assistance from the Seashore.
- A study of lower Lagunitas Creek and Walker Creek by UC Davis Extension (Lewis and Atwill 2007).

The results of these studies indicate that Tomales Bay and its tributaries have exceeded shellfish and water quality standards over the last three decades (Ghodrati and Tuden 2005). In 1974, DHS designed a study (TBSTAC 2000 *in* Ghodrati and Tuden 2005) to determine the water quality of Tomales Bay and tributary streams during wet weather conditions and relate the results to the bacteriological quality of the shellfish grown in the Bay. Shoreline samples showed elevated total and fecal coliform levels at numerous stations, which were attributed to the possibility of shoreline drainage, tributary streams entering the Bay, and possible failing septic systems. The study concluded that the high coliform counts were due to contribution of wastes by upstream dairies and, in lower Keyes Creek, from raw sewage discharges from the town of Tomales.

The RWQCB conducted a shoreline and tributary sampling survey during the winters of 1976–77 and 1977–78 (TBSTAC 2000 *in* Ghodrati and Tuden 2005), to evaluate the effectiveness of the RWQCB's recent requirements for dairy waste practices. Stream conditions improved for areas in which dairies had come into compliance with the minimum guidelines, although none of the shoreline or stream stations sampled met coliform objectives for water contact and non-contact recreation following periods of rainfall. Stream stations showed decreases in coliform between 1976–77 and 1977–78 following implementation of the minimum guidelines. The report also concluded that sewer system installation of the town of Tomales in June 1977 resulted in decreased levels of coliform in Keyes Creek downstream of developed areas.

In 1980, the Food and Drug Administration (FDA) conducted a sanitary survey from February 24 through March12 to determine the degree of pollution and the recovery rate of the Bay during periods of rainfall, (TBSTAC 2000 *in* Ghodrati and Tuden 2005). The results of this study showed that the shellfish market standard for fecal coliform was exceeded in all Bay water quality stations during wet periods. The dry period samples met the standard, with the exception of stations at the head of the Bay and near the mouth of Walker Creek. Seven out of eight shellfish samples exceeded the market standard. Fecal coliform densities in the streams during dry weather were equal to sewage from about 150 to 200 people. During wet weather, fecal coliform densities increased to the equivalent of sewage from 1,500 to 2,000 people or 500 to 700 cows. The highest loading rates documented after rain events revealed a bacterial equivalent of 40,000 to 50,000 people or 15,000 to 20,000 cows. The 1980 study concluded that the portions of the Bay most seriously affected by pollution from rainfall and runoff were the head of the Bay (Millerton Point south) and the Walker Creek delta. Rural and livestock sources of nonpoint pollution were considered to be the most likely cause of high fecal coliform densities in the Bay.

The pilot study conducted by DHS in the winter of 1994–95 was a prelude to the study during 1995–96 (TBSTAC 2000 *in* Ghodrati and Tuden 2005). Both of these studies were initiated as a result of Tomales Bay being listed as threatened under the Shellfish Protection Act and the formation of TBSTAC. The data from the pilot study support the theory that the major source of fecal contamination to the Bay is rainfall-related runoff from tributaries. Two seasonal patterns of fecal coliform densities were observed: 1) sites that showed declining fecal coliform densities throughout the winter, suggesting a nonrenewable source of coliforms, and 2) sites that exhibited high fecal coliform densities throughout the season, suggesting a renewable source.

Following completion of the pilot study, the RWQCB and DHS conducted an intensive RWQCB-funded study of bacteriological and pathogen levels in the water of Tomales Bay and its watershed (TBSTAC 2000 *in* Ghodrati and Tuden 2005). As before, bacterial densities usually exceeded the standards within the first one or two days of each rainfall event, then, typically decreased to acceptable levels by the last day of sampling. Fecal coliform levels in the middle portion of Tomales Bay were generally lower than either the outer- or inner-bay regions, although all Bay stations experienced elevated concentrations of fecal coliforms immediately following rainfall. Consistently high bacterial levels were detected during most of the study at sites within the Walker/Keyes/Chileno Watershed and along the eastern shoreline watershed. Slightly lower concentrations of fecal coliforms were detected throughout the Lagunitas and Olema Cree subwatersheds. In contrast, bacterial levels at the western shoreline watershed stations were generally 10 to 100 times lower than those from all other subwatersheds. The highest loadings estimated were within the Walker/Keyes/Chileno and the Lagunitas and Olema subwatersheds. Within the overall Lagunitas sub-watershed, Lagunitas Creek contributed the largest share of the fecal load, followed by Olema Creek. The Bear Valley drainage contributed the lowest loadings to this sub-watershed.

In the winter of 2000–2001, the RWQCB, in conjunction with TBSTAC and the Seashore, designed and conducted a study with the purpose of implementing some TBSTAC recommendations from the 1995–96 study. This study looked at both fecal coliform and *E. coli* as indicators for the presence of pathogens through both one-time and repeated measurements throughout three storm events, with repeated *E. coli* sampling used to estimate total loading rates for some of the sampling locations. Throughout the three wet-weather sampling events, the fecal coliform levels for all watershed and Bay station samples significantly exceeded the designated water quality objectives for shellfish harvesting waters and, in most cases, for contact and non-contact water recreation (RWQCB 2001). In general, fecal coliform levels remained high during all rainfall events sampled in all watersheds, typically increasing during the second day of each wet-weather sampling event (RWQCB 2001). Intensive time series sampling conducted on Olema Creek by the Seashore as part of this study showed that bacteria loading as represented by *E.*

coli closely tracked stream discharge in terms of the rise and fall in flows, although there was often a two-hour lag in this system between peak stream discharge and peak *E. coli* levels (Ketcham 2001).

Of the inner Bay station samples, the highest fecal coliform levels were consistently detected at the inner Bay Station 1 (located south of the Tomales Bay Oyster Company lease area), which is closest to the outlet of Lagunitas and Olema Creeks (RWQCB 2001). The lower Walker Creek subwatershed contributed the highest one-time and highest overall instantaneous fecal coliform loadings (RWQCB 2001). Lower and upper San Geronimo Creek subwatersheds, which are tributaries to Lagunitas Creek, and lower (7.46×10^{13}) and upper Lagunitas Creek (5.13×10^{13}) ranked as the second and third and fifth and sixth largest contributors, respectively, in terms of instantaneous fecal coliform loading rates (RWQCB 2001). The Keyes Creek and Olema Creek subwatersheds recorded the lowest instantaneous fecal coliform loadings, with Olema Creek estimated at 8.67×10^{12} (RWQCB 2001). While pathogens concentrations are often higher in Olema Creek than Lagunitas Creek, the greater volume of stream discharge in Lagunitas Creek increases the loading potential of Lagunitas Creek relative to Olema (Ketcham 2001). In terms of total loading, Walker Creek again had the highest loading rates per day (3.97×10^{14}), followed by Lagunitas Creek (8.66×10^{13}) and Olema Creek (7.53×10^{13}; RWQCB 2001).

The 2007 study by Lewis and Atwill (2007) expanded upon earlier efforts by investigating coliform and *E. coli* in both sediment and water in lower Lagunitas and Walker Creeks, in addition to three other northern California estuaries. They found that mean fecal coliform concentrations were above water quality for shellfish harvesting in all three flow seasons (wet-base flow, wet-storm flow, and dry-base flow), but that the mean bacterial concentrations during dry season base flow came close to meeting shellfish harvesting standards (Lewis and Atwill 2007). Mean fecal coliform concentrations exceeded many of the Basin Plan standards at all five estuaries during wet season storm flow conditions, but Lagunitas Creek also had the highest counts of bacteria during dry season base flow conditions, suggesting that some direct discharge of source bacteria is contributing to loads in addition to precipitation and associated run-off (Lewis and Atwill 2007).

Results of the 2000-2001 and 2007 studies support results from the pilot study, which suggested either the presence of a renewable source or the introduction of new sources of fecal coliform throughout portions of the watershed (RWQCB 2001). As with many other previous studies, the 2000-2001 report speculated that agricultural sources are one of the major contributors of pathogens to Tomales Bay, particularly as the watersheds with the highest concentrations and loadings are primarily agricultural (RWQCB 2001). The RWQCB pointed to runoff from animal pastures (containing manure) and failing onsite sewage disposal systems or as some of the potential new or renewable sources of fecal coliform (RWQCB 2001). In another 2001 study, researchers found that concentration and loading of fecal coliform in creeks near a representative dairy was three times higher than that from a control watershed (Lewis et al. 2001). However, high levels of fecal coliform observed in San Geronimo Creek, which is not heavily agricultural, and Point Reyes Station storm drains indicates that developed areas cannot be discounted as a source (Ketcham 2001).

While most previous studies loosely refer to dairy and beef cattle operations as a primary source of pathogens, the 2001 study by Lewis and colleagues (2001) attempted to better define which portions of agricultural operations might be causing problems. Results appeared to point at dairy facilities rather than pastures – even manured pastures – as the highest potential agricultural contribution to pathogen loading (Lewis et al. 2001). The worst offenders for fecal coliform included manure stockpiles, feed lots, storm drains, and facility runoff, with potential fecal coliform loading from runoff from manure stockpiles and feed lots two to sometimes three orders of magnitude greater than loading from other parts of dairy facilities (Lewis et al. 2001).

Project Area

Based on data collected between 2001- 2006, fecal coliform concentrations were one(1) to five (5) orders of magnitude greater in the Project Area than in undiked wetlands in Tomales Bay and elsewhere. Fecal coliform concentrations within of all Project Area sampling locations regularly to consistently exceeded TMDL standards proposed for the Lagunitas Creek watershed, with more than 72 percent of the sampling events having levels higher than 200 mpn/100 ml (Table 9). In addition to TMDL standards, fecal coliform concentrations also consistently exceeded the Basin Plan standards for shellfish and municipal surface water supply beneficial uses and regularly to consistently exceeded standards for water and even non-contact water recreation beneficial uses, with the Project Area portion of Lagunitas Creek and the Giacomini Ranch East Pasture exceeding 2,000 mpn/100 ml (non-contact water recreation standard) during more than 26-61 percent of the sampling events respectively (Table 9).

It should be noted that TMDL and Basin Plan standards are based on geometric means or medians for groups of samples collected over a specific sampling period (30 days), not single samples, but for the purposes of this document, both the number of objective exceedances by single samples and overall group means or medians were used to evaluate existing conditions within the Project Area. Most of the Basin Plan objectives focus on geometric means rather than arithmetic or the more traditional mean, because bacteria concentrations are calculated in a logarithmic –based scale that is more appropriately expressed as a geometric mean that divides the number of samples by the product rather than the sum of the values.

Lagunitas Creek

While pathogen levels were better in Lagunitas Creek than in some portions of the Project Area, pathogen indicators such as fecal coliform exceeded most of the Basin Plan and TMDL standards.

Fecal coliform in Lagunitas Creek consistently exceeded the TMDL load allocation for Lagunitas Creek at the Green Bridge, with values exceeding 95 mpn/100 ml in all of the sampling events (Table 9). Levels exceeded the 200 mpn/100 ml threshold established as the TMDL for Lagunitas Creek and other major creeks during approximately 72 percent of the sampling periods (Table 9). Some of the lower thresholds established as part of the Basin Plan objectives for beneficial uses such as shellfish harvesting (14 mpn/100 ml) and municipal water supply (20 mpn/100 ml) were exceeded during more than 98 percent of the sampling periods: the municipal water supply standards are more applicable to reaches of Lagunitas Creek upstream of the Green Bridge and Project Area where the NMWD groundwater wells are located adjacent to the creek. Exceedances of the highest thresholds, established for non-contact water recreation, of 2,000 and 4,000 mpn/100 ml were considerably less, ranging from 26 to 16 percent, respectively (Table 9).

Using statistical procedures for estimating summary statistics when data include values below or above the laboratory detection limit, estimated median fecal coliform concentrations for the Project Area portion of Lagunitas Creek were 584.6 mpn/100 ml (Figure 25): using these methods and a lognormal distribution, the geometric mean is approximately equivalent to the median value (D. Helsel, USGS, *pers.comm*.).   Based on this median or geometric mean, Lagunitas Creek consistently exceeded all Basin Plan and TMDL objectives (Table 9). The 90th percentile was estimated at 6,146.8 mpn/100 ml, which exceeded all 90th percentile standards (Figure 25, Table 9). Showing the influence of large loading events on arithmetic means, estimated concentrations averaged 3,153.1 ± 16,711.5 (SD) mpn/100 ml (Figure 25, Table 9). For just the upstream section of Lagunitas Creek at the Green Bridge, estimated median or geometric mean coliform concentrations were even higher than for the project reach as a whole – 955.3 mpn/100 ml, with the 90th percentile estimated at 5,852.7 mpn/100 ml.

As with nutrients, instantaneous loading rates for fecal coliform – or volume of coliforms relative to stream discharge -- remained consistently highest in Lagunitas Creek, although concentrations were almost always lower than many other Project Area sampling locations. The estimated median or geometric mean loading rate for the Project Area portion of Lagunitas Creek averaged 6,949.7 mpn/s (Figure 26). The 90th percentile for loading was estimated at 349,697 mpn/s (Figure 26). Median loading rates for the Green Bridge sampling site were slightly higher (12,430.6 mpn/s) than for the reach as a whole, with the 90th percentile estimated at slightly lower rates (261,067 mpn/s).

Similar to concentrations, the arithmetic mean for loading rates, which was estimated at 744,652 mpn/s, was skewed by some extremely high values, including a loading rate of approximately 10 million mpn/s during the April 2006 storm, which was approximately a 2.25-year flood event (Figure 26). In fact, the three highest loading rates during the four-year period were recorded on Lagunitas Creek. Estimated loading rates reached 786,432 mpn/s at the Green Bridge sampling location only one month later, with loading rates exceeding 672,282 mpn/s documented at the downstream sampling location in late April 2006. The late April 2006 sampling event also occurred after a series of storms, although it had rained little in the previous five (5) days (Table 3). (Of the top 33 highest estimated fecal coliform loading rates during the study, approximately 11 or 33 percent of them occurred during the late April 2006 sampling event.)

Most of the highest values occurred either during storm events or during the wet season – approximately 64 percent of them – however, higher loading rates were episodically recorded during the summer, with an estimated loading rate as high as 13,356 mpn/s in August 2005 in the downstream section of Lagunitas Creek and 7,680 mpn/s at the upstream location in July 2006. Both of these areas were subject to the influence of cattle, with cattle often in or adjacent to the creek directly upstream of the Green Bridge and crossing the creek midway through the Project Area reach as part of the Giacomini Ranch cattle operations. During synoptic sampling conducted in 2003, cow manure was observed in creek waters, with cows directly upstream (Appendix E). Two other peaks in estimated loading rates were documented during fall sampling events when there had been recent rain both immediately preceding the sampling event and/or in the preceding month (76,341.4 mpn/100 ml in October 2004 and 59,201 mpn/100 ml in October 2005). Both of these occurred at the upstream or Green Bridge sampling site.

Giacomini driving cattle across Lagunitas Creek in the 1950s

As was discussed with nitrates, patterns of loading for nutrients and pollutants from Lagunitas Creek are complicated by regulation of a large portion of the upper part of the watershed. Typically, downstream streamflow would increase once surrounding watershed soils are saturated and run-off increases, however, during the early part of the season, most of the flow is trapped behind dams in the upper part of the watershed. Water flows increase, but not as much as they would under unregulated conditions. In addition to trapping flow, these dams also undoubtedly capture some portion of the pathogen load, particularly those carried in suspension as particulate material. Once reservoirs reach close to capacity, which usually occurs after sufficient rainfall has occurred, more stormwater is allowed to bypass the reservoirs and flow downstream. The implication of this reservoir management program for pathogen loading is that large rainfall events on Lagunitas Creek may not necessarily correlate with the highest concentrations or loading rates as they might in unregulated watersheds.

Loading of fecal coliform at the upstream sampling site on Lagunitas Creek did not show a strong relationship with streamflow or recent rainfall amounts, but results of statistical analysis indicate that some relationship may exist with cumulative rainfall totals (MLE Regression, p=0.052, model p<<0.0001, model R^2=0.60; Figure 24). While loading did not appear to be linearly related with cumulative rainfall – despite regression results -- a closer examination of the data that includes some of the peak values discussed above suggests that some pattern still may have existed. From this graph, it would appear that loading rates were lowest (1,000 to 10,000 mpn/s) during the summer and early fall when no rain has occurred (Figure 24). They increased substantially in the early fall (~100,000 mpn/s) with recent rainfall, even if cumulative rainfall was low, perhaps in response to flushing of readily available sources of coliform bacteria. Later in the wet season, loading rates dropped to lower levels (1,000 – 10,000 mpn/s) even though cumulative rainfall totals were now higher. However, once rainfall totals reached 30-33 inches, loading rates began to increase exponentially, perhaps because more of the watershed flow – and pollutants – were being delivered downstream. The amount of data available does not allow for drawing any definitive conclusions, but preliminary findings suggest that the dynamics of coliform loading on Lagunitas Creek are not simple.

Seasonal patterns were not so clear with coliform concentrations, although the very highest or peak concentrations at both upstream and downstream sampling sites were recorded during storm events or the wet season. There was no relationship with streamflow, recent rainfall totals, or cumulative rainfall totals (MLE Regression, all p> 0.394, model 0.20>0>0.10; model R^2=0.11). In fact, higher concentrations were also observed during many other seasons of the year, pointing to sources other than storm-loading from upstream watershed sources such as cattle activity as also contributing to pathogen levels in the portion of Lagunitas Creek. As discussed earlier under Tomales Bay, a recent study by Lewis and Atwill (2007) on pathogen transport in five northern California estuaries, including the Lagunitas Creek subwatershed, found that Lagunitas Creek exhibited the highest counts of bacteria during dry season base flow conditions, which the authors felt pointed to a source of bacteria being directly discharged into the creek or, alternatively, tidal regime and high water residency time may be concentrating bacteria.

Unlike nitrates, no strong trend was discerned relative to fecal coliform concentrations or loading being reduced at downstream portions of the Project Area, although power of analyses may have been compromised by high data variability. Estimated median concentrations did appear to drop from 955.3 mpn/100 ml at the Green Bridge to 356.9 mpn/100 ml at the downstream location near the Giacomini Ranch North Levee, however, these differences may not be considered statistically significant (MLE Regression, n=38, df=1, Chi-Square=3.01, 0.10>p>0.05). Loading rates also suggested some downstream reductions, with estimated median rates dropping from 12,430.6 mpn/s at the Green Bridge to 2,533.1 mpn/s at the North Levee, but, again, analyses do not show conclusive differences (MLE Regression, n=30, df=1, Chi-Square=2.11, 0.20>p>0.10).

Giacomini Ranch

As has been described in other sections of this document, while both the East and West Pastures were used for dairying, land use and management was much more intensive in the East Pasture than the West Pasture, which was managed more as grazing land than a dairy pasture. Tomasini Creek, which was leveed to run alongside the East Pasture, had only minimal interaction with this pasture because of the levees, and it was not frequently used or visited by dairy herds. This different land use intensity is reflected in many of the water quality parameters assessed, including, not surprisingly, fecal coliform.

The East Pasture consistently (>98 percent of the samples) exceeded the thresholds established under the Basin Plan for shellfish harvesting (14 mpn/100 ml, Table 9). In fact, it exceeded the 90th percentile threshold for non-contact water recreation of 4,000 mpn/100 ml an estimated 55 percent of the time (Table 9). The estimated geometric or median of 6,298.8 mpn/100 ml exceeded all Basin Plan standards, as did the estimated 90th percentile of 307,254 mpn/100 ml (Table 9). Mean concentrations for the East Pasture were estimated at 626,889 ± 62,387,794 (SD) mpn/100 ml, a six (6) order of magnitude difference from the median or geometric mean (Figure 25, Table 9). Of the 10 highest concentrations recorded during the study, all of them occurred in the East Pasture (>16,000 mpn/100ml): Concentrations as high as 160,000

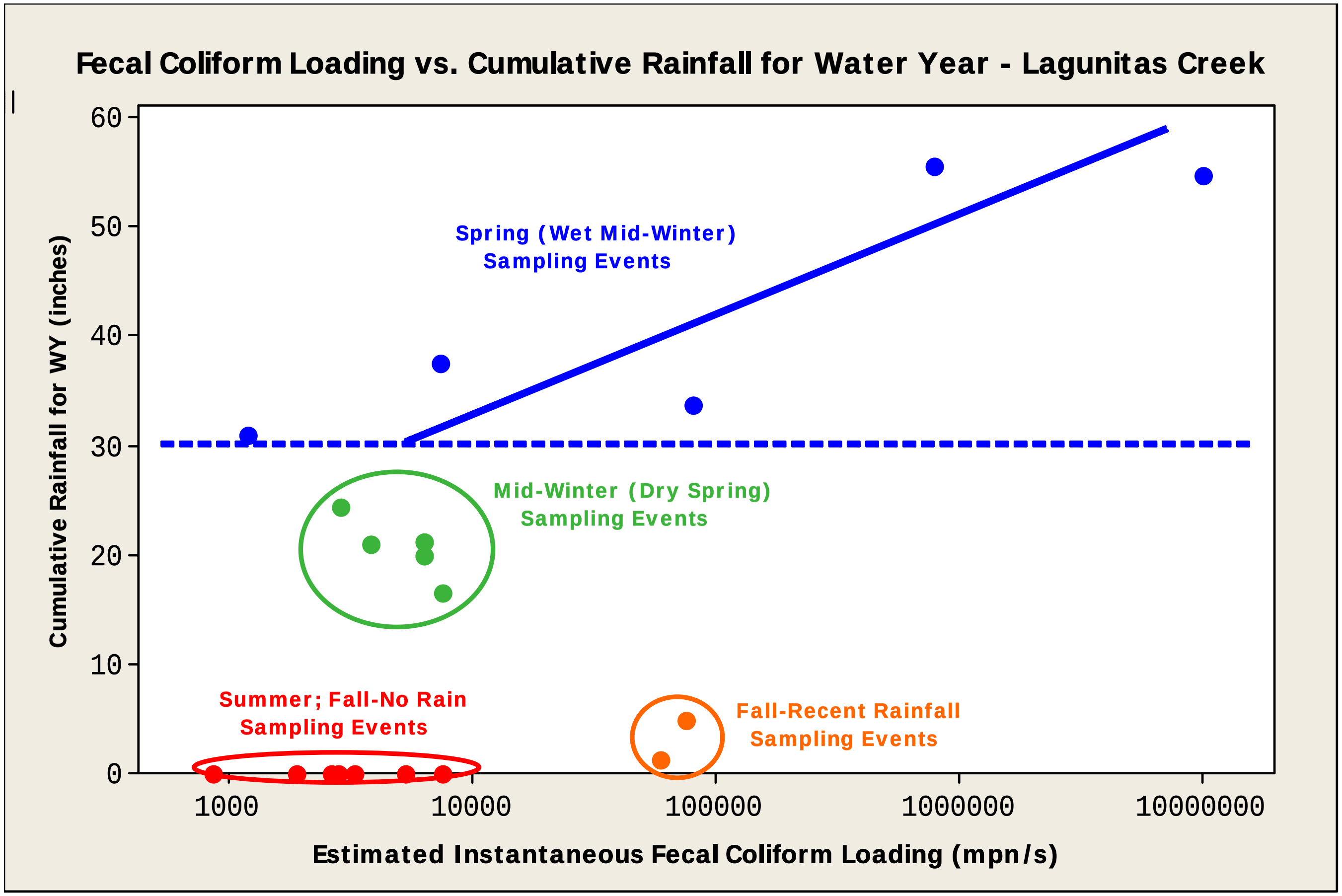


FIGURE 24. Estimated instantaneous fecal coliform loading rates at the upstream sampling site on Lagunitas Creek versus cumulative rainfall for the water year (Yr. Oct. 1-Sept 30; MLE Regression, $p<0.001$; Overall Model $p<0.0001$, $R^2=0.60$). Sampling events listed in parentheses refer to more infrequent sampling events.

mpn/100ml or even exceeding 160,000 mpn/100ml frequently occurred in one of the drainage ditches in the East Pasture and another ditch that receives stormwater run-off from the town of Point Reyes Station, as well as potentially septic-influenced groundwater.

Most of the other Project Area subsampling areas also consistenly exceeded Basin Plan standards for shellfish harvesting and municipal water supply, ranging from 97 percent to 98 percent of the time for Tomasini Creek and the West Pasture, respectively. However, the upper range of coliform levels in these subsampling areas was compressed relative to the East Pasture: while the East Pasture exceeded contact water recreation standards of 200 mpn/100 ml 84 percent of the time, Tomasini Creek and the West Pasture only exceeded these standards 69-71 percent of the time, respectively (Table 9). For the non-contact water recreation, the contrast becomes even sharper, with the 90th percentile standard of 4,000 mpn/100 ml only exceeded 18 percent (Tomasini Creek) to 22 percent (West Pasture) of the time, compared to 55 percent of the time in the East Pasture (Table 9). Downstream portions of Fish Hatchery Creek in the West Pasture occasionally (~30 percent of the time or 5 sampling events) had concentrations equaling or exceeding 16,000 mpn/100 ml and once even had concentrations exceeding 160,000 mpn/100 ml in July 2003. No other sampling location in the West Pasture or Tomasini Creek had concentrations equaling or exceeding 16,000 mpn/100 ml during more than three sampling events.

The geometric means or medians for the other subsampling areas were also significantly lower than that of the East Pasture, with levels estimated at 562 mpn/100 ml for Tomasini Creek and 1,131.7 mpn/100 ml for the West Pasture (MLE Regression, n=229, df=4, Chi-Square=28.3, p<0.0001; Z-tests all p<0.0001, Figure 25, Table 9). These estimates exceed all Basin Plan objectives, except for non-contact water recreation. The 90th percentiles were estimated at 7,794.9 mpn/100 ml for Tomasini Creek and 11,558.2 mpn/100 ml for the West Pasture (Table 9). Again, as with the East Pasture, these exceeded all Basin Plan standards. Interestingly, the disparity between the geometric and arithmetic means was slightly less marked than it was for the East Pasture, with arithmetic means only five (5) orders of magnitude larger than the geometric means (range = 4,614.1 ± 37,603.3 (SD) mpn/100 ml in Tomasini Creek and 6,835.0 ± 55,555.6 (SD) mpn/100 ml for the West Pasture) compared to the six (6) orders of magnitude difference in these statistics for the East Pasture.

No exceptionally strong trend was visible between season and coliform concentrations in the Giacomini Ranch, with many of the highest estimated concentrations occurring in the East Pasture during the summer months. The muted tidal areas in the West Pasture and Tomasini Creek showed more instances of concentrations being higher in the wet season or during rainfall events, although concentrations were sometimes elevated during other periods, as well. For the East Pasture, concentrations almost seemed lower during the winter or rainfall events, perhaps because these waters diluted coliform concentrations. Of the 10 highest concentrations recorded during the study – all of which, as noted earlier, occurred in the East Pasture – all took place during summer, fall, and, to a lesser extent, spring sampling events.

In contrast to concentrations, the East Pasture had the lowest loading rates, because it was completely disconnected from Lagunitas Creek with inflow from the creek and outflow to the creek only occurring during moderate to large storms when the levees overtopped and, in the case of outflow, when the Giacominis pumped ditch waters to downstream portions of Lagunitas Creek. Estimated medians for instantaneous loading rates for other Project Area creeks were moderate – 504.5 mpn/s for Tomasini Creek and 64.8 mpn/s for the West Pasture (Figure 26). There was more disparity in the 90th percentile loading rates, which were estimated at 321,775 mpn/s for Tomasini Creek and only 5102.4 mpn/s for the West Pasture. The Tomasini Creek median reflects several peak loading events of 353,324.2 mpn/s and at least 77,033.6 mpn/s in downstream and upstream creek sections in late April 2006, as well as 90,202.6 mpn/s in the upstream section in April 2006. There were also several other large loading events on Tomasini Creek with rates ranging from 8,641.0 to 27,833.9 mpn/s in January and October 2004.

All of these peak loading events for Tomasini Creek occurred either after storms or during the wet season. Some of the highest values for Giacomini Ranch creeks, drainages, and other water features or sources occurred several weeks after a large series of storms in late April 2006, with instantaneous loading rates totaling 7,200.9 mpn/s for the 1906 Drainage and 11,558.31 mpn/s for Fish Hatchery Creek upstream of the Project Area. In general, estimated geometric mean loading rates during all four years of monitoring for creeks flowing into the Project Area ranged from 28.0 mpn/s for the 1906 Drainage to 307.4 mpn/s for Fish Hatchery Creek, while portions of the Project Area affected by high concentrations of fecal coliforms in groundwater inflow and/or non-point source run-off had estimated mean instantaneous loading rates ranging from as low as 1.46 mpn/s to as high as 458 mpn/s.

As with Lagunitas Creek, no definitive conclusions could be reached about upstream-downstream trends in fecal coliform concentrations or loading in Tomasini Creek. There were no statistically significant differences between estimated average upstream and downstream concentrations for Tomasini Creek (591.4 mpn/100 ml vs 532.8 mpn/100ml; MLE Regression, n=39, df=1, Chi-Square=0.03, p>0.20). The same was seemingly true of loading, although estimated median downstream rates of 387.2 mpn/s seemed lower than the estimated median upstream rates of 771.8 mpn/s (MLE Regression, n=21, df=1, Chi-Square=0.02, p>0.20). Large variability definitely reduced power of statistical analyses of loading data, but it is difficult to determine whether this variability masked true upstream-downstream differences.

Conversely, for Fish Hatchery Creek, estimated median concentrations actually appeared to increase in a downstream direction (777.4 mpn/100 ml vs 2,459 mpn/100 ml), however, again, these differences may not be considered statistically significant (MLE Regression, n=38, df=1, Chi-Square=2.94, 0.10>p>0.05). Similarly, differences in estimated loading may also not be statistically significant, although, if there was a trend, it was seemingly reversed relative to concentrations, with upstream rates estimated at 863.1 mpn/s and downstream rates, 98.9 mpn/s (MLE Regression, n=23, df=1, Chi-Square=3.30, 0.10>p>0.05). Large variability in loading rates during storms undoubtedly hamper the ability of these analyses to detect true differences, even if they exist.

Olema Marsh

Despite the fact that Olema Marsh is not directly within or below a dairy, fecal coliform concentrations were relatively high in the marsh, which is the downstream reach of Bear Valley Creek prior to its confluence with Lagunitas Creek. Olema Marsh may be affected by some ranching operations upstream, livestock influences from horses being present on Bear Valley Trail adjacent to the creek, and leaking septic from adjacent residential development.

Fecal coliform levels regularly exceeded Basin Plan and TMDL standards for shellfish harvesting, municipal water supply, and water contact recreation, with approximately 81 percent of the sampling events having values greater than 200 mpn/100 ml (Table 9). The non-contact water recreation Basin Plan objectives of 2,000 mpn/100ml to 4,000 mpn/100ml were exceeded during 39 percent of the sampling events (Table 9). The geometric mean or median for Olema Marsh for the period of 2004-2006 was estimated at 1,821.4 mpn/100 ml, with the 90th percentile estimated at 13,346.8 mpn/100 ml (Figure 25, Table 9). These values exceeded all TMDL and Basin Plan bacteria standards or objectives. As with the West Pasture and Tomasini Creek, the disparity between the geometric and arithmetic means was not quite as marked for Olema Marsh as it was for the East Pasture, with the arithmetic mean (7,080.2 ± 41,922.5 (SD) mpn/100 ml) only five (5) rather than six (6) orders of magnitude larger than the geometric mean (Figure 25, Table 9).

The geometric mean for instantaneous loading of coliform during the two years of sampling was estimated at 885.2 mpn/s, with the 90th percentile estimated at 89,857.1 mpn/s (Figure 26). As with many of the other sites, large loading events skewed the arithmetic mean substantially, with the average estimated at 587,865 ± 3.9 X 10^{8} mpn/s (Figure 26). At the upstream end of the marsh adjacent to Bear Valley, loading rates peaked at an 948,049.9 mpn/s in the late April 2006 sampling event, with the rest of periods having rates usually much lower than 2,534.7 mpn/s (July 2006). Conversely, rates did not peak as high at the downstream end of the marsh near Levee Road – 15,643.8 mpn/s in July 2006 being the highest value – but many of the other estimated rates were pretty high, as well: 9,631.9 mpn/s in late April 2006, 9,670.3 mpn/s in October 2005, and 7,271.0 mpn/s in October 2004.

Not surprisingly, given these numbers, estimated median loading rates actually appeared to increase in a downstream direction from 498.4 mpn/s at the upstream site to 2,273.8 mpn/s at the downstream site, but strong variability compromised our ability to draw any definitive conclusion about differences (MLE Regression, n=17, df=1, Chi-Square=0.828, p>0.20). Estimated median concentrations also showed no definitive differences between upstream (749.8 mpn/100 ml) and downstream (1,821.4 mpn/100 ml) sampling sites (MLE Regression, n=18, df=1, Chi-Square = 1.09, p>0.20). In fact, there were only two instances where downstream loading was lower than upstream loading, and one of these periods occurred during late April 2006, after a fairly wet spring.

This increase in downstream concentrations and loading suggest that there are some additional inputs to this marsh system other than simply loading from upstream sections of Bear Valley Creek during stormflow and baseflow conditions. Typically, vegetated marshes with a mix of shallow vegetated and open water areas that water detention times typically exceeding 10 days have been shown to have very high rates of fecal coliform removal – as high as 90 percent (Kadlec and Knight 1996): the small drainages and groundwater that flow off the Inverness Ridge into the west end of the marsh may be influenced by leaking septic systems. Also, coliforms could result from wildlife use of the marsh or even some type of cycling of pathogens previously trapped in the peat-dominated sediments.

Reference Areas

Based on use of fecal coliform as an indicator, pathogenic levels in Reference Areas appeared lower than in the Project Area. As a whole, concentrations during more than 66 percent of the sampling events did exceed Basin Plan standards for shellfish harvesting (14 mpn/100 ml) and municipal water supply (20 mpn/100 ml, Table 9). However, only 34 percent actually exceeded the threshold of 200 mpn/100 ml for contact water recreation, a considerable difference from the Project Area, where, collectively, more than 75 percent of the samples exceeded this value (Table 9). The percentage of exceedances drops even further for non-contact water recreation, with only approximately 7 to 11 percent of the samples exceeding 4,000 and 2,000 mpn/100 ml, respectively.

There was some variation among Reference Areas in the percentage of samples exceeding thresholds established under the Basin Plan objectives. The Undiked Marsh north of Giacomini Ranch exceeded more of the various thresholds than did Walker Creek Marsh and Limantour Marsh (Table 9). For example, 89 percent of samples from the Undiked Marsh exceeded 20 mpn/100 ml, compared to 52- to 57 percent for Limantour Marsh and Walker Creek Marsh, respectively. Furthermore, 63 percent of the samples from the Undiked Marsh had values larger than 200 mpn/100 ml, and 29 percent exceeded 2,000 mpn/100 ml, compared to 22 percent and 5 percent, respectively, for Walker Creek Marsh and 12 percent and <1 percent, respectively, for Limantour Marsh (Table 9).

Because values were generally low, Walker Creek Marsh and Limantour Marsh actually came close to meeting Basin Plan standards for municipal water supply. Estimated geometric means for these marshes were 33.3 mpn/100 ml and 23.1 mpn/100 ml, respectively (Figure 25, Table 9). In addition, Limantour Marsh would have met the 90th percentile for contact water recreation of 400 mpn/100 ml, with an estimated 90th percentile of 245.2 mpn/100ml, while the estimated 90th

percentile for Walker Creek Marsh – 849.3 mpn/100 ml – would have fallen below at least the 90th percentile threshold for non-contact water recreation (4,000 mpn/100 ml, Figure 25, Table 9).

Conversely, the estimated geometric mean or median for the Undiked Marsh of 478.6 mpn/100 ml exceeded all but the non-contact water recreation standard (2,000 mpn/100 ml), and the estimated 90th percentile – 13,953.6 mpn/100 ml – exceeded all Basin Plan standards (Figure 25, Table 9). Differences between the geometric mean for the Undiked Marsh and those for the other marshes were highly significant (MLE Regression, n=150, df=2, Chi-Square=41.2, $p<<0.0001$), with Limantour Marsh and Walker Creek Marsh considered equivalent (Z-test, p=0.45). Arithmetic means for all the reference marshes exceeded medians considerably, ranging from 126 ± 680.3 (SD) mpn/100 ml for Limantour Marsh to 13,953.6 ± 487,137 (SD) mpn/100 ml for the Undiked Marsh (Figure 25, Table 9).

This same pattern holds true for coliform loading. The Undiked Marsh had the highest estimated median loading rates at 274.3 mpn/s, followed by Walker Creek Marsh with 118.6 mpn/100 ml and Limantour Marsh with 24.9 mpn/s (MLE Regression, n=110, df=2, Chi-Square=6.36, $0.05>p>0.02$, Figure 26). Again, differences between Limantour Marsh and Walker Creek Marsh were not considered significant (Z-test, p=0.073). The 90th percentiles for loading in these marshes were estimated at 50,676.8 mpn/s for the Undiked Marsh, 16,128.4 mpn/100 ml for Walker Creek Marsh and 397.3 mpn/s for Limantour Marsh. The large standard deviations and large differences between geometric means and arithmetic means -- ranging from 257.8 ± 2,661.1 (SD) mpn/s for Limantour Marsh to $1.10 \times 10^6 \pm 4.37 \times 10^9$ (SD) mpn/s for the Undiked Marsh -- indicates, as with many other sites and parameters, that coliform loading is highly influenced by peak flow events (Figure 26).

Almost all of the peaking loading events in the Reference Areas occurred during storm events or the wet season, with only a few occurring in the summer. The highest value recorded in Reference Areas took place on a section of Fish Hatchery Creek well downstream of the Giacomini Ranch close to Inverness, where estimated loading rates reached 336,803 mpn/s during the late April 2006, after a series of large storm events, although it had rained little during the previous five (5) days (Table 3). The second highest value came from a large interior tidal marsh channel in the Undiked Marsh that receives most of its direct hydrologic influence from the Bay except during times of flooding: rates reached at least 142,503.4 mpn/s in this channel during January 2005. High values were also recorded on the mainstem of Walker Creek during the late April 2006 and January 2005 sampling events – ≥ 127,947.4 mpn/s and 35,736 mpn/s, respectively. A section of Fish Hatchery Creek directly downstream of the Giacomini Ranch also displayed some large loading rates at times, with peak values of 25,804.8 mpn/s in October 2005 and ≥ 16,124.9 mpn/s in late April 2006. Approximately 5 inches of rain fell before the October 2005 sampling event.

While the fact that the Undiked Marsh appears to have generally higher coliform concentrations and loading than the other marshes would suggest that, perhaps, the marsh was unduly influenced by inflow from the Giacomini Ranch West Pasture, closer evaluation of estimated loading rates would suggest that this is not necessarily the case. During two events in 2006, loading rates generally did not show an appreciable change in median rates from the upstream to downstream portions of Fish Hatchery Creek in the Giacomini Ranch, but often climbed sharply in the section outside the ranch. For example, in August 2005, loading rates were 6,300.5 mpn/s at the upstream site near Sir Francis Drake Boulevard. They dropped to 460.8 mpn/s at the downstream end of Fish Hatchery Creek in the West Pasture, climbed up to 8,736 mpn/s just downstream of the Giacomini Ranch, and peaked at 16,742.4 mpn/s at the furthest downstream site near Inverness. Sampling at these sites were conducted within a few days of each other during summer baseflow conditions.

These results suggest that the higher coliform concentrations and loading rates in the Undiked Marsh did not necessarily result entirely from downstream loading from the Giacomini Ranch. Many small drainages and groundwater flow off the Inverness Ridge into the western edge of the marsh, specifically Fish Hatchery Creek, which hugs this western edge. The small subwatersheds support rural residential development, which may influence surface flow and groundwater through leaking septic systems. In addition, the marsh also becomes more hydrologically connected to Lagunitas Creek during higher high tide and flood events, when floodwaters often blanket the entire marsh surface. Lastly, many of the areas also receive inputs from Tomales Bay itself, particularly during summer months, when the freshwater inflow rates drop and allow more tidal waters to move up the estuary.

Comparison Between Project Area and Reference Areas

The Project Area had substantially higher estimated median concentrations of fecal coliforms (1,600.9 mpn/100 ml) than the Reference Areas (72.0 mpn/100 ml; Z-test, $p<0.001$), although seeming differences with Upstream Areas (637.1 mpn/100 ml) might have been obscured to some degree by high variance in the data (Z-test; $p=0.025$; MLE Regression, $n=379$, $df=2$, Chi-Square=98.5, $p<<0.0001$, Figure 25, Table 9). Within only the Project Area, significant differences existed among estimated geometric means or medians between subsampling areas, with the East Pasture (6,298.8 mpn/100 ml) significantly different from all groups except Olema Marsh (1,821.4 mpn/100 ml: Z-test, $p=0.3$; Overall MLE Regression, $n=133$, $df=4$, Chi-Square=20.6, $p<<0.0001$). Estimated geometric means or medians for all other subsampling areas ranged between 356.9 mpn/100 ml for downstream Lagunitas Creek to 1,131.7 mpn/100 ml for the West Pasture (Z-tests, $p<0.005$). (This analysis does not include upstream sampling sites included in Upstream Areas).

In terms of compliance with Basin Plan or TMDL standards, more than 90 percent of all samples collected from the Project Area – this time, including upstream sites – exceeded objectives for shellfish harvesting and municipal water supply of 14 - 43 mpn/100 ml (Table 9). Seventy-eight (78) percent exceeded contact water recreation standards of 200 mpn/100 ml, and 36 to 47 percent of the values actually were higher than 4,000 to 2,000 mpn/100 ml, respectively, the standards for non-contact water recreation (Table 9). Estimated geometric means or medians calculated using for four years of sampling results showed that, taken collectively, all of the Project area subsampling areas exceeded all Basin Plan standards, including the Project Area portion of Lagunitas Creek (Table 9).

Lagunitas Creek exceeded the TMDL standard of 200 mpn/100 ml during 72 percent of the sampling events and the 90^{th} percentile standard of 400 mpn/100 ml 58 percent of the time, with the overall geometric mean and 90^{th} percentile estimated at 584.6 mpn/100 ml and 6,146.8 mpn/100 ml. (Table 9) The TMDL load-based allocation of 95 mpn/100 ml set for Green Bridge location on Lagunitas Creek was never met during the study period sampling events (Table 9).

In comparison, 34 percent of Reference Area samples exceeded contact water recreation standards, and only 11 percent exceeded non-contact water recreation standards (Table 9). Two of the marshes came close to meeting objectives for shellfish harvesting or municipal water supply, with estimated geometric means of 33.3 mpn/100 ml (Walker Creek Marsh) and 23.1 mpn/100 ml (Limantour Marsh; Figure 25, Table 9). These medians are significantly lower than that for the Undiked Marsh (478.6 mpn/100 ml; MLE Regression, $n=150$, $df=2$, Chi-Square=41.2, $p<<0.0001$; Z-test, $p<0.001$; Figure 25, Table 9). While Walker Creek had a similar geometric or median to Limantour, the differences between these marshes is clearer from arithmetic means, with Limantour Marsh having a lower arithmetic mean (126.3 ± 56.2 (SE) mpn/100 ml) than Walker Creek Marsh (812.8 ± 630.6 (SE) mpn/100 ml, Figure 25, Table 9). The Undiked Marsh exceeded all mean-related objectives (Table 9). In terms of the 90^{th} percentiles, Limantour Marsh (245.2 mpn/100 ml) met standards for contact water recreation, if not shellfish harvesting (43 mpn/100 ml); Walker Creek Marsh (849.3 mpn/100 ml) met standards for non-contact water recreation, and the Undiked Marsh (13,953.6 mpn/100 ml) exceeded all percentile-based objectives (Table 9).

Based on the estimated Reference Area population, the 95th percentile of coliform concentrations fell around 6,201.3 mpn/100 ml (Table 9). Interestingly, only 28 percent of the Project Area estimated concentrations exceeded this percentile. Approximately 48 percent of the Project Area coliform levels exceeded the highest 16.7 percent of values estimated for the Reference Area (~1,482 mpn/100 ml), which falls slightly below the 50 percent threshold for this progress criterion (Table 9). The coefficient of variation was estimated at 0.54, well above the 0.2 threshold characterized as having low variability.

Upstream Areas displayed more similarity to the Project Area than to Reference Areas in terms of Basin Plan exceedances. More than 94 percent of all sampling events had coliform levels that exceed shellfish harvesting and municipal water supply standards, compared to 92 percent for the Project Area (Table 9). Contact water recreation standards of 200 mpn/100 ml were exceeded approximately 75 percent of the time in Upstream Areas compared to 78 percent of the time in the Project Area, while standards of 400 mpn/100 ml were exceeded 60 (Upstream Areas) to 69 (Project Area) percent of the sampling periods (Table 9). Geometric mean (637.1 mpn/100 ml), mean (2,906.9 ± 12,940.5 mpn/100 ml), and 90th percentile (5,942.4) exceeded all Basin Plan standards, just as did those for the Project Area (Figure 25, Table 9).

Where the Upstream Areas diverge from the Project Area is in the percentage of highest values. While 47 percent of the Project Area sampling events had coliform levels exceeding 2,000 mpn/100 ml, only 26 percent of the sampling events in Upstream Areas showed levels this high (Table 9). This disparity between Study Areas only widens as numbers grow larger. Approximately 36 percent of sampling events in the Project Area had levels exceeding 4,000 mpn/100 ml, while only 16 percent of those in Upstream Areas exceeded that concentration (Table 9). This same trend is apparent in the Sub-Group Sampling Areas for the Project Area and the Undiked Marsh Reference Area. While percent exceedances are very similar between areas for coliform levels equal to or below 200 mpn/100 ml, with 69 to 84 percent of samples exceeding this concentration, most areas begin to diverge from the East Pasture around 400 mpn/100 ml, with the disparity even sharper at higher concentrations (Table 9). For example, 55 percent of the East Pasture samples exceeded 4,000 mpn/100 ml, compared to only 16 (Lagunitas Creek) to 27 percent (Olema Marsh) of the other sub-group sampling areas (Table 9). Based on these results, it would appear that the effect of intensive dairying in the East Pasture may be evident principally in the larger dispersion of data in the upper portion of the data range. The high percentage of values in the lower portion of the data range present in all of the Project Area and adjacent Reference Area sampling sites may represent "background" noise in this subwatershed related to pollutant loading from other pollutant sources.

Estimated instantaneous loading rates differed significantly between the Project Area and Upstream Areas (Z-test, p=0.001), although not between the Project Area and Reference Areas (MLE Regression, n=275, df=2, Chi-Square=10.7, 0.01>p>0.001, Figure 26). Estimated loading rates averaged 3.86 ± 6.5 million (SE) mpn/s for Upstream Areas; 249,389 ± 369,023 (SE) mpn/s for the Project Area; and 60,094.1 ± 61,273.8 (SE) mpn/s for Reference Areas (Figure 26). Median loading rates were considerably smaller, again showing the influence of pulses during the winter or wet season sampling events. Medians were estimated as 437.2 mg/s for Upstream Areas, 56.0 mpn/s for the Project Area, and 98.3 mpn/s for Reference Areas.

Within the Project Area (e.g., excluding upstream sampling sites), estimated loading rates also varied significantly, with the East Pasture being lower than all other subsampling areas (MLE Regression, n= 91, df=4, Chi-Square=53.6, p<0.0001). Downstream Lagunitas Creek had the highest estimated mean instantaneous loading rate (3.12 ± 1.10 million (SE) mpn/s), followed by Tomasini Creek (1.81 ± 8.16 million (SE) mpn/s), Olema Marsh (254,691 ± 753, 607 (SE) mpn/s), and the West Pasture (8,766.9 ± 14,556.7 (SE) mpn/s). Median loading rates were much lower and closer together, with values estimated at 2,533.1 mpn/s for downstream Lagunitas Creek, 2,273.8 mpn/s for Olema Marsh, 387.2 mpn/s for downstream Tomasini Creek, and 55.5 mpn/s for the West Pasture. These numbers will not correspond with loading rates discussed earlier, because they exclude upstream sampling sites.

Unlike nitrates, no clear pattern emerged between upstream and downstream concentrations and loading rates for fecal coliform on some of the major Project Area creeks, including Lagunitas Creek, Fish Hatchery Creek, Tomasini Creek and Bear Valley Creek in Olema Marsh. In some cases, variance in the data appeared to be large enough to potentially mask any potential differences and lessen power of statistical analyses (e.g., concentration and loading rates in Lagunitas Creek and loading rates in Tomasini Creek and Fish Hatchery Creek). For example, in Lagunitas Creek, estimated median concentrations appeared to drop from 955.3 mpn/100 ml at the Green Bridge to 356.9 mpn/100 ml near the Giacomini Ranch North Levee, and loading rates seemingly also dropped, with estimated median rates dropping from 12,430.6 mpn/s at the Green Bridge and 2,533.1 mpn/s at the North Levee, however, neither of these differences might be considered statistically significant (MLE Regression, $p>0.05$).

In other cases, results appeared to point to actually an increase in concentrations, loading, or both at downstream locations, however, as with the other analyses, statistical results were not conclusive. In Fish Hatchery Creek, estimated median concentrations actually appeared to increase downstream (777.4 mpn/100 ml at upstream location vs 2,459 mpn/100 ml at downstream location; MLE Regression, $n=38$, $df=1$, Chi-Square=2.94, $0.10>p>0.05$). Both median loading and concentrations appeared to increase at downstream locations in Olema Marsh: This suggests that there are some additional inputs to this marsh system other than the upper portions of the Bear Valley Creek watershed, such as septic-influenced surface water and groundwater flowing from the Inverness Ridge into the west end of the marsh, wildlife use of the marsh, and potentially internal recycling. Also, retention rates may vary in some systems depending on flow and loading volume, with higher retention rates correlated with larger flow or loading events.

Loading rates also differed considerably between Reference Areas (MLE Regression, $n=110$, $df=2$, Chi-Square=7.8, $0.05>p>0.02$, Figure 26). Estimated instantaneous loading rates averaged 1.1 ± 2.46 million (SE) mpn/s in the Undiked Marsh; 184,175 ± 371,930 (SE) mpn/s in Walker Creek Marsh; and 257.8 ± 182.4 (SE) mpn/s in Limantour Marsh (Figure 26). The disparity between median loading rates was not quite as striking, with the Undiked Marsh estimated at 274.3 mpn/s; Walker Creek Marsh, 118.6 mpn/s; and Limantour Marsh, 24.9 mpn/s (Figure 26). The highest value recorded in Reference Areas occurred in the Undiked Marsh on Fish Hatchery Creek near Inverness, where estimated loading rates reached 336,803 mpn/s during late April 2006. High values were also recorded on the mainstem of Walker Creek during the late April 2006 and January 2005 sampling events – ≥ 127,947.4 mpn/s and 35,736 mpn/s, respectively.

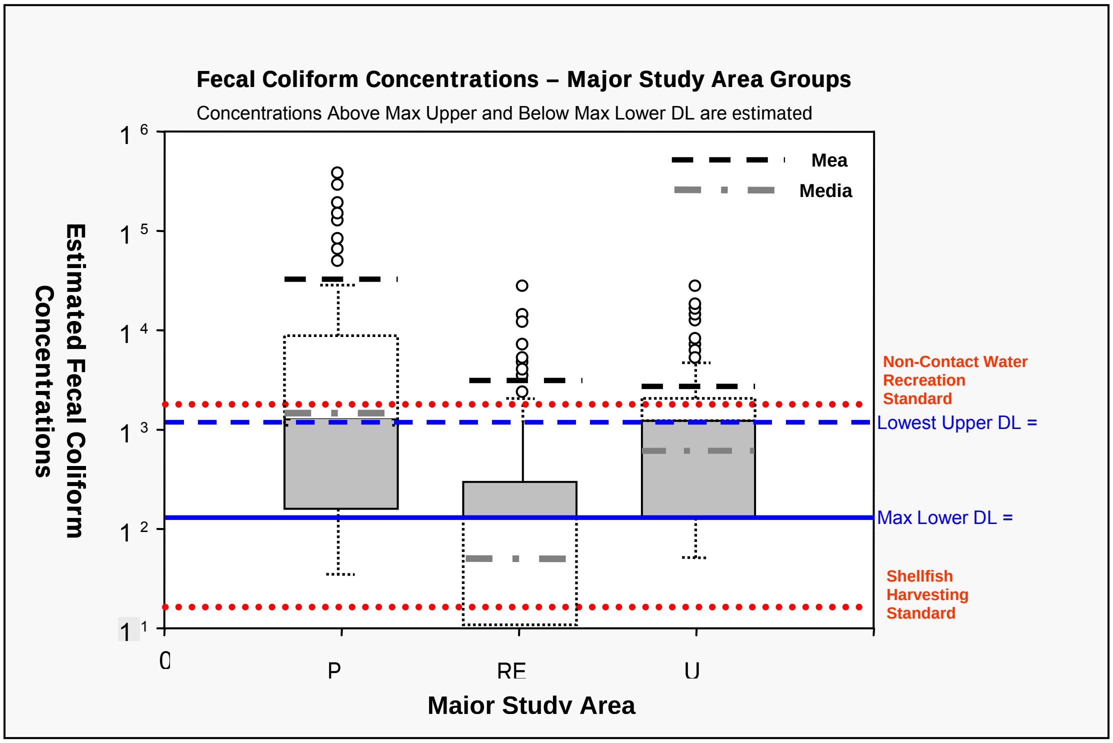
The 95th percentile for loading within Reference Areas as a whole was estimated at 35,596.7 mpn/s: approximately 5 percent of the Project Area rates exceeded this value (Figure 26). Approximately 19 percent of the rates estimated for the Project Area were also higher than the highest 16.7 percent of values estimated for the Reference Area (3,000 mpn/s), which falls below the 50 percent threshold established for this progress criterion. The coefficient of variation for this parameter greatly exceeds 1.

Seasonal patterns varied somewhat between concentrations and loading. While some of the highest levels in Lagunitas Creek were recorded during storm events or the wet season, there were spikes in concentrations also observed during many other seasons of the year, pointing to sources other than storm-loading from upstream watershed sources such as cattle activity as also contributing to pathogen levels in the portion of Lagunitas Creek. In the Giacomini Ranch East Pasture, many of the highest concentrations occurred during summer months, with concentrations seemingly diluted during winter or wet season sampling events. The muted tidal areas in the West Pasture and Tomasini Creek showed more instances of concentrations being higher in the wet season or during rainfall events, although concentrations were sometimes elevated during other periods, as well.

Loading rates showed more consistent fidelity with wet season or winter sampling events, although pulses occurred occasionally during dry season sampling events, as well. For Lagunitas Creek, most of the highest values occurred either during storm events or during the wet season – approximately 64 percent of them – however, higher loading rates were episodically recorded during the summer, with an estimated loading rate as high as 13,356 mpn/s in August 2005 in the downstream section of Lagunitas Creek and 7,680 mpn/s at the upstream location in July 2006. As noted above, both of these areas were subject to the influence of cattle, with cattle often in or adjacent to the creek directly upstream of the Green Bridge and crossing the creek midway through the Project Area reach as part of the Giacomini Ranch cattle operations. Some of the highest values for Giacomini Ranch and Reference Area creeks, drainages, and other water features or sources occurred several weeks after a large series of storms in late April 2006.

As was discussed with nitrates, patterns of loading for nutrients and pollutants from Lagunitas Creek are complicated by regulation of a large portion of the upper part of the watershed. Dams capture much of the flow during the early part of the season. Once reservoirs reach close to capacity, which usually occurs after there has been sufficient rainfall to fill reservoirs, more stormwater is allowed to bypass reservoirs and flow downstream. Because dams are probably capturing pathogen and nutrient loads, as well as flow, reservoir management greatly complicates the dynamics of pathogen and nutrient loading in this system relative to unregulated watersheds.

Fecal coliform loading was not strongly associated with either streamflow or recent rainfall (MLE Regression, $p>0.20$), but cumulative rainfall totals did show some relationship ($p=0.052$) with loading, albeit not a linear one (Figure 24). Based on the data, coliform loading appears to be lowest in the summer and dry season fall sampling events, increase substantially during early fall season rainfall events, decrease to lower levels during the mid-year wet season period, and then climb exponentially when cumulative rainfall reaches between 30-33 inches (Figure 24). This potential pattern could result from mobilization of readily available sources of coliform bacteria following the first rains in the fall, with loading rates then dropping to lower levels until rainfall reaches a sufficient volume to allow for more flows to bypass the upper reservoirs. The amount of data available does not allow for drawing any definitive conclusions, but preliminary findings suggest that the dynamics of coliform loading on Lagunitas Creek are not necessarily simple.



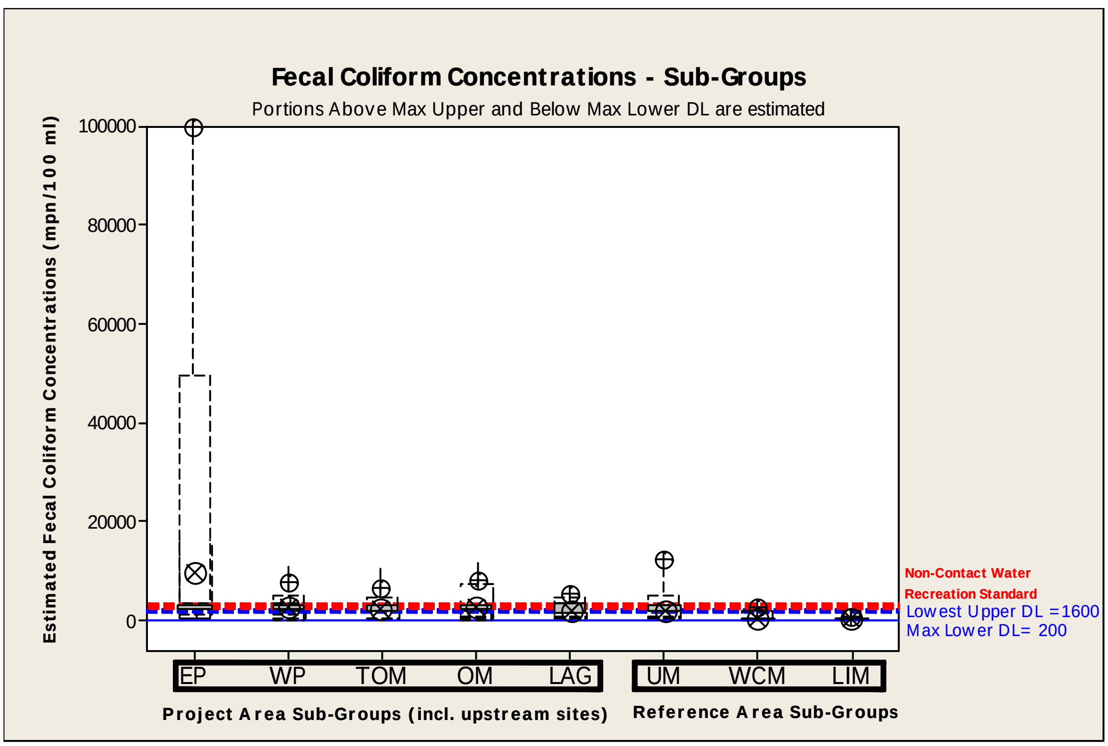
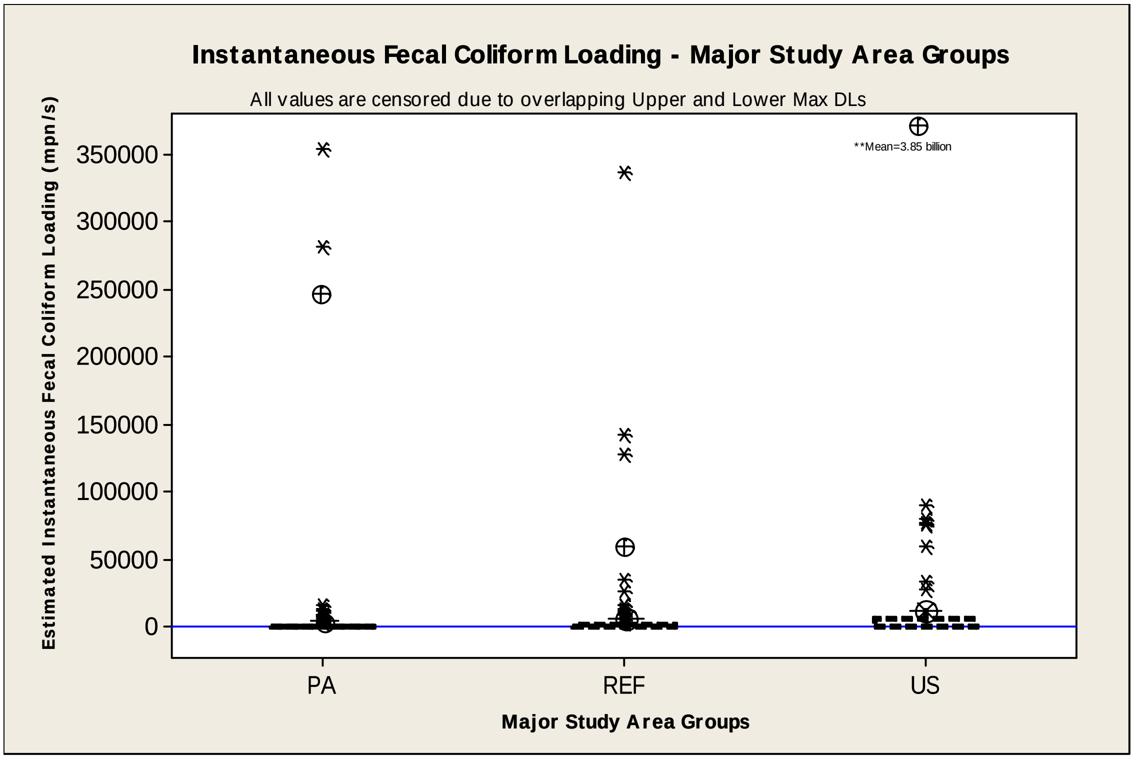


FIGURE 25. Estimated fecal coliform concentrations in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines -10th and 90th percentiles. The upper and lower maximum and minimum detection limits used for censoring data are shown with a blue line: Estimated values are shown in white; non-censored values are shown in grey. Basin Plan standards are shown with red line. In lower graph, means are represented with a cross-hatched circle, and medians, with a diagonal cross-hatched circle.



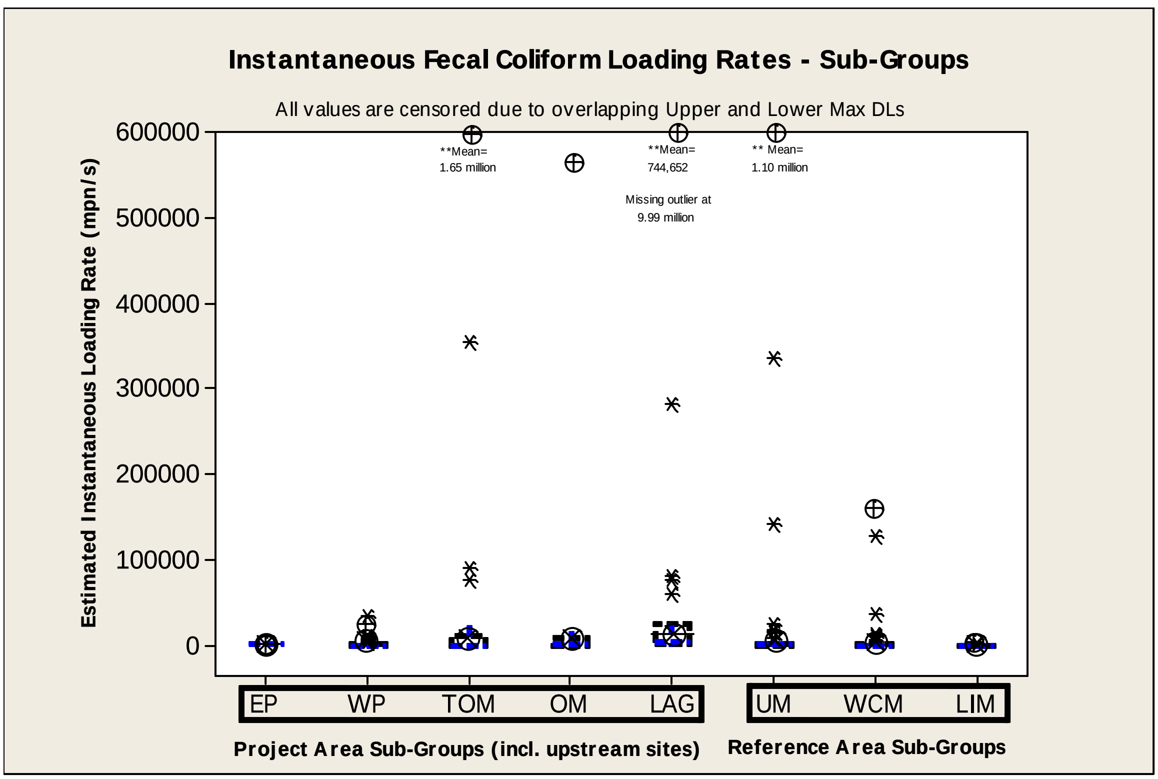


FIGURE 26. Estimated fecal coliform instantaneous loading in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Estimated values are shown in white; non-censored values are shown in grey. In lower graph, means are represented with a cross-hatched circle, and medians, with a diagonal cross-hatched circle.

TABLE 9. Summary data for fecal coliform concentrations – Giacomini Wetland Restoration Project pre-restoration water quality monitoring. Major Study Area Groups include Project Area (PA), Reference Areas (REF), and Upstream Areas (US). Project Area sub-groups in this chart include upstream sampling sites that are broken out as US in other analyses. Summary data are estimated using survival analysis statistical techniques recommended by Helsel (2005) for multiply censored or non-detect/exceed MDL data. Chart gives percentage of samples that exceeded Basin Plan or TMDL standards.

	Major Study Area Groups					Project Area Sub-Groups (including upstream sites)						Reference Area Sub-Groups		
	PA	*Range*	**REF**	**US**		**EP**	**WP**	**TOM**	**LAG**	**OM**		**UM**	**WCM**	**LIM**
Fecal Coliform (mpn/100 ml)														
Arithmetic Mean	47,018.5 3			2,906.9		626,899	6,835	4,614.1 3,1	53.1	7,080.2	1	5,272.3	812.8	126.3
Geometric Mean or Median[1]	1,600.9 7			637.1		6298.8	1,13 1.7	562.0	584.6	1,821.4		478.6	33.3	23.1
90th Percentile	42,926.4 2			5,942.4		307,254	11,558.2	7,794,9 6,1	46.8 13,34	6.8	1	3,953.6	849.3	245.2
Basin Plan: Shellfish: Median > 14 (%) 97			70	99		98	98	97	98	99		92	63	61
Basin Plan: Water Supply: *Geometric mean* > 20 (%)	95		66	98		97	97	95	97	98		89	57	52
Basin Plan: Shellfish: *90th* > 43 (%)	92		46	94		95	92	89	92	96		83	47	38
Basin Plan: Contact-Water: *Geometric mean* > 200 (%)	78		34	75		84	71	69	72	81		63	22	12
Basin Plan: Contact-Water: *90th* > 400 (%)	69		26	60		81	62	58	58	71		54	17	6
Basin Plan: Non-Contact-Water: *Mean* > 2,000 (%)	47		11	26		61	33	28	26	39		29	5	<1
Basin Plan: Non-Contact-Water: *90th* > 4,000 (%)	36		7	16		55	22	18	16	27		22	2	<1
TMDL: Lagunitas Creek: *Geometric mean* > 200 (%)									72					
TMDL: Lagunitas Creek: *90th* > 400 (%)									58					
TMDL: Lagunitas Creek @ ***Green Bridge***: *Geometric mean* >95 (%)									100					
5th	19.4	↕72%	0.6											
95th	111,698		6,201.3											
83.3rd	22,316.4	↓51%	1,482.0											
CV 0.54														

[1] When censored data are analyzed using MLE and a lognormal distribution, medians are equivalent to the geometric mean (D. Helsel, USGS, *pers. comm.*).

Estuarine Productivity in the Watershed and Project Area

One of the most compelling reasons for preserving wetlands has been their importance to estuarine and marine food webs and many of the commercially and recreationally valuable species that live in these coastal environments. In the 1970s-1980s, estuarine scientists advanced the “outwelling hypothesis” in which they asserted that the amount of organic matter produced by an estuary exceeded internal use by organisms and that some of this excess material was exported seaward through tidal flushing where it represented a cornerstone of the outer estuarine and marine food webs, substantially supporting coastal fisheries (Day et al. 1989).

Since some of this early work on Georgia salt marshes, there have been a number of studies further exploring the relationship between marshes, estuaries, and trophic or food chain support. The results of these studies have shown that the classic detrital food web paradigm does not necessarily hold universally true within systems or even within all portions of systems. Phytoplankton often plays a large role in supporting the transfer of energy in the food web, and there are complex interactions between detritus and bacteria, the latter of which usually represent the real food value for organisms, not the detritus itself (Day et al. 1989). To make the issue even more complicated, dead phytoplankton become part of the detrital pathway.

Many studies now show that systems are not necessarily dominated by just one energy-transfer mechanism. Some systems show spatial heterogeneity in trophic dependence upon either phytoplankton or detritus. In a Massachusetts estuary, the upper, more freshwater-dominated portions of the system showed a mixture of freshwater marsh vegetation and phytoplankton, while, in the middle and lower, more open water portions, consumers appeared to rely more on cordgrass (*Spartina* spp.), benthic microalgae, and marine phytoplankton (Deegan and Garritt 1997). In a Dutch estuary, the food web relied primarily on detritus in the upstream, brackish portions of the system, particularly around the estuarine turbidity maximum zone, while the downstream, seaward portions exhibited more of a dependence on seasonally fluctuating high primary production by phytoplankton (Hummel et al. 1988). Heterogeneity in the structure of the food web extends, not surprisingly, even to differences between consumer groups with benthic organisms in the Massachusetts system more dependent on detritus while pelagic organisms relied more on phytoplankton (Deegan and Garritt 1997);.

Turbid systems have been labeled by some as being more likely to have detritus as the primary pathway for energy transfer (Wolanski 2007). Phytoplankton productivity is limited in waters where sunlight cannot penetrate more than just surface waters. However, the San Francisco Bay-Sacramento Delta estuary, which is a very turbid system, has recently been characterized as being one in which primary production was the primary source of organic matter used in the Delta’s pelagic food web, even though production rates are comparatively very low, and detritus dominates riverine and estuarine organic matter supply and supports the majority of the estuary’s metabolism (Sobczak et al. 2005). Some of this reliance on phytoplankton may result from the fact that a higher proportion of the bioavailable organic matter comes from particulate organic carbon (POC), and phytoplankton was a large and important component of the bioavailable POC: POC is utilized within the metazoan food web at a much greater efficiency than DOC, because, whereas POC can be ingested directly, DOC must be routed through the so-called microbial loop (Sobczak et al. 2002). Riverine organic matter may be older and more recalcitrant and, therefore, less bioavailable (Sobczak et al. 2002).

Further study in the Delta has shown that zooplankton may be food-limited when chlorophyll a concentrations dip below 10 *u*g/liter: most Delta sampling locations consistently had concentrations at or below this threshold (Sobczak et al. 2002). This limitation has probably only been exacerbated by recent declines in phytoplankton biomass from overconsumption by an invasive clam species, Asian clam (*Potamocorbula amurensis*), which has changed phytoplankton dynamics in Suisun Bay (Alpine and Cloern 1992 *in* Jassby et al. 2003). This effect can cascade up through the food web, with lower phytoplankton levels causing declines in key zooplankton communities (Jassby et al. 2003).

Ironically, efforts to link fish food webs in restoring marshes of northern San Francisco Bay, which is just downstream of the Delta, with import of phytoplankton from the Bay were unsuccessful, with resident and potential transient fish species in both restoring and mature marshes relying primarily on internal or autochthonous marsh production, specifically organic matter derived from pickleweed (*Sarcocornia virginica*), Pacific cordgrass (*Spartina foliosa*), and alkali bulrush (*Schoenoplectus maritimus*; Howe and Simenstad undated).

As with nutrients, there can be too much of a good thing with both organic matter (DOC and POC) and algae. Systems where algae grows uncontrollably due to high nutrient influx, warm temperatures, and long water residency times often become eutrophic, causing wide swings in oxygen levels that can negatively affected and even kill fish. In addition, changes in pH associated with excessive oxygen production by phytoplankton can also trigger shifts in the chemistry of waters, helping to lead to the formation, for example, of unionized ammonia, which increases when both temperatures and pH increase. Unionized ammonia is toxic to aquatic organisms. In the recent evaluation of the health of the nation's estuaries by NOAA, a majority of the estuaries showed signs of eutrophication, with one of the most common symptoms of eutrophication being high chlorophyll a (Bricker et al. 2007). In addition, eutrophication can have seemingly more subtle effects on estuarine communities by leading to physical or biogeochemical changes that eventually cause shifts in invertebrate community structure and a reduction in the function and value of these areas for estuarine fisheries (Deegan 2002).

While organic matter represents an important part of the estuarine food web, high levels of organic matter can play havoc in systems where estuarine and riverine waters are also used for water supply. When disinfectants such as chlorine are added to drinking water to kill microbial pathogens, they react with bromide and organic matter to form disinection by-products. When these are consumed in excess over a number of years, they can have deleterious effects on the liver, kidneys, or central nervous system or may cause an increased risk of cancer or anemia (Bull and Kopfler 1991 *in* Jassby et al. 2003). In 2006, California Department of Health and Safety established disinfection by-products as a primary drinking water standard.

In terms of eutrophication or other water quality issues, there are no Basin Plan standards for receiving waters for chlorophyll a, DOC, or POC. There are also no numerical Basin Plan (1995) objectives for ambient turbidity conditions, which would be associated with phytoplankton productivity.

Tomales Bay

As was discussed earlier under nutrients, nutrient dynamics within Tomales Bay are driven by both oceanic and terrestrial forces. Tomales Bay is considered a heterotrophic estuary in that ecosystem respiration or conversion of organic matter from non-estuarine sources to inorganic nutrients exceeds external supply or internal production of inorganic nutrients by about 10 percent (Smith and Hollibaugh 1997b). Most of this converted organic matter is eventually either lost to the atmosphere or recycled internally, although some is exoorted to the ocean as phosphorous(Smith and Hollibaugh 1997b). As might be expected based on the seasonality of terrestrial and oceanic inputs, research has shown that the external supply of organic matter to Tomales Bay varies over seasonal and inter-annual time scales (Chambers 2000; Lewis et al. 2001).

Organic matter inputs into Tomales Bay come from terrestrial sources (50 percent) and the ocean (50 percent; Smith and Hollibaugh 1997b). Oceanic sources of organic matter come from upwelling or funneling of ocean-derived organic matter in offshore currents. The most intensive upwelling occurs during the summer, in response to strong, often persistent northwesterly winds (Smith and Hollibaugh 1997b). Upwelling elevates the concentration of particulate organic matter in the coastal waters, which is then delivered to the bay by tides and particle settling (Smith and Hollibaugh 1997b).

Terrestrial sources consist of organic matter, as well as sediment-bound and suspended forms of inorganic nutrients, from the surrounding watershed that flow into the Bay, typically during high rainfall periods. Most of this organic matter and inorganic nutrients enter the Bay through surface flows of its largest tributaries: as described earlier, Lagunitas Creek and its tributaries account for approximately two-thirds of the surface water freshwater inflow to the Bay, while Walker Creek and other small drainages account for the remaining one-third (Fischer et al. 1996). Some of the organic matter in surface waters -- and perhaps even groundwater depending on the discharge point -- flow through fringing and deltaic marshes on the perimeter of Tomales Bay before entering Bay waters. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that these systems act as sources of inorganic nitrogen and phosphorous to the Bay during the summer, probably due to breakdown of organic matter (Chambers et al. 1994b).

Internal sources of organic matter or inorganic nutrients to Tomales Bay are primarily represented by phytoplankton, macroalgae, and aquatic organisms through excretion and decay.

Despite its water quality problems, Tomales Bay has not been characterized as an eutrophic estuary (Cole 1989; Chambers 2000; Lewis et al. 2001), although a recent report on the health of U.S. estuaries characterized this estuary as being “highly susceptible” to eutrophication because of high nitrogen loading or other factors (Bricker at al. 2007). No macroalgal blooms have ever been documented in this estuary, unlike highly eutrophic estuaries in warmer climates such as Upper Newport Bay in southern California.

Studies in 1985-1986 in Tomales Bay indicated that spatial and temporal variations in primary productivity indicators such as chlorophyll a were similar to variations in phytoplankton biomass (Cole 1989). During summer months productivity was highest in the seaward and central regions of the bay and lowest in the shallow landward region (Cole 1989). This lack of sustained high phytoplankton concentrations at the mouth of the Bay suggests that the shallowness of the southern region, its shallow photic depths, wind-induced turbidity, and feeding of benthic organisms keeps the populations at a lower level than other parts of the bay (Cole 1989). However, little is known about the phytoplankton dynamics in Tomales Bay and the shifting location of the maximum chlorophyll a concentrations – variable used to measure phytoplankton – during different sampling periods indicates the dominant processes controlling phytoplankton biomass vary (Cole 1989).

Project Area

Lagunitas Creek

Dissolved Organic Carbon: Dissolved organic carbon (DOC) concentrations averaged 2.7 ± 0.6 (SD) mg/L in the Project Area reach or portion of Lagunitas Creek (Figure 27, Table 10). Median concentrations were equivalent (2.7 mg/L), suggesting that levels within the creek do not necessarily show sharp peaks, but are rather uniform between sampling events (Figure 27, Table 10). The 5th and 95th percentiles support this assumption, being fairly tightly clustered at 1.9 and 3.6 mg/L, respectively (Table 10). In fact, the maximum value recorded at both upstream and downstream locations on Lagunitas Creek was 3.7 mg/L.

Conversely, instantaneous loading rates of DOC to Tomales Bay averaged 8.4 ± 13.9 (SD) mg/s, with a median loading rate of 2.5 mg/s (Figure 28). The large standard devation and much lower median loading rate suggests that, while concentrations do not necessarily vary substantially among sampling times, loading does, probably in response to variations in creek flow. These conclusions are borne out by the data, which show remarkably little variation in concentrations between seasons and sampling dates, although there were a few peaks in loading. Loading reached as high as 60.5 and 28.7 m/s at the downstream and upstream locations, respectively, in the January 2006 storm sampling event. The 5th and 95th percentile estimates for loading ranged from a low of 0.06 and 28.7 mg/s, respectively.

Chlorophyll a and Turbidity: Chlorophyll a concentrations in Lagunitas Creek averaged 2.57 ± 3.09 (SD) mg/L, with a median concentration of 1.6 mg/L (Figure 29, Table 10). The 5th and 95th percentiles were estimated at below 0.01 mg/L (most sampling events had a minimum detection limit of 1 mg/L) and 9.33 mg/L (Figure 29, Table 10). The maximum value recorded was 10 mg/L at the downstream end of Lagunitas Creek near the Giacomini Ranch North Levee in October 2005 and 11 mg/L at the upstream end in October 2002. Most of the higher values occurred in spring and fall, with a few higher values in summer: this may relate to an optimal balance in nutrients, temperature, lower winds, and other factors, with nutrient inflow expected to be lower during summer months. Estimated instantaneous loading averaged 2.29 ± 5.08 (SD) mg/s, with estimated median loading of 0.61 mg/s (Figure 30). The moderate disparity between mean and median and the larger standard deviation were driven by an extremely high value of 21.35 m/s in April 2003, with the second highest value being 9.14 mg/s in August 2005: the former represented the estimated 95th percentile loading rate.

Turbidity values in Lagunitas Creek were generally below 50 Nephelometric Turbidity Units (NTU), with the exception of the highest measured turbidity of 266 NTU at the Giacomini Ranch North Levee in June 2003. This measurement may be an anomaly or the result of exchange with downstream Tomales Bay waters during an incoming tide or discharge of pasture waters from an adjacent pump, as values upstream in Lagunitas Creek never exceeded an NTU of 26 on this same date. Turbidity averaged 18.2 ± 29.9 (SD) NTU, with a median of 11.2 NTU and a 95th percentile estimate of 46.4 NTU (Table 10). To some degree, measurements of turbidity generally showed a seasonal trend, with the highest values surprisingly in spring, summer, or early fall: turbidity is typically expected to be highest during the winter when sediment is being actively moved by creeks. The production of suspended particles may be due to events such as upstream dam releases, biological activity, cattle use, tides, and other activities within upper or lower portions of the creek.

Giacomini Ranch and Olema Marsh

Dissolved Organic Carbon: The East Pasture had very high levels of DOC relative to the other Project Area subsampling areas (Kruskal-Wallis, n=155, df=4, H=86.9, p<0.0001). Concentrations averaged 19.0 ± 24.0 (SD) mg/L, with a lower median concentration (14.5 mg/L, Figure 27, Table 10). While most of the highest concentrations ranged between 15-25 mg/L, a few times, they jumped to as high as 130 mg/L in a small ditch that receives stormwater run-off from the town of Point Reyes Station and 77 mg/L in one of the main drainage ditches. Both of these occurred in October 2004. The 95th percentile was estimated at 59.5, considerably higher than any of the other subsampling areas (Table 10).

In general, there were no clear seasonal patterns in DOC levels in the East Pasture, with high values detected in all seasons. The lack of seasonality could result from the fact that ditch maintenance, mowing, and other agricultural management practices that might have increased organic matter loading occurred throughout the year, except perhaps in winter. While concentrations were extraordinarily high in the East Pasture, because it was leveed, it contributed essentially nothing to downstream loading, with the possible exception of when moderate to large flood flows overtopped the levees or when ditch waters were pumped by the Giacominis to the creek.

Pulses were more infrequent in other subsampling areas, but they also occurred throughout the season (spring, fall, winter/wet season, and summer). The other subsampling areas had comparatively much lower DOC concentrations, with all of them below 5-6 mg/L: Tomasini Creek (5.7 ± 3.4 (SD) mg/L), West Pasture (4.6 ± 3.9 (SD) mg/L), and Olema Marsh (3.7 ± 1.9 (SD) mg/L; Figure 27, Table 10). Medians were approximately 3.1 mg/L for Olema Marsh, 3.2 mg/L for the West Pasture and 4.4 mg/L for Tomasini Creek (Figure 27, Table 10). The 95th percentiles for these areas ranged from 6.9 mg/L (Olema Marsh) to 13.6 mg/L (Tomasini Creek), well below that estimated for the East Pasture (Table 10).

Median instantaneous loading rates ranged from 0.0 for the East Pasture to 0.5 mg/s for Olema Marsh and were significantly different from those of the East Pasture (Kruskall-Wallis, n= 118, df=4, H=74.1, $p<0.0001$; Figure 28). With the exception of Lagunitas Creek (discussed above), the other subsampling areas had essentially equivalent median loading rates (Kruskal Wallis, all $p>0.08$). Estimated loading rates averaged 0.3 ± 0.5 (SD) mg/s for the West Pasture, 2.0 ± 4.3 (SD) mg/s for Tomasini Creek, and 1.9 ± 4.1 (SD) mg/s for Olema Marsh (Figure 28). No clear seasonal pattern was apparent, although there were occasional pulses present during storm events, particularly during the ones in late April 2006 and late October 2004.

Chlorophyll a and Turbidity: Similar to DOC, strong differences existed between the East Pasture and other subsampling areas in chlorophyll a concentrations (Wilcoxon Score, n=151, df=4, Chi-Square=36.9, $p<0.0001$). Chlorophyll levels averaged an estimated 69.0 ± 159.8 (SD) mg/L in the East Pasture, with the median considerably lower (9.8 mg/L; Figure 29, Table 10). The other subsampling areas had estimated means ranging from 5.8 ± 12.9 (SD) mg/L at Tomasini Creek to 11.8 ± 28.5 (SD) mg/L in the West Pasture (Figure 29, Table 10). Estimated medians ranged from 1.1 mg/L at Tomasini Creek to 4.9 mg/L in Olema Marsh, with the West Pasture being 2.1 mg/L (Figure 29, Table 1).

For all of the subsampling areas, means were skewed by some extremely high values. Chlorophyll levels reached the highest levels recorded in the East Pasture in a ditch that receives non-point source run-off from the town of Point Reyes Station, as well as groundwater potentially influenced by leaking septic systems. Concentrations of 860, 370, and 130 mg/L were recorded at this site in July 2003, October 2003, and April 2004, respectively. Some of the drainage ditches also occasionally had levels reaching as high as 120 mg/L to 190 mg/L. In the West Pasture, chlorophyll levels infrequently climbed to as high as 130 mg/L in the roadside ditch adjacent to Sir Francis Drake Boulevard and the West Pasture Freshwater Marsh, with levels never exceeding 110 mg/L in other portions of the West Pasture. Maximum chlorophyll levels were even lower elsewhere, with concentrations never exceeding 46 mg/L in Tomasini Creek and, somewhat surprisingly, 18 mg/L in Olema Marsh. Many of the peaks in Tomasini Creek occurred in the pool below the culvert at Mesa Road when surface flows had dried up in the late summer-early fall.

Unlike Lagunitas, chlorophyll concentrations in the Giacomini Ranch and Olema Marsh were typically highest in the summer and fall, with occasional peaks in spring. At least for Giacomini Ranch, nutrient inputs into this system continued pretty much year-round with agricultural management, and the levees may have effectively shielded ditches and other waterways from the churning effects of summer winds. For Olema Marsh, sufficient nutrients may have been generated from internal recycling of organic matter that nutrients were not limiting to phytoplankton production during low flow periods.

Chlorophyll loading also differed between subsampling areas (Wilcoxon Score, n=97, df=4, Chi-Square=60.1, $p<0.0001$, Figure 30). Because the East Pasture is leveed, there is essentially no downstream export of chlorophyll, except during times of flooding when the levees overtop or when the Giacominis occasionally pumped ditch water to the creek. Chlorophyll a concentrations were unlikely to be high enough during the wet season to generate much downstream loading, even if levees overtopped. Estimated mean instantaneous loading rates for other subsampling areas ranged from 0.09 ± 0.25 (SD) mg/s in Tomasini Creek to 0.29 ± 0.42 (SD) mg/s for Olema Marsh (Figure 30). Estimated median loading rates were even lower, ranging from 0 in the West Pasture to 0.09 mg/s in Olema Marsh (Figure 30).

All of these means are much lower than Lagunitas Creek (discussed above), which averaged 2.29 ± 5.08 (SD) mg/s, although the median loading rate (0.61 mg/s) was much closer to that of Giacomini Ranch and Olema Marsh subsampling areas. As is evident from the fact that median loading is not that much lower than mean rates for most of the subsampling areas, there were relatively few peak loading events: the upstream sampling site flowing into Olema Marsh had an estimated 12.24 mg/s loading rate in July 2006, while the old slough in the West Pasture had an estimated 5.85 mg/s in October 2004 during a wet period. Otherwise, almost all of the other loading rates fell below 0.2 mg/s (West Pasture), 0.8 mg/s (Tomasini Creek), and 1.1 mg/s (Olema Marsh).

As with other indicators, turbidity was highest in the East Pasture (36.6 ± 97.0 (SD) NTU), falling to considerably lower levels elsewhere, with values estimated at 13.3 ± 18.2 (SD) NTU for the West Pasture, 17.3 ± 20.2 (SD) NTU in Tomasini Creek, and 13.8 ± 9.6 (SD) NTU for Olema Marsh (Table 10). The 95th percentiles ranged from a high of 125.4 NTU in the East Pasture to a low of 30.8 NTU in Olema Marsh, with the West Pasture and Tomasini Creek ranging from 40.3 to 61.9 NTU, respectively (Table 10). In Tomasini Creek, turbidity generally ranged between 1 and 40 NTU, with spikes occasionally above 50 NTU occurring during the fall (KHE 2006a). Turbidity values for Fish Hatchery Creek generally fell below 50 NTU, with seasonal spikes over 50 NTU observed during the summer of 2003 and 2004 at downstream locations in the West Pasture (KHE 2006a).

Reference Areas

Dissolved Organic Carbon: DOC concentrations did not significantly differ between reference areas (Kruskal-Wallis, n=104, df=2, H=1.14, p=0.57, Figure 27). Means ranged from 3.0 ± 1.7 (SD) mg/L in Limantour Marsh to 3.3 ± 1.6 (SD) mg/L in Walker Creek Marsh, with medians ranging from 2.8 mg/L in Limantour Marsh and 3.1 mg/L in Walker Creek and the Undiked Marsh (Figure 27, Table 10). Levels never exceeded 7.5 mg/L in any of the marshes, with most of the highest values ranging from 6.6 mg/L (Limantour Marsh) to 7.5 mg/L (Undiked Marsh). For the Reference Area as a whole, the 5th and 95th percentiles were estimated at 1.1 and 6.1 mg/L, respectively, with the 95th percentile for Walker Creek Marsh slightly exceeding this (6.3 mg/L, Table 10).

Interestingly, the timing of these higher values differed between marshes. At Limantour Marsh, the highest values were observed in the winter/wet season and spring; in the Undiked Marsh, the highest values occurred almost exclusively in the fall with some winter/wet season high values; and, at Walker Creek Marsh, the highest number of peak values occurred in spring, summer, and winter/wet season sampling events in that order. At Limantour Marsh, the Muddy Hollow reservoir may affect timing of organic matter inputs from upstream reaches of Muddy Hollow Creek, with delivery increased during high rainfall periods when more waters flow out of the spillway. Conversely, in the Undiked Marsh, peaks in fall may point to surges in internal recycling of organic matter and breakdown of senescing, decomposing plants.

Similar to concentrations, no differences occurred in instantaneous loading rates for DOC between Reference Areas (Kruskal-Wallis, n=99, df=2, H=0.19, P=0.91, Figure 28). Median loading rates ranged from 0.23 mg/s in the Undiked Marsh to 0.29 mg/s at Limantour Marsh. In comparison, there was stronger disparity between marshes in mean loading rates, which averaged 0.65 ± 0.81 (SD) mg/s for Limantour Marsh, 0.83 ± 1.29 (SD) mg/s for the Undiked Marsh, and 2.8 ± 6.37 (SD) mg/s for Walker Creek Marsh (Figure 28). As evidenced by the lower median (0.27 mg/s), Walker Creek Marsh's mean was highly influenced by some peak loading events in Walker Creek itself of 34.4 mg/s in late April 2006, 10.3 mg/s during a storm event in January 2005, and 9.1 mg/s in July 2006.

Chlorophyll a and Turbidity: Chlorophyll concentrations did not differ significantly between reference marshes (Wilcoxon Score, n=110, df=2, Chi-Square=2.98, p=0.23, Figure 29). The estimated mean for Walker Creek Marsh (17.6 ± 49.6 (SD) mg/L) was seemingly higher than those for the Undiked Marsh (4.7 ± 5.2 (SD) mg/L) and Limantour Marsh (4.5 ± 11.0 (SD) mg/L), however, medians were more similar, ranging from 1.6 mg/L for Limantour Marsh to 3.1 mg/L for Walker Creek Marsh (Figure 29, Table 10).

Not surprisingly, Walker Creek Marsh had the higher number of peak values and the highest values generally, including one at 290 mg/L. More than seven (7) chlorophyll levels exceeding 23 mg/L occurred during primarily spring and summer sampling events in two interior channels of Walker Creek Marsh at opposite ends of the Bay-upland salinity gradient: none of these peaks were recorded in Walker Creek itself. In comparison, none of the four (4) high values in the Undiked Marsh even exceeded 20 mg/L, ranging between 13 to 20 mg/L. There were also four (4) "outlier" values at Limantour Marsh, with values ranging from 13 to 65 mg/L. The 95th percentiles were estimated at 19 mg/L (Undiked Marsh), 25 mg/L (Limantour Marsh), and 98 mg/L (Walker Creek Marsh, Table 10).

Estimated instantaneous loading rates also did not appear to differ between Reference Areas (Wilcoxon Score, n=63, df=2, Chi-Square=3.88, p=0.14, Figure 30). Estimated median rates ranged from 0.03 mg/s in the Undiked Marsh to 0.18 mg/s for both Walker Creek and Limantour Marshes (Figure 30). Sporadic pulses in internal waterways drove up the estimated mean instantaneous loading rate for Walker Creek Marsh (3.3 ± 8.2 (SD) mg/s) relative to the other marshes – Limantour Marsh (mean=1.3 ± 3.7 (SD) mg/s) and the Undiked Marsh (0.65 ± 2.28 (SD) mg/s), but large variance in the data seemingly reduced power of this analysis, potentially masking true differences in loading rates between the marshes.

The 95th percentiles were estimated at 16.9 mg/s (Limantour Marsh), 10.3 mg/s (Undiked Marsh), and 35.7 mg/s(Walker Creek Marsh). Limantour Marsh really had one very large value: 16.9 mg/L in April 2004, with the second highest value being 2.3 mg/L in January 2004. Most recorded chlorophyll levels in Limantour Marsh fell below 1.0 mg/s and were generally even lower (<0.5 mg/s). There were also approximately two high values in the Undiked Marsh of 10.3 mg/s on upstream sections of Fish Hatchery Creek (outside the diked area) in April 2004 and 2.25 mg/s on downstream sections of Fish Hatchery Creek in July 2006, with the rest of the values being below 0.25 mg/s. Walker Creek Marsh had a greater number (at least 5) of high or peak values than the other marshes, with the highest being 35.7 mg/s on Walker Creek in October 2003. Several other high values also occurred in October and even on the same date in 2003, ranging from 2.8 mg/s (2003) to 7.0 mg/s (2004). A few other peaks were recorded in January 2004 and April 2004.

Turbidity levels were also seemingly higher at Walker Creek Marsh (25.8 ± 37.3 (SD) NTU) than at the other marshes: Undiked Marsh (17.1 ± 13.0 (SD) NTU) and Limantour Marsh (16.0 ± 14.5 (SD) NTU, Table 10). Median turbidity levels were much tighter between reference marshes, ranging from 10.4 NTU (Limantour Marsh) to 14.4 NTU (Walker Creek Marsh, Table 10). The 95th percentile, however, was actually lowest at the Undiked Marsh (43.5 NTU), followed by Limantour Marsh (52.7 NTU) and Walker Creek Marsh (75.4 NTU, Table 10).

Comparison Between Project Area and Reference Areas

Dissolved Organic Carbon

DOC concentrations varied between the Project Area (median = 4.2 mg/L) and the Reference (2.9 mg/L) and Upstream (3.1 mg/L), although there were no statistically significant differences between Reference and Upstream Areas (Kruskal-Wallis, n=259, df=2, H=47.9, p<0.0001, Figure

27, Table 10). A greater disparity existed with means, with DOC levels averaging 10.1 ± 17.3 (SD) mg/L for the Project Area, 3.1 ± 1.4 (SD) mg/L for Reference Areas, and 4.0 ± 2.7 (SD) mg/L for Upstream Areas (Figure 27, Table 10). Within the Project Area itself (e.g., not including sampling stations upstream of the restoration area), differences also existed between the subsampling areas, with the East Pasture having the highest concentrations (median=14.5 mg/L), followed by the West Pasture and Tomasini Creek (median=4.3 mg/L), Olema Marsh (3.4 mg/l), and Lagunitas Creek (2.5 mg/L; Kruskal-Wallis, n=102, df=4, p<0.0001). Conversely, there were no significant differences between Reference Area marshes (Kruskal-Wallis, n=104, df=2, H=1.14, p=0.57), with medians ranging from 2.8 mg/L (Limantour Marsh) to 3.1 mg/L (Walker Creek and the Undiked Marsh, Figure 27, Table 10).

The 5th and 95th percentiles for DOC levels in Reference Areas were 1.1 and 6.1 mg/L, respectively (Table 10). Approximately 37 percent of the values in the Project Area fell outside the range of natural variability, with a substantial amount of this coming from the East Pasture alone. Approximately 53 percent exceeded the highest 16.7 percent of values found in reference marshes (4.4 mg/L), which exceeds the 50 percent threshold established as one of the progress criteria. The coefficient of variation in DOC values among Reference Areas totaled approximately 0.45 – values below 0.2 are considered to have low variability.

In comparison to concentrations, instantaneous loading rates did not appear to differ between the Project Area (median=0.02 mg/s), Reference Areas (median=0.27 mg/s), and Upstream Areas (median=0.13 mg/s; ANOVA, n=238, df=2, F=0.69, p=0.51, Figure 28). In general, mean instantaneous loading rates were slightly higher than median rates, ranging from 1.4 ± 0.4 (SE) mg/s within Reference Areas and 1.5 ± 0.8 (SE) mg/s for the Project Area to 2.4 ± 0.7 (SE) mg/s for Upstream Areas (Figure 28).

Within the Project Area (e.g., not including sampling stations upstream of the restoration area), loading rates did vary significantly (Kruskal-Wallis, n=80, df=4, H=55.0, p<0.0001), with the downstream sampling station of Lagunitas Creek at the Giacomini Ranch North Levee having the highest loading (median=2.0 mg/s) and the East Pasture having the lowest (median=0.0 mg/s). Mean loading rates were skewed in all of the subsampling areas by sharp peaks in loading during certain sample periods, with loads averaging 0.1 ± 0.03 (SE) mg/s for the West Pasture, 1.2 ± 0.8 (SE) mg/s for Tomasini Creek and Olema Marsh, and 9.2 ± 5.8 (SE) mg/s for Lagunitas Creek. With the exception of Lagunitas Creek, which had loading rates estimated of 60.5 mg/s in February 2006, peak values did not exceed 7.7 mg/s in the Project Area.

As was discussed earlier under Reference Areas, loading rates did not differ significantly between reference marshes (Kruskal-Wallis, n=99, df=2, H=0.19, p=0.91), with median loading rates varying only slightly between 0.23 mg/s at the Undiked Marsh to 0.29 mg/s at Limantour Marsh (Figure 28). Sharp peaks in loading drove up mean loading rates relative to the medians, particularly for Walker Creek Marsh, which had a mean of 2.8 ± 1.1 (SE) mg/s and median of 0.27 mg/s. While concentrations were always among the lowest on the mainstem of Walker Creek relative to interior tidal channels, the mainstem did display frequent pulses in DOC loading, with some of the higher values being 9.1 mg/s in July 2006, 10.3 mg/s in January 2005, and 34.4 mg/s in April 2006.

The 5th and 95th percentile estimates for DOC loading in Reference Areas were 0 and 6.22 mg/s. Due in large part to the fact that the East Pasture was leveed, only 5 percent of the Project Area values exceeded the 95th percentile, and only 9 percent exceeded the highest 16.7 percent of Reference Area values (2.45 mg/s), well below the 50 percent threshold established as a progress criterion. As was discussed under Nitrates, even if the East Pasture had been fully or even muted tidal rather than non-tidal, the size of the drainage ditches and remnant tidal sloughs that had not been filled would have minimized its contribution to downstream loading rates regardless. The coefficient of variation for DOC loading in Reference Areas approximated 0.36, where 0.2 and below indicates low variability.

No clear seasonal patterns emerged for DOC. In Lagunitas Creek, concentrations appeared rather uniform between sampling events, with increased flow often associated with peak loading events. In the East Pasture, there were frequent peaks or pulses in DOC that did not correspond to any particular season or time of year: the lack of seasonality could result from the fact that ditch maintenance, mowing, and other agricultural management practices that might have increased organic matter loading occurred throughout the year, except perhaps in winter. Fewer pulses occurred in other Project Area subsampling areas, but, in general, both sharp increases in either concentrations or instantaneous loading occurred throughout the year, although quite a few did occur during the winter or a storm event in the fall or spring.

Even in reference marshes, disparity existed, with Limantour Marsh having its highest values in the winter/wet season and spring and the Undiked Marsh having its highest values almost exclusively in the fall with some winter/wet season high values. Some of the differences in reference marsh temporal patterns may relate to factors outside of the marsh, as well as inside, such as upstream land use and management such as reservoirs, agriculture, and rural residential developments: these may affect the volume and timing of riverine organic matter delivered to downstream estuaries. In conjunction with periods of higher-than-average rates of internal recycling of decomposing plant and plankton material, this could lead to pulses in DOC concentrations and, to some extent, loading throughout the year.

Chlorophyll a and Turbidity

Estimated median chlorophyll concentrations were higher in the Project Area (3.0 mg/L) than in Upstream Areas (1.8 mg/L; $p<0.017$), but roughly similar to Reference Areas (2.8 mg/L; Kruskal-Wallis, $n=261$, $df=2$, $H=7.4$, $p=0.03$, Figure 29, Table 10). Due to some large values, estimated mean concentrations showed stronger disparity, with levels averaging 30.7 ± 10.7 (SE) mg/L in the Project Area compared to 9.2 ± 2.9 (SE) mg/L in Reference Areas and 8.3 ± 2.9 (SE) mg/L in Upstream Areas (Figure 29, Table 10).

Chlorophyll a levels also differed significantly within the Project Area (e.g., not including sampling sites upstream of the Project Area; Kruskal-Wallis, $n=91$, $df=4$, $H=16.0$, $p=0.003$). The East Pasture had significantly higher levels of chlorophyll a than any of other subsampling areas (all $p<0.01$), with medians estimated at 9.8 mg/L for the East Pasture, 3.3 mg/L for the West Pasture, 2.1 mg/L for Olema Marsh, 1.5 mg/L for Lagunitas Creek, and 0.06 mg/L for Tomasini Creek. All of the estimated means were skewed by episodic pulses in chlorophyll levels, particularly the East Pasture, which had levels averaging 69.0 ± 27.4 (SE) mg/L. The next highest estimated mean occurred in the West Pasture (13.3 ± 5.1 (SE) mg/L), followed by Olema Marsh (4.5 ± 2.3 (SE) mg/L), Lagunitas Creek (2.8 ± 0.9 (SE) mg/L), and Tomasini Creek (1.6 ± 0.7 (SE) mg/L). Because they exclude upstream sampling sites, these numbers will not correspond with numbers discussed earlier in this section.

Chlorophyll a concentrations did not appear to vary significantly between reference marshes (Kruskal-Wallis, $n=110$, $df=2$, $H=4.6$, $p=0.10$), although the median for Limantour Marsh (1.6 mg/L) was seemingly a little lower than those for the Undiked Marsh (3.0 mg/L) and Walker Creek Marsh (3.1 mg/L, Figure 29, Table 10). In terms of estimated means, pulses in phytoplankton productivity appeared to drive up levels in Walker Creek Marsh (17.6 ± 7.9 (SE) mg/L) more so than in the Undiked Marsh (4.7 ± 0.9 (SE) mg/L) or Limantour Marsh (4.5 ± 1.8 (SE) mg/L, Figure 29, Table 10). The 95th percentile for Reference Areas was estimated at 30 mg/L, and approximately 15 percent of the Project Area values exceeded this level. The 95^{th} percentile for the Project Area was estimated at 150 mg/L (Table 10). Approximately 30 percent of the Project Area values exceeded the highest 16.7 percent of values in the Reference Areas (8.3 mg/L), which is well below the 50 percent threshold established as a progress criterion. The coefficient of variation exceeded 1.0.

In contrast to concentrations, chlorophyll loading to downstream areas appeared to be higher in the Reference Areas (est. median=0.05 mg/s) than in the Project Area (est. median=0) or Upstream Areas (est. median =0.01 mg/s; Wilcoxon Score, n=160, df=2, Chi-Square=14.4, p=0.001, Figure 30). The disparity was even more striking with estimated mean loading rates, with Reference Areas averaging 1.7 ± 0.7 (SE) mg/s; Upstream Areas averaging 0.8 ± 0.001 (SE) mg/s; and the Project Area averaging 0.4 ± 0.2 (SE) mg/s. This disparity was driven by the lack of any "loading" of chlorophyll from the East Pasture and several large pulses in loading in the mainstem of Walker Creek, despite the fact that concentrations were always relatively low to moderate in the creek. Due to these pulses, Walker Creek Marsh had the highest loading rate of any subsampling area, with loading averaging an estimated 3.3 ± 1.8 (SE) mg/s.

Within the Project Area (e.g., excluding upstream sampling locations), downstream Lagunitas Creek had significantly higher estimated mean loading rates (1.9 ± 1.5 (SE) mg/s) than the other subsampling areas, which ranged from 0 in the East Pasture to 0.5 ± 0.2 (SE) mg/s for Olema Marsh (Wilcoxon Score, n=47, df=4, Chi-Square=37, p<0.0001). Interestingly, Olema Marsh and Lagunitas Creek actually had the highest median loading rates of 0.7 and 0.5 mg/s, respectively, with Tomasini Creek (0.02 mg/s) and the West Pasture (0.01 mg/s) having much lower rates.

Despite the fact that Walker Creek Marsh had the highest estimated mean instantaneous loading rates, differences between reference marshes were not considered statistically significant (Wilcoxon Score, n=63, df=2, Chi-Square=3.9, p=0.14): high variance in the data may have limited the power of this analysis. Median loading rates were estimated at 0.2 mg/s for Walker Creek Marsh and Limantour Marsh and 0.02 mg/s for the Undiked Marsh (Figure 30). Estimated mean loading rates for Limantour Marsh and the Undiked Marsh averaged 1.3 ± 0.8 (SE) mg/s and 0.7 ± 0.5 (SE) mg/s, respectively, compared to 3.3 ± 1.8 (SE) mg/s for Walker Creek Marsh (Figure 30). The 95th percentile for Reference Areas was estimated at 14.0 mg/s: none of the Project Area values exceeded this rate. Approximately 3 percent of the Project Area values exceeded the highest 16.7 percent of values in the Reference Areas (2.2 mg/s), considerably below the 50 percent threshold established as a progress criterion. The coefficient of variation for this parameter exceeded 100 percent in Reference Areas.

As with DOC, chlorophyll a showed a remarkable lack of clear seasonal patterns. In Lagunitas Creek within the Project Area boundaries, most of the higher chlorophyll levels and loading rates occurred in spring and fall, with a few higher values in summer: this may relate to an optimal balance in nutrients, temperature, lower winds, and other factors, with nutrient inflow expected to be lower during summer months. In contrast, chlorophyll concentrations in the Giacomini Ranch and Olema Marsh were typically highest in the fall and summer, with occasional peaks in spring. At least for Giacomini Ranch, nutrient inputs into this system continued pretty much year-round with agricultural management, and the levees may have effectively shielded ditches and other waterways from the churning effects of summer winds. For Olema Marsh, sufficient nutrients may have been generated from internal recycling of organic matter that nutrients were not limiting to phytoplankton production during summer and fall months.

Temporal patterns were not any more distinct in reference marshes. Concentrations were highest in spring and summer in internal tidal channels in Walker Creek Marsh, but loading was highest in the mainstem of Walker Creek during fall and winter/wet season sampling events, because of increases in flow volume. Some of the highest concentrations in Limantour Marsh occurred in the winter, spring, and summer sampling events, but loading was typically highest in the fall. In the Undiked Marsh, peak values were recorded mostly in the non-winter months, with loading rates highest in the spring and fall. Similar to DOC, external factors may be contributing to the indistinct temporal patterns, with upstream land use and management such as reservoirs, agriculture, and rural residential developments affecting the volume and timing of nutrients delivered to these systems and thereby potentially affecting phytoplankton productivity.

Turbidity levels appeared to differ at least slightly between the Project Area (median=10.7 NTU) and Reference Areas (median=12.2 NTU), with Upstream Areas having the lowest levels (median=5.7 NTU; Kruskal-Wallis, n=1,086, df=2, H=43.0, p<0.0001, Table 10). This same pattern was apparent with mean turbidity levels, with values estimated at 22.7 ± 2.3 (SE) NTU for the Project Area, 19.9 ± 1.5 (SE) NTU for Reference Areas and 13.4 ± 1.8 (SE) NTU for Upstream Areas (Table 10). Based on this, it would appear that turbidity levels are similar between the Project Area and Reference Areas, but much lower in the fluvially dominated Upstream Area portions of the system. This result counters to what might be expected in that fluvially dominated areas would be expected to have higher suspended sediment concentrations.

Differences also existed within the Project Area itself (excluding upstream sampling sites). Turbidity levels were higher in the East Pasture (median=13.5 NTU) than in the other Project Area sub-groups, which ranged from a median of 8.0 NTU in the West Pasture to 11.3 NTU in Olema Marsh (Kruskal-Wallis, n=658, df=4, H=24.0, p<0.001, Table 10). The disparity between sub-groups was even more apparent with means, with turbidity averaging 36.6 ± 97.0 (SD) NTU in the East Pasture and from 13.3 ± 18.25 (SD) NTU in the West Pastur e to 17.3 ± 20.2 (SD) NTU in Tomasini Creek (Table 10). Again, these numbers will not necessarily correspond with those discussed earlier in this section, because they exclude upstream sampling sites.

The highest measured turbidity occurred at the downstream sampling station near the Giacomini Ranch North Levee in June 2003 with a value of 266 NTU. As discussed earlier, this may have been an anomaly or the result of exchange with downstream Tomales Bay waters during an incoming tide or discharge of pasture waters from an adjacent pump, as values on upstream portions of Lagunitas Creek never exceeded a NTU of 26 on this same date. In general, turbidity fell below 50 NTU in Lagunitas and Fish Hatchery Creeks and 40 NTU in Tomasini Creek.

Reference Area estimates were substantially influenced by higher means for Walker Creek (25.8 ± 37.3 (SD) NTU) than for the other marshes: Undiked Marsh (17.1 ± 13.0 (SD) NTU) and Limantour Marsh (16.0 ± 14.5 (SD) NTU, Table 10). However, despite this, differences between Reference Areas were not statistically significant, with medians ranging from 10.4 NTU at Limantour Marsh and 14.4 NTU at Walker Creek Marsh (Kruskal-Wallis, n=283, df=2, H=2.55, p=0.279, Table 10). The 5th and 95th percentiles for turbidity in Reference Areas were estimated at 3.1 and 55.4 NTU, respectively (Table 10). Approximately 14 percent of the samples from the Project Area fell outside of this range, with at least 8 percent of those 14 falling below the 5th percentile. Approximately 17 percent exceeded the highest 16.7 percent of values in the Reference Areas (30.1 NTU), which is essentially equivalent to what would be expected in Reference Areas. The coefficient of variation for turbidity greatly exceeds 1.0.

As with DOC and chlorophyll a, turbidity showed a somewhat unexpected temporal trend, with the highest values surprisingly in spring, summer, or early fall: turbidity is typically expected to be highest during the winter when sediment is being actively moved by creeks. The production of suspended particles may be due to events such as upstream dam releases, biological activity, cattle activity, tidal action, and other activities within streams, ditches, and other water bodies.

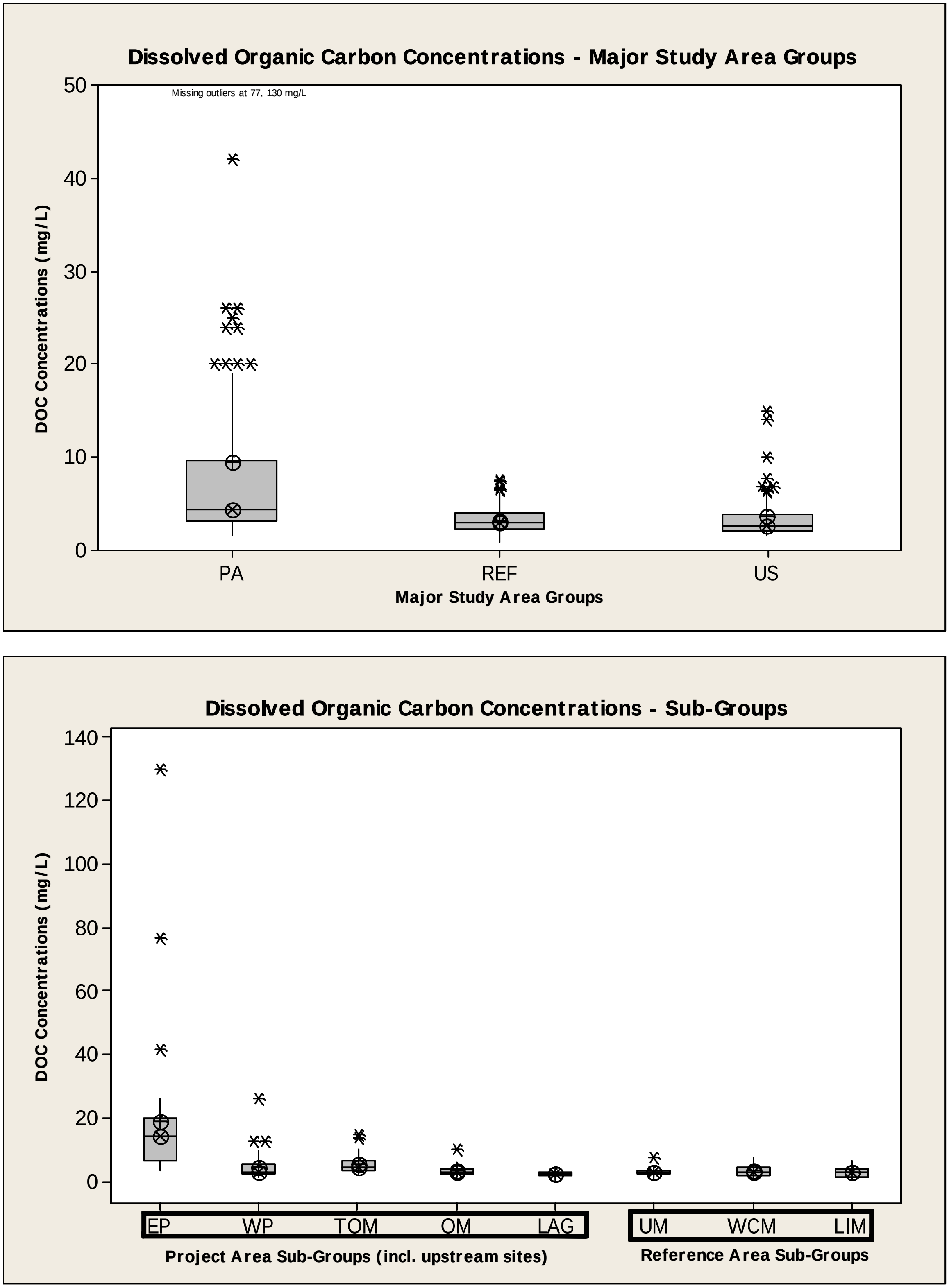
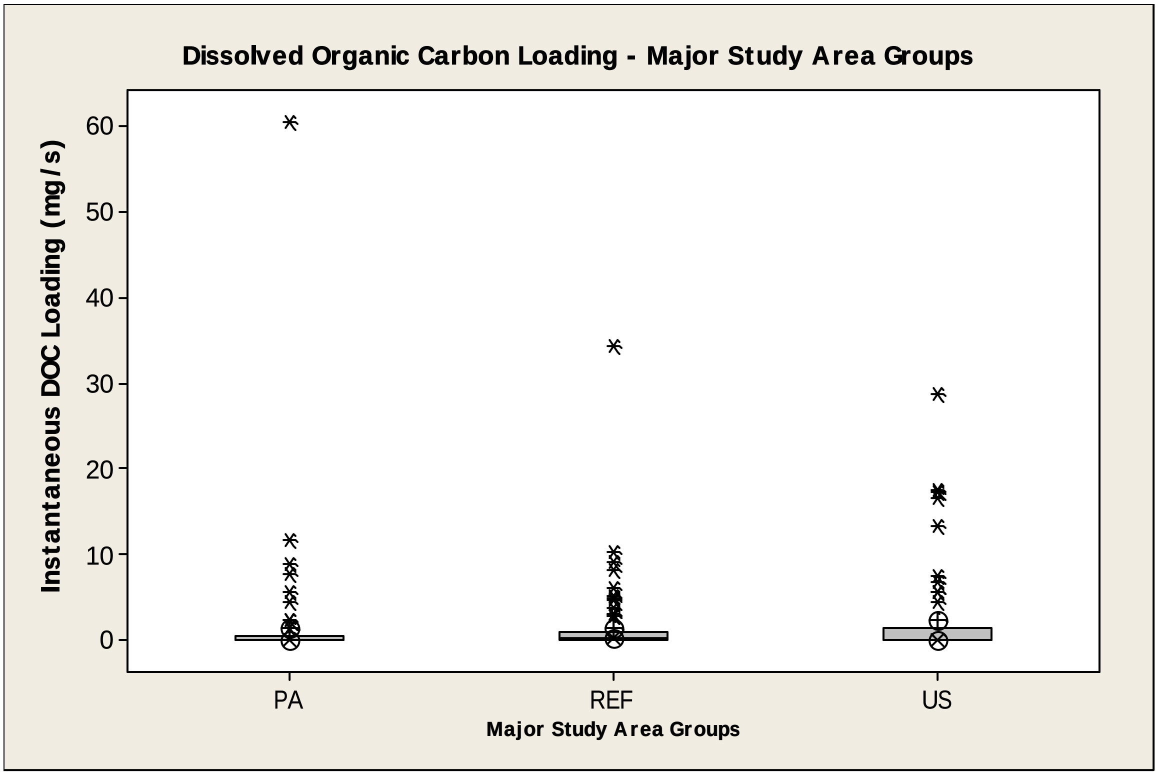


FIGURE 27. Dissolved organic carbon (DOC) concentrations in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



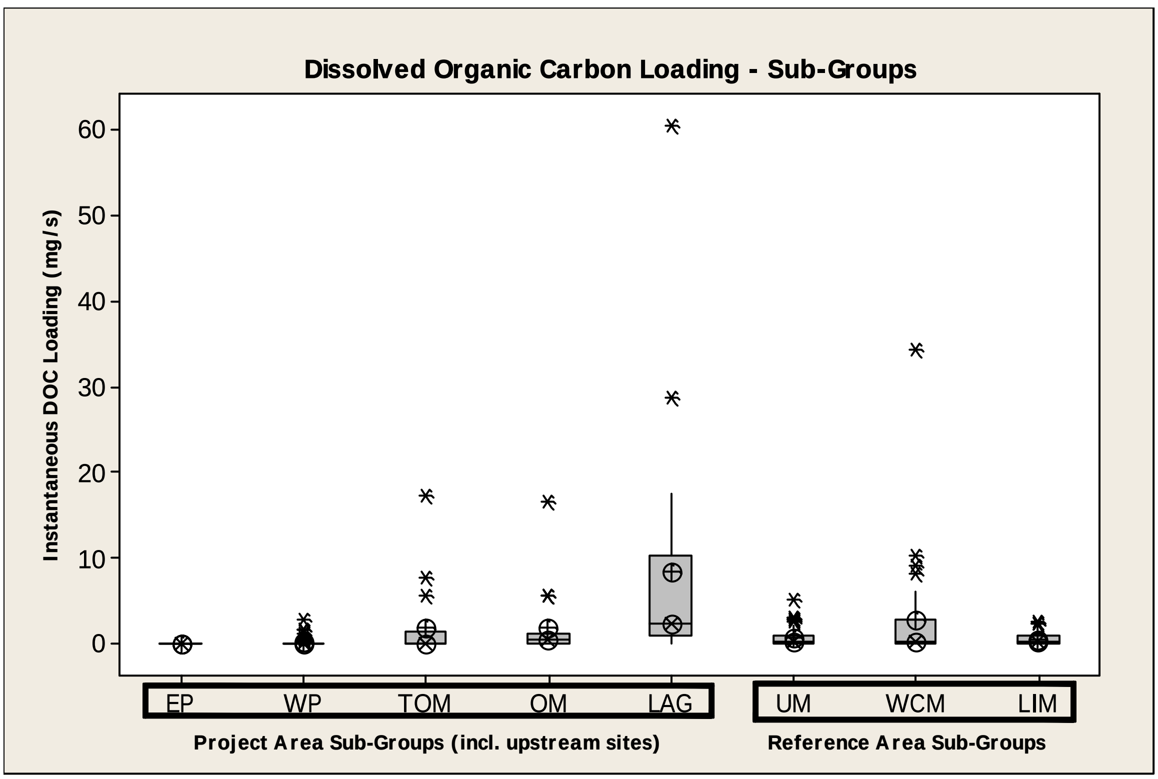
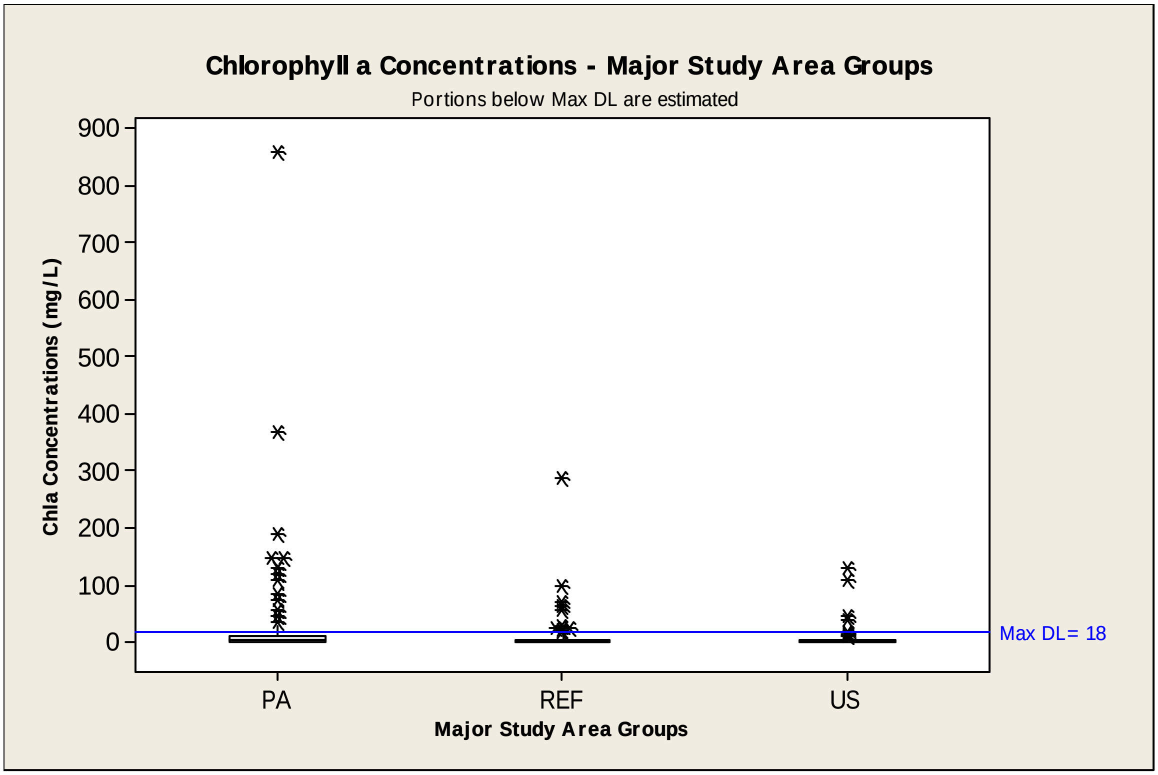


FIGURE 28. Instantaneous dissolved organic carbon (DOC) loading in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



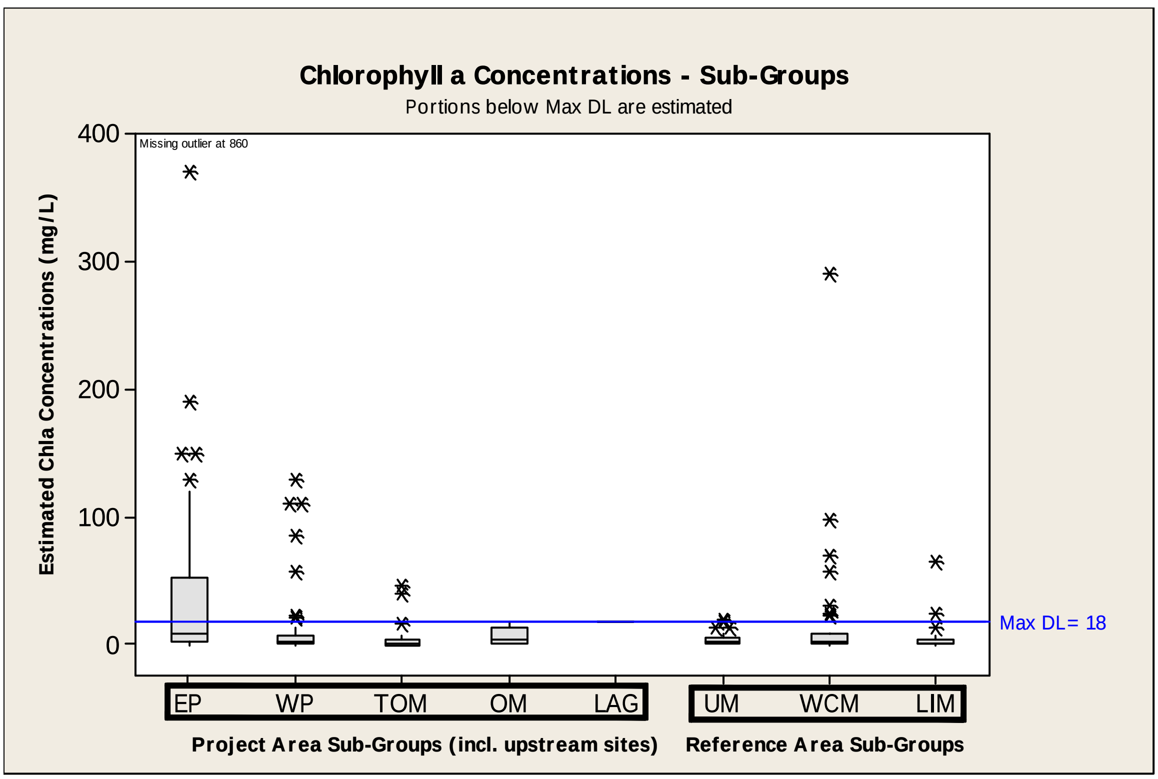
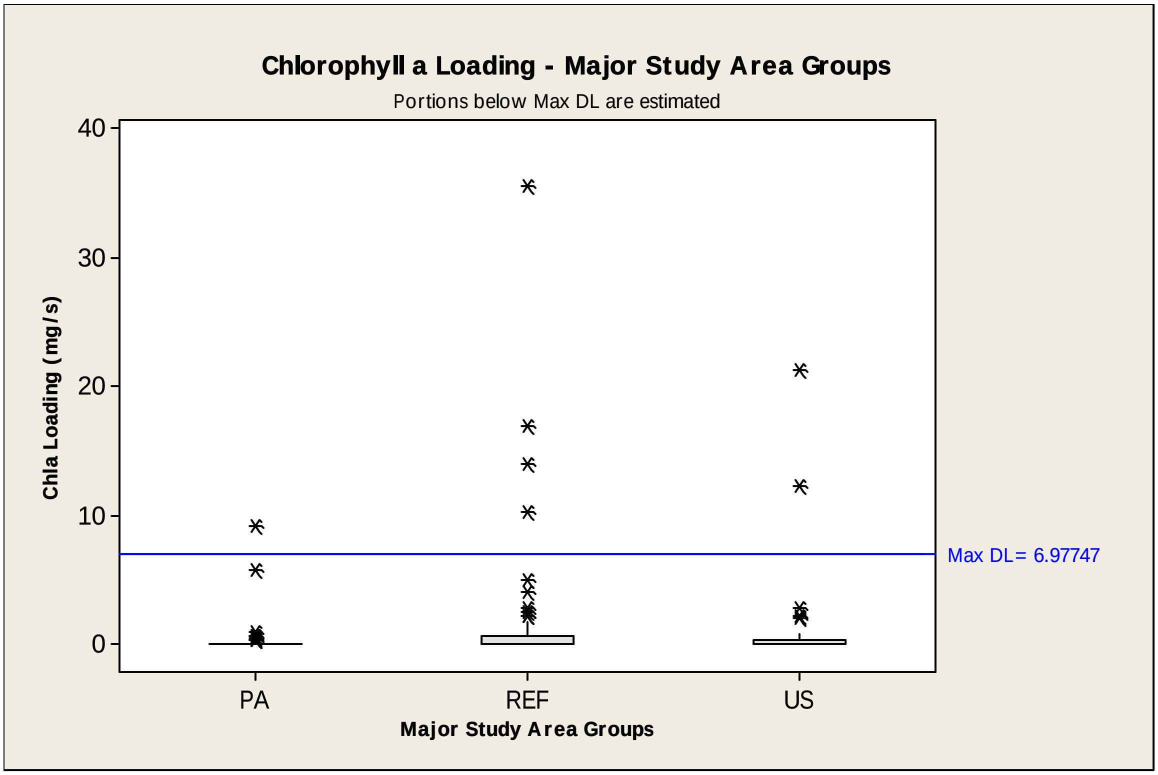


FIGURE 29. Estimated chlorophyll a concentrations in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.



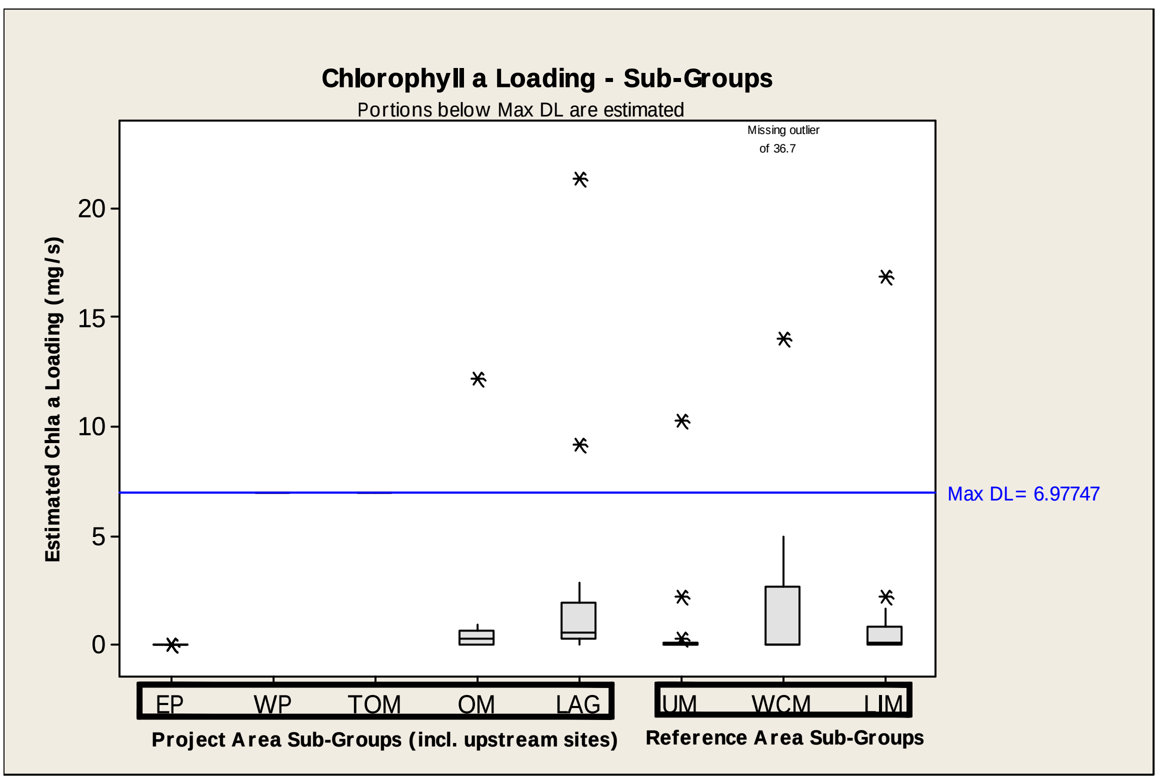


FIGURE 30. Estimated instantaneous chlorophyll a loading in the Major Study Area Groups and Sub-Groups. Boxplots indicate first and third quartiles (25%, 75%) with lines indicating 10^{th} and 90^{th} percentiles. Medians are indicated by diagonal-hatched circle with line and means with horizontal/vertical slashed circle.

TABLE 10. Summary data for DOC, chlorophyll a, and turbidity concentrations – Giacomini Wetland Restoration Project pre-restoration water quality monitoring. Major Study Area Groups include Project Area (PA), Reference Areas (REF), and Upstream Areas (US). Project Area sub-groups in this chart include upstream sampling sites that are broken out as US in other analyses. Some of the summary data are estimated using survival analysis statistical techniques recommended by Helsel (2005) for censored or non-detect data.

	Major Study Area Groups					Project Area Sub-Groups (including upstream sites)						Reference Area Sub-Groups		
	PA	***Range***	**REF**	**US**		**EP**	**WP**	**TOM**	**LAG**	**OM**		**UM**	**WCM**	**LIM**
Dissolved Organic Carbon (mg/L)														
Mean 10.1			3.1	4.0		19.0	4.6	5.7	2.7	3.7		3.2	3.3	3.0
SD 17.3			1.4	2.7		24.0	3.9	3.4	0.6	1.9		1.0	1.6	1.7
Median 4.2			2.9	3.1		14.5	3.2	4.4	2.7	3.1		3.1	3.1	2.8
5^{th} 2.2		↕63%	1.1	1.9		3.7	1.9	2.9	1.9	2.3		2.0	1.2	1.0
95^{th} 26.0			6.1	7.8		59.5	10.1	13.6	3.6	6.9		4.7	6.3	6.0
83.3rd		↓47%	4.4											
CV			0.45											
Chlorophyll a (mg/L)														
Mean 30.7			9.2	8.3		69.0	11.8	5.8	2.6	6.3		4.7	17.6	4.5
SD 102.5			30.7	22.7		159.8	28.5	12.9	3.1	6.4		5.2	49.6	11.0
Median 3.0			2.8	1.8		9.8	2.1	1.1	1.6	4.9		3.0	3.1	1.6
5^{th} <0.02		↓85%	<0.02	<1.0		<0.02	*NE*	*NE*	*NE*	*NE*		*NE*	*NE*	*NE*
95^{th} 150.0			30.0	46.0		370.0	110.0	46.0	9.33	*NE*		19.0	98.0	25.0
83.3rd		↓70%	8.3											
CV			>1.0											
Turbidity (NTU)														
Mean 22.7			19.9	13.4		36.6	13.3	17.3	18.2	13.8		17.1	25.8	16.0
SD	59.8		25.3	21.6		97.0	18.2	20.2	29.9	9.6		13.0	37.3	14.5
Median 10.7			12.2	5.7		13.5	8.0	9.8	11.2	11.3		12.1	14.4	10.4
5^{th} 2.7		↕86%	3.1	0.9		3.9	1.6	3.0	2.6	5.2		3.0	3.8	2.8
95^{th} 69.6			55.4	43.5		125.4	40.3	61.9	46.4	30.8		43.5	75.4	52.7
83.3rd		↓83.3%	30.1											
CV			>1.0											

NE=non-estimatable

Summary and Conclusions

- **As Expected, Salinities Differ Between Project Area and Other Study Areas**: The Project Area lies in the Estuarine Transition Zone, the dynamic interface between freshwater and saltwater influences. For this reason, salinity regimes and patterns are understandably dynamic both spatially and temporally. To some degree, the Reference Areas also occur within this transition zone, but the magnitude of effects is seemingly dampened by either a smaller watershed size (e.g., Walker Creek Marsh and Limantour Marsh) or distance downstream from the mouth (e.g., Undiked Marsh). This difference between the Project Area and the Reference Areas has only been exacerbated by the system of levees, roads, and culverts that have kept tides out or minimized their influence and impounded freshwater in the Project Area. Much of this freshwater comes from the copious amount of small freshwater drainages and emergent groundwater flow from the Point Reyes Mesa and Inverness Ridge, as well as the larger creeks such as Lagunitas Creek, Olema Creek, Bear Valley Creek, Fish Hatchery Creek, and Tomasini Creek.

  Not surprisingly, then, median salinities differed significantly between the Project Area and other Study Areas. Salinity averaged 6.9 ppt in the Project Area, with a median salinity of 1.6 ppt: the much lower median suggests that the mean was strongly influenced by a few areas or periods of hypersalinity in the diked system (Table 6). Conversely, in Reference Areas, salinities averaged 22.0 ppt, with a median salinity of 25.2 ppt, which shows that the mean was strongly influenced by some very low values (Table 6). For the Project Area, the 5th and 95th percentiles were estimated at 0.1 and 29 ppt, respectively, which actually did not differ that much from those estimated for Reference Areas -- 0.6 and 35.4 ppt, respectively (Table 6). Understandably, salinities for Upstream Areas fell below those of either the Project Area or Reference Marshes, as they receive less or no tidal influence and strong perennial or seasonal freshwater influences. Salinity averaged 0.6 ppt in Upstream Areas, with a median salinity of 0.1 ppt (Table 6).

  Median salinities also differed between subsampling areas within the Project Area, with the range of medians for the West Pasture, Tomasini Creek, and the Project Area portion of Lagunitas Creek (3.8 to 4.8 ppt) higher than that for Olema Marsh and the East Pasture (0.2 to 0.6 ppt, Table 6). Lower salinities in Olema Marsh and the East Pasture result from the almost total exclusion of tidal influence from these systems.

  The effect of landscape position on salinity can also be seen in differences between salinities in reference marshes, with the Undiked Marsh having a significantly lower mean salinity (17.4 ppt) than either Limantour Marsh (24.0 ppt) or Walker Creek Marsh (24.4 ppt) due probably to the abundant freshwater inflow from Project Area creeks, as well as numerous other small drainages and emergent groundwater flow from the Inverness Ridge that flow into this system (Table 6).

- **Dissolved Oxygen Lowest in Heavily Managed and Impounded Areas**: Dissolved oxygen represents an important parameter of water quality health. Too little oxygen results in the death of fish and other aquatic organisms, and too much oxygen points to an imbalance in primary productivity that may result from an overabundant supply of inorganic nutrients or high water residence times that may also subsequently lead to wide diel swings in oxygen concentrations, fish death, and production of the toxic ammonia.

  Within the Project Area, most of the extremely low oxygen concentrations occurred in the East Pasture drainage ditches, where frequent ditching increased oxygen demand by filling ditch waters with vegetation material that was consumed by oxygen-dependent bacteria.

This management practice, coupled with the relatively infrequent exchange or subsidy of ditch waters except during the winter or when irrigation was performed, typically kept oxygen levels below 5 mg/L and often below 2 mg/L. Median oxygen levels in the East Pasture were 4.56 mg/L, with the mean actually slightly higher (4.98 mg/L; Table 7). These same factors – copious amount of organic matter and infrequent exchange between the impounded marsh and Lagunitas Creek -- also contributed to consistently low levels of oxygen in Olema Marsh, although levels were not as low as the East Pasture. Oxygen levels averaged 5.83 mg/L in Olema Marsh, with a median concentration of 6.15 mg/L (Table 7). Median oxygen concentrations in other Project Area subsampling areas or sub-groups – excluding upstream sampling sites -- ranged from 8.77 mg/L in Lagunitas Creek to 7.78 mg/L for Tomasini Creek, with the less heavily managed West Pasture having slightly higher levels (9.00 mg/L; Table 7).

The effect of these low oxygen levels in the East Pasture and Olema Marsh were evident in the significant differences in median oxygen concentrations between the Project Area (7.58 mg/L) and those of the Reference Areas (8.32 mg/L) and Upstream Areas (9.51 mg/L; Table 7). In general, Reference Areas had very similar average oxygen concentrations, with medians ranging from 7.75 mg/L in the Undiked Marsh to 8.56 mg/L at Walker Creek Marsh and means for these marshes ranging from 8.39 mg/L and 9.21 mg/L (Table 7).

Approximately 8 percent of the oxygen concentrations recorded in reference marshes fell below 5 mg/L, the Basin Plan standard, and another 1.2 percent fell below 2 mg/L, the threshold for hypoxia (Table 7). There were no instances in which oxygen levels fell below 0.5 mg/L (Table 7). In contrast, in the Project Area, oxygen concentrations fell below the Basin Plan standard during 25 percent of the sampling periods and the hypoxic threshold during approximately 12.2 percent of the sampling periods, with 5.4 percent of the values plummeting below 0.5 mg/L, the threshold for anoxia (Table 7). Most of these exceedances occurred in the East Pasture. Oxygen concentrations in Upstream Areas fell between those of the Project Area and Reference Marshes, with 14 percent of the values recorded falling below 5 mg/L and 4 percent falling below 2 mg/L (Table 7). Only a few values fell below 0.5 mg/L.

- **No Real Difference in pH Between Waters in Project Area and Reference Areas**: The pH of Study Area waters is influenced by a number of factors, including source of waters (i.e., tidal versus potentially granite-derived freshwater and groundwater), biogeochemical processes (breakdown of organic matter and production of humic acids), and primary productivity of algae (production of bases when phytoplankton become more active). Ultimately, even climate change may affect pH through acidification of ocean and estuarine waters. These factors can affect aquatic communities in the Study Area by promoting the production of toxic forms of ammonia when pH is high and decreasing production of certain nutrients (i.e., nitrates) when pH is low. In addition, extremely low and high pH can cause physical damage to skin, gills and eyes of fish, as well as other physiological problems.

  Mean (geometric) pH conditions did not appear to differ significantly between Study Areas. The geometric mean of pH was estimated as 7.60 in the Project Area, 7.62 in the Reference Area, and 7.63 in Upstream Areas (Table 7). Interestingly, while Major Study Areas did not have significant differences in pH, pH did differ within the Project Area (excluding upstream sampling sites) and Reference Areas. Low within-site variance may have led to statistically significant differences between seemingly similar median pH values in the Project Area. The geometric mean pH in most of the Project Area ranged tightly between 7.50 in East Pasture to 7.79 in Project Area portion of Lagunitas Creek, although the median pH for Olema Marsh fell considerably below this range (6.90).

  The pH tends to be higher in tidally influenced areas as tidal waters tend to be more alkaline (~ 7.8) or during times or in areas of abundant phytoplankton productivity. However, in the

West Pasture, where the median pHs was estimate at 7.60, baseline pH also appeared to be higher in the upstream portions of Fish Hatchery Creek that flows off the Inverness Ridge (~7.8 – 8.1), which may be related to the underlying chemistry that exists from weathering of this granite-dominated geologic formation. Often, granitic substrates are associated with lower pH values (Smedley 1991), but some mineral or group of minerals within this particular geologic formation may lead to run-off having higher pH values. In addition, pH in portions of Tomasini Creek waters upstream of tidal influence had a median value of 7.7: Tomasini Creek flows off of the more Franciscan Formation-dominated ridges on the east side of Tomales Bay. Conversely, baseline pH appeared to be slightly depressed (~5.9 – 6.6) in locations primarily influenced by groundwater. Most of the low pHs in the West Pasture Old Slough were recorded in upstream sampling locations of the West Pasture Old Slough, which is fed by groundwater from an adjacent parcel and surface run-off.

Mean (geometric) pH also differed seemingly between reference marshes, although the range of means was relatively tight at least from a biological standpoint (7.47 in the Undiked Marsh to 7.87 at Limantour Marsh; Table 7). Approximately 11 percent of the pHs recorded in reference marshes exceeded 8.5, the upper Basin Plan limit, while pH never fell below 6.5 (Table 7). In comparison, in the Project Area, pH fell below 6.5 during approximately 2 percent of the sampling periods and exceeded 8.5 approximately 3 percent of the time. In Upstream Areas, approximately 1 percent of the values recorded fell below 6.5, and approximately 2.6 percent exceeded 8.5 (Table 7). The 5th and 95th percentiles for Upstream Areas were 6.90 and 8.44, respectively, which, again, falls very close to those estimated for the Reference Marshes and Project Area.

- **Strong Freshwater Influence Maintains Lower Temperatures in Project Area than Reference Areas**: Water temperatures are driven by a number of factors, including ambient air temperatures, water residency time, solar radiation, degree of shading of waters from vegetation, as well as the magnitude of freshwater and groundwater influences as both freshwater and groundwater tending to be colder than estuarine waters. Temperatures of waters within these areas have important ramifications on aquatic organisms, with listed species such as tidewater goby and salmonids either not thriving or even dying at higher temperatures (i.e., 25 degrees Centigrade).

  While diking of the Giacomini Ranch and the culvert-levee road system at Olema Marsh resulted in longer residency time for waters – and more time for sunlight to drive up water temperature – the substantial freshwater influences from both creek and emergent groundwater flow appeared to moderate the effect of these management impacts on water temperature. In fact, median temperatures in the Project Area (15.1 degrees Centigrade) were lower than those in Reference Areas (17.3 degrees Centigrade), but, not surprisingly, higher than those in Upstream Areas (12.7 degrees Centigrade; Table 7).

  Temperature differences within the Project Area – excluding upstream sampling sites -- were not considered significantly different, with medians ranging from 13.3 to 13.8 degrees Centigrade for Tomasini Creek and Olema Marsh, respectively; 14.4 degrees Centigrade for the Project Area portion of Lagunitas Creek, and 15.3 to 15.4 degrees Centigrade for the East and West Pastures, respectively.

  Temperatures were also relatively similar between Reference Area marshes. Median temperatures were remarkably similar, ranging between 15.7 degrees Centigrade for Walker Creek Marsh and 16.5 degrees Centigrade for the Undiked Marsh (Table 7). Means were slightly higher, ranging from 16.9 degrees Centigrade for Walker Creek Marsh and 17.5 degrees Centigrade for Limantour Marsh (Table 7).

  During the study period, approximately 6.7 percent of the temperatures recorded in reference marshes exceeded the lethal limit for salmonids of 25 degrees Centigrade (Moyle 2002), and another 17.8 percent exceeded 22 degrees Centigrade, the suboptimal limit for salmonids (Moyle 2002). Comparatively, in the Project Area, temperatures exceeded the lethal limit during 5 percent of the sampling periods and exceeded the suboptimal limit during approximately 15 percent of the sampling periods. As noted earlier, lower medians and fewer exceedances of temperature thresholds in the Project Area than in reference marshes despite diking and low to non-existent exchange with outside water bodies undoubtedly results from the large volume of cool freshwater and groundwater inflow that flows into the Project Area and lowers ambient temperatures in creeks, ditched sloughs, drainage ditches, and other exposed water features.

- **Nitrates Are the Primary Dissolved Nutrient in the Project and Reference Areas:** Nutrients are vital to most life, both plant and animal. They make plants and algae grow and, in the form of food, sustain animal life. However, in excessive amounts, nutrients can prove problematic to estuarine health, encouraging over-proliferation of algae that result in wide swings in oxygen levels of waters during the day with potentially dire consequences to aquatic life. Surges in primary productivity during the day can inadvertently increase concentrations of nutrients that are actually toxic to fish and other animals, such as nitrates, nitrites, and unionized ammonia. Sources of nutrients to estuarine systems include export of inorganic and organic nutrients from the upper watershed and the ocean, as well as point source and non-point source discharges from on-site or adjacent agricultural, urban, and commercial land uses.

  Within the Study Areas, nitrates clearly represented the dominant nutrient source. In contrast to ammonia and phosphates, nitrates were only very rarely not detected, even at relatively high commercial laboratory detection limits. Average nitrate concentrations differed between Major Study Area Groups, although median concentrations within the Project Area (0.83 mg/L) were actually not considered significantly different from those in the Reference Areas (0.7 mg/L; Table 8). Statistical analysis power may have been reduced by high variance in the data, as is evident from the considerable difference in the Project Area median and mean: estimated means ranged from 3.22 mg/L for the Project Area to 0.86 mg/L for Reference Areas (Table 8). Even results from the LMER/BRIE study a decade earlier – which were, at least for Bay samples, generally much lower in magnitude than ours – showed nitrates to typically represent the predominant source of nutrients.

  The Project Area mean was substantially influenced by consistently high values in the more heavily managed East Pasture, which supported two active dairy herds, as well as being more actively managed in terms of irrigation, manure spreading, haying, land leveling, and other actions. Within the Project Area (excluding upstream sampling sites), estimated nitrate concentrations averaged 7.25 mg/L for the East Pasture and then dropped to below 1.1 mg/L for the other sub-groups: 1.06 mg/L for Olema Marsh; 1.02 mg/L for Tomasini Creek; 0.87 mg/L for Lagunitas Creek; and 0.75 mg/L for the West Pasture. While nitrate concentrations were lower in less heavily managed portions of the Project Area, these areas were still subject to nitrate inputs from passive agricultural management of the West Pasture (e.g., grazing of dry or less active dairy herds), dairy use of Lagunitas Creek both inside and directly upstream of the Project Area, non-point source run-off and stormwater flow from the town of Point Reyes Station, and potential influence of leaking septic systems in groundwater that flows along the perimeter of the Giacomini Ranch and Olema Marsh.

  In most of the Project and Reference Areas, nitrates never exceeded USEPA water quality objectives of 10 mg/L as nitrate-N for human consumption. However, in the East Pasture, approximately 7 percent of the nitrate samples collected exceeded 10 mg/L, with all of the exceedances coming from a ditch at the base of the Dairy Mesa (Table 8). Interestingly, nitrites were generally not detected (<0.05 mg/L), in the Project Area, but they were occasionally found in Reference Areas, with Walker Creek and Limantour Marsh both having six (6) detections, although only three (3) samples exceeded RWQCB recommended thresholds of 0.5 mg/L (Table 8).

Despite high concentrations in the Project Area, loading rates for the Giacomini Ranch and Olema Marsh were only slightly higher than Reference Areas. Estimated instantaneous loading rates for the Project Area averaged 0.54 mg/s, compared to 0.51 mg/s for Reference Areas. Incorporated into this estimated mean is the fact that the East Pasture – where concentrations were highest – essentially contributed nothing to downstream loading, because it was diked. The only potential for loading from the East Pasture came during moderate to large storm events when floodwaters overtop the levees or when the Giacominis occasionally pumped ditch waters into Lagunitas Creek. However, even if the East Pasture had been operated as a muted tidal unit, the volume of water that these ditches and sloughs could have contributed to downstream flow would have limited loading rates to between 0.1 and 1.15 mg/s for the East Pasture Old Slough based on average discharge for similarly sized creeks in the adjacent Undiked Marsh. The upper estimated loading rate represents approximately the 89th percentile of loading for Reference Area creeks.

In comparison, estimated nitrate loading from Upstream Areas (mean=4.22 mg/s) was considerably higher than that of the Project Area or Reference Areas. This exceptionally high estimated average for loading rates in Upstream Areas is driven by storms occurring during some of the sampling events, which increased means for Lagunitas Creek and upstream areas of Bear Valley Creek. In addition, Reference Area means were also highly influenced by high estimated average loading rates for Walker Creek. Nitrate loading averaged an estimated 1.02 mg/s at Walker Creek Marsh, compared to 0.31 mg/s for Limantour Marsh and 0.20 mg/s for the Undiked Marsh.

While loading was considerably higher at Walker Creek Marsh relative to the other marshes, little difference existed in average nitrate concentrations between Reference Areas, with means estimated at 0.82 mg/L for Limantour; 0.87 mg/L for Walker Creek Marsh, and 0.89 mg/L for the Undiked Marsh. Based on the degree of watershed development, a larger variation in nitrates would have been expected between Limantour Marsh and the other marshes and possibly even between Walker Creek Marsh and the Undiked Marsh. Limantour Marsh occurs in the Seashore in an extremely lightly developed watershed. While there was some agricultural development historically, the watershed has not supported agriculture for quite some time. There are a very small number of residences used for park housing, as well as recreational use of adjacent trails by hikers and equestrians. In contrast, Walker Creek Marsh lies at the terminus of a heavily agricultural watershed, although there are few homes and towns, with most development associated with ranches. The Undiked Marsh is situated adjacent to two fairly populated rural residential developments in Inverness Park and Inverness and is also influenced by surface water inflow from Lagunitas and tributary subwatersheds that still support beef and dairy cattle ranches, as well as several densely populated communities.

The similarity in nitrate concentrations between these very different watersheds suggests that nitrogen and other nutrient levels are strongly controlled by internal as well as external factors such as agricultural and residential development. This premise is supported by the fact that there were no clear seasonal patterns in nitrate concentrations in Reference Areas. Similarly, while concentrations of nitrates were highest in winter and fall sampling events in the Project Area, there were occasionally spikes or pulses in spring or summer that were unrelated to increases in streamflow or run-off. Within the Project Area, some of these may relate to the presence of cows either inside or directly upstream of the ranch. However, within Reference Areas (and possibly the Project Area), some of the pulses in nitrates during non-flood periods may result from inorganic nutrients being regenerated “internally” from breakdown of organic matter within marshes. Smith et al. (1996) did find that nitrate concentrations varied sharply with flow below a certain streamflow threshold value of 50,000 m^3 (1.77 million cf^3 per day), which occurs almost 300 days per year, so concentrations should have dropped with decreases in streamflow during the summer and fall if nitrates were tied strictly to inputs from outside sources. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that these systems acted as sources of inorganic nitrogen and phosphorous to the Bay during the summer, probably due to breakdown of organic matter (Chambers et al. 1994b).

Higher relative levels of nitrates are also promoted by biochemical processes in creeks and marshes. Well-oxygenated waters within Reference Areas and most of the Project Area ensure that, if the ammonia form of nitrogen does enter these systems, it is promptly converted to nitrates. Ammonia was only infrequently detected, and most of the detections came from the Project Area and the East Pasture specifically. Within the Project Area (excluding upstream sites), estimated ammonia concentrations in the East Pasture averaged 2.61 mg/L, which differed significantly from values estimated for the West Pasture (0.45 mg/L) and Tomasini Creek (0.20 mg/L; ~MDL). Estimated means were substantially higher than medians due to the influence of occasional ammonia pulses, with medians ranging from 0.61 mg/L in the East Pasture to less than 0.001 mg/L for Lagunitas Creek. Ammonia was not detected in Olema Marsh. Some of the areas with the highest ammonia concentrations included the Giacomini Ranch's East Pasture drainage ditches, the drainage ditch receiving groundwater and feedlot-influenced stormwater run-off from Point Reyes Station, and shallowly flooded flats in the West Pasture. A few spikes also occurred in the downstream portion of Lagunitas Creek, with levels once totaling 13 mg/L after a potential discharge of flood waters from the pasture: estimated concentrations at this downstream Lagunitas Creek location averaged 0.68 mg/L.

Most of the ammonia pulses in the Project Area occurred in waters with lower oxygen (or pH) levels and appeared more related to cattle grazing and other management practices such as ditch maintenance than with timing of storm inflows or run-off. Cattle grazing provided a source of ammonia that would be maintained in low oxygen waters, while ditch maintenance promotes hypoxic conditions by increasing organic matter available for mineral decomposition and creating a surge in biological oxygen demand. These conditions favor retention of nitrogen as ammonia over nitrates. Within the Project Area, ammonia was more frequently detected during sampling events in fall, summer, and spring than in winter, with only 23 percent of ammonia detections occurring during the winter sampling periods. During the winter, the water column would have had higher levels of oxygen due to higher streamflow, lower water residence time, and less diel variability in oxygen due to lower primary productivity levels, so inputs of ammonia and other forms of nitrogen into the system would have been more likely to be quickly converted to nitrates.

Ammonia pulses in Reference Areas more likely resulted from decreases in oxygen levels in tidal creek waters due to high primary productivity and subsequent respiration or an increase in water residency time, while sporadic pulses in creeks such as Lagunitas and Walker Creek probably related more to the immediate proximity of a source of ammonia than low oxygen waters. The Reference Area mean for ammonia loading was highly influenced by an estimated loading value of 1.89 mg/s for the mainstem of Walker Creek adjacent to the marsh in October 2003. The Project Area (est. mean = 0.007 mg/s) and Upstream Area (est. mean = 0.009 mg/s) had seemingly lower estimated loading rates than Reference Areas (0.034 mg/s), but they were not statistically different.

Interestingly, despite occasional spikes in ammonia concentrations, only a few sampling locations exceeded the maximum concentration limit for unionized ammonia in estuarine waters of 0.16 mg/L. One event occurred in the one East Pasture drainage ditch in which ammonia concentrations reached 76 mg/L, with the corresponding unionized ammonia concentrated estimated at 2.52 mg/L, well above Basin Plan standards. In addition, unionized ammonia likely exceeded this limit in Lagunitas Creek in April 2003, when total ammonia levels climbed to as high as 13 mg/L. While ammonia was obviously detected in lower, but still relatively high, concentrations elsewhere, particularly in the East Pasture, temperature and/or pH did not climb high enough to encourage dissociation of ammonia into its unionized ion.

Phosphates, too, appeared to be driven more by biochemical processes than upstream loading, at least in most of the Project Area. As with ammonia, phosphates were only infrequently detected, and most of the detections occurred in the Project Area, specifically the East Pasture. Phosphates averaged an estimated 0.99 mg/L in the Project Area compared to 0.23 mg/L for Reference Areas and 0.12 mg/L for Upstream Areas: estimated medians were even lower, ranging from 0.23 mg/L for the Project Area to 0.08 mg/L for Reference Areas (Table 8). In the East Pasture, concentrations were estimated to average 2.40 mg/L, which was significantly higher than the means for the rest of the Project Area (excluding upstream sampling sites): West Pasture (0.15 mg/L), Tomasini Creek and the downstream portion of Lagunitas Creek (0.16 mg/L), and Olema Marsh (0.24 mg/L).

Within Reference Areas, estimated average concentrations of phosphates were lower in the Undiked Marsh (0.16 mg/L) than in either Walker Creek Marsh (0.26 mg/L) or Limantour Marsh (0.37 mg/L). In fact, estimated mean phosphate loading rates for Reference Areas (0.15 mg/s) were actually higher than either Project Areas (0.03 mg/s) or Upstream Areas (0.06 mg/s). The Reference Area mean was skewed by some high loading values estimated for the mainstem of Walker Creek (range = 3.04 to 3.57 mg/s), which drove up the Walker Creek mean (0.33 mg/s). Lagunitas Creek had the second highest mean loading rate (0.20 mg/s), followed actually by Limantour Marsh (0.11 mg/s).

While concentrations of phosphates were sometimes high during storm events – as was observed in Walker Creek and Lagunitas Creek -- they also showed peaks during spring and fall. These spring and fall peaks probably resulted from recirculation of phosphates from sediments into overlying waters when the upper sediment and bottom water layers became anoxic due to low oxygen levels the soil-water interface, which can happen when respiration rates increase substantially. Phosphate concentrations were highest in the Project Area and, specifically, in the East Pasture due to not only the proximity to sources such as cattle and septic-influenced groundwater, but also due to agricultural management regimes that caused oxygen levels within ditch waters to frequently be low. Low oxygen levels also probably accounted for the higher estimated average phosphate concentrations for Olema Marsh and for the higher estimated average concentration and loading rates for many of the Reference Areas such as Limantour and Walker Creek marshes. In addition, Reference Areas are closer to the ocean than are the Project Area and Upstream Areas (with the Undiked Marsh being the farthest from the inlet): phosphorous is naturally higher in marine-influenced environments (Mitsch and Gosselink 2000, Day et al. 1989).

- **Pathogen Indicators Support Earlier Findings of High Pathogens in Project Area:** In general, pathogens represent one of the major water quality issues facing Tomales Bay. Pathogens, along with the mercury that resulted from improper closure of a mine in the Walker Creek watershed, have the largest potential to affect human and wildlife health. The Bay supports not only a considerable number of oyster-growing operations, but recreational activities such as boating, kayaking, and swimming. While seemingly pristine, the Bay and its surrounding watershed generate a considerable volume of pathogen indicator bacteria, total and fecal coliform, because of the large amount of land in agricultural use, leaking septic systems in the many rural residential communities perched on the Bay's edge, and other factors such as bilge discharge from boats. During the last few decades, poor water quality in Tomales Bay has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak. These problems have resulted in a number of listings of the Bay by regulatory agencies, including a listing of "threatened" under the state's Shellfish Protection Act and impaired under Section 303(d) of the CWA for shellfish harvesting, municipal water supply, and contact and non-contact water recreation.

With Giacomini Ranch supporting a considerable number of dairy cattle during its operation, the Project Area was certainly located in an area where it could have had maximum impact on downstream water quality. The ranch straddles the head of Tomales Bay bisected by Lagunitas Creek, which flows through the ranch and large Lagunitas Creek Delta into open water portions of the Bay. The Project Area did have substantially higher estimated median concentrations of fecal coliforms (1,600.9 mpn/100 ml) than the Reference Areas (72.0 mpn/100 ml) and, seemingly, Upstream Areas (637.1 mpn/100 ml), although these differences were not statistically significant (Table 9). Not surprisingly, the heavily managed East Pasture had significantly higher estimated geometric means or medians (6,298.8 mpn/100 ml) than most of the other sub-sampling or Sub-Group areas (excluding upstream sampling sites), with the possible exception, from a statistical standpoint, of Olema Marsh (1,821.4 mpn/100 ml). Estimated geometric means or medians for all other subsampling areas ranged between 356.9 mpn/100 ml for downstream Lagunitas Creek to 1,131.7 mpn/100 ml for the West Pasture.

In terms of compliance with Basin Plan or TMDL standards, more than 95 percent of all samples collected from the Project Area – this time, including upstream sites – exceeded objectives for shellfish harvesting and municipal water supply of 14 and 20 mpn/100 ml respectively (Table 9). Approximately 78 percent exceeded contact water recreation standards of 200 mpn/100 ml, and 36-47 percent of the values actually were higher than 2,000 to 4,000 mpn/100 ml, the standards for non-contact water recreation (Table 9). Estimated geometric means or medians calculated using for four years of sampling results showed that the East Pasture exceeded all Basin Plan standards, while the other subsampling areas at least met the 2,000 mpn/100 ml threshold for non-contact water recreation, if not other objectives. Lagunitas Creek exceeded the TMDL standard of 200 mpn/100 ml during 72 percent of the sampling events and the 90th percentile standard of 400 mpn/100 ml 58 percent of the time, with the overall geometric mean and 90th percentile estimated at 584.6 mpn/100 ml and 6,146.8 mpn/100 ml, respectively (Table 9). The TMDL load-based allocation of 95 mpn/100 ml set for Green Bridge location on Lagunitas Creek was never met during the study period (Table 9).

In comparison, only 34 percent of Reference Area samples exceeded contact water recreation standards, and less than 12 percent exceeded non-contact water recreation standards (Table 9). Two of the marshes came close to meeting objectives for shellfish harvesting or municipal water supply, with estimated geometric means of 33.3 mpn/100 ml (Walker Creek Marsh) and 23.1 mpn/100 ml (Limantour Marsh; Table 9). These medians are significantly lower than that estimated for the Undiked Marsh (478.6 mpn/100 ml), which exceeded all mean-related objectives except for non-contact water recreation (Table 9). While Walker Creek had a similar estimated geometric or median to Limantour, the differences between these marshes is clearer from the estimated arithmetic means, with Limantour Marsh having a lower arithmetic mean (126.3 mpn/100 ml) than Walker Creek Marsh (812.8 mpn/100 ml; Table 9). Estimated average loading rates also differed considerably between Reference Areas, averaging 1.1 million mpn/s in the Undiked Marsh; 184,175 mpn/s in Walker Creek Marsh; and 257.8 mpn/s in Limantour Marsh. The disparity between estimated median loading rates was not quite as striking, with the Undiked Marsh estimated at 274.3 mpn/s; Walker Creek Marsh, 118.6 mpn/s; and Limantour Marsh, 24.9 mpn/s.

In terms of potential impacts to downstream water quality, the East Pasture would seem to have posed the largest threat. However, because the East Pasture was diked and largely disconnected from Lagunitas Creek, estimated instantaneous loading rates were considerably lower in the Project Area than Upstream Areas, although not necessarily lower than Reference Areas. Estimated loading rates averaged 3.86 million mpn/s for Upstream Areas; 249,389 mpn/s for the Project Area; and 60,094.1 mpn/s for Reference Areas. As with many of the other pollutants, estimated median loading rates were considerably smaller, showing the influence of pulses during the winter or wet season sampling events. Estimated medians were 437.2 mpn/s for Upstream Areas, 56.0 mpn/s for the Project Area, and 98.3 mpn/s for Reference Areas. Within the Project Area (e.g., excluding upstream sampling sites), downstream Lagunitas Creek had the highest estimated mean instantaneous loading rate (3.12 million mpn/s), followed by Tomasini Creek (1.81 million mpn/s), Olema Marsh (254,691 mpn/s), and the West Pasture (8,766.9 mpn/s). Estimated median loading rates were generally lower and showed less variance between sites, with values estimated at 2,533.1 mpn/s for downstream Lagunitas Creek, 2,273.8 mpn/s for Olema Marsh, 387.2 mpn/s for downstream Tomasini Creek, and 55.5 mpn/s for the West Pasture.

Seasonal patterns varied somewhat between concentrations and loading. While some of the highest levels and loading events were recorded during storm events or the wet season, there were spikes in concentrations also observed during many other seasons of the year. These results point to sources other than storm-loading from upstream watershed sources such as cattle activity as also contributing to pathogen levels in the portion of Lagunitas Creek. For Lagunitas Creek, approximately 64 percent of the highest values occurred either during storm events or during the wet season, however, estimated loading reached as high as 13,356 mpn/s in August 2005 in the downstream section of Lagunitas Creek and 7,680 mpn/s at the upstream location in July 2006. Both of these areas were subject to the influence of cattle during these periods, with cattle often in or adjacent to the creek directly upstream of the Green Bridge and crossing the creek midway through the Project Area reach as part of the Giacomini Ranch cattle operations (Appendix E). A recent study by Lewis and Atwill (2007) on pathogen transport in five northern California estuaries, including the Lagunitas Creek subwatershed, found that Lagunitas Creek exhibited the highest counts of bacteria during dry season base flow conditions, which the authors felt pointed to a source of bacteria being directly discharged into the creek

Some of the highest values for Giacomini Ranch and Reference Area creeks, drainages, and other water features or sources occurred several weeks after a large series of storms in late April 2006. In the Giacomini Ranch East Pasture, many of the highest concentrations occurred during summer months, with concentrations seemingly diluted during winter or wet season sampling events. The muted tidal areas in the West Pasture and Tomasini Creek showed more instances of concentrations being higher in the wet season or during rainfall events, although concentrations were sometimes elevated during other periods, as well.

- **High Primary Production Potential in Project Area**: One of the most compelling reasons for preserving wetlands has been their importance to estuarine and marine food webs and to many of the commercially and recreationally valuable species that live in these coastal environments. In the 1970s-1980s, estuarine scientists hypothesized that estuaries exported a large amount of the organic matter produced from decaying vascular plants into outer estuarine and marine food webs, thereby supporting aquatic organisms such as fisheries in these systems (Day et al. 1989). Since then, the status of estuaries as exporters and the relative importance of detritus relative to other food sources such as phytoplankton to estuarine and marine food webs have been actively debated in the scientific community, with, not surprisingly, differences in trophic status and food source apparent between systems, longitudinal gradients within systems, seasons, and consumer groups or guilds. For example, in the Sacramento Delta, phytoplankton and POC derived from decomposition of phytoplankton represent the cornerstone of the food web (Sobczak et al. 2005), while, in northern San Francisco Bay restoring and natural marshes, vascular plant detritus appeared to be potentially more important (Howe and Simenstad, undated).

  As with nutrients, there can be too much of a good thing with both organic matter (DOC and POC) and algae. Systems where algae grows uncontrollably due to high nutrient influx, warm temperatures, and long water residency times often become eutrophic, causing wide swings in oxygen levels that can negatively affected and even kill fish. In addition, changes in pH associated with excessive oxygen production by phytoplankton can also trigger shifts in the chemistry of waters, helping to lead to the formation of unionized ammonia, which increases when both temperatures and pH increase. Unionized ammonia is toxic to aquatic organisms. In the recent evaluation of the health of the nation's estuaries by NOAA, a majority of the estuaries showed signs of eutrophication, with one of the most common symptoms of eutrophication being high chlorophyll a (Bricker et al. 2007). Tomales Bay was listed as highly susceptible due to nitrogen loading or other factors, although the Bay has not been characterized as an eutrophic estuary by other researchers (Cole 1989; Chambers 2000; Lewis et al. 2001).

While organic matter represents an important part of the estuarine food web, high levels of organic matter can play havoc in systems where estuarine and riverine waters are also used for water supply. When disinfectants such as chlorine are added to drinking water to kill microbial pathogens, they react with bromide and organic matter to form disinection by-products. When these are consumed in excess over a number of years, they can have deleterious effects on the liver, kidneys, or central nervous system or may cause an increased risk of cancer or anemia (Bull and Kopfler 1991 *in* Jassby et al. 2003). In 2006, California Department of Health and Safety established disinfection by-products as a primary drinking water standard.

As with many of the other parameters, the Project Area had substantially higher levels of DOC (med. = 4.2 mg/L) than either the Reference (med.= 2.9 mg/L) or Upstream (med.= 3.1 mg/L; Table 10) Areas. Similarly, chlorophyll concentrations were also higher in the Project Area (med.= 3.0 mg/L) than in Upstream Areas (1.8 mg/L), but were actually similar to those in Reference Areas (2.8 mg/L; Table 10). Due to some large values, estimated mean chlorophyll concentrations showed stronger disparity, with levels averaging 30.7 mg/L in the Project Area compared to 9.2 in Reference Areas and 8.3 mg/L in Upstream Areas (Table 10).

Within the Project Area itself (e.g., not including sampling stations upstream of the restoration area), the East Pasture had the highest DOC and chlorophyll a concentrations. Median DOC concentrations were 14.5 mg/L, followed by 4.3 mg/L for the West Pasture and Tomasini Creek, 3.4 mg/L for Olema Marsh, and 2.5 mg/L for Lagunitas Creek. For chlorophyll a, medians were estimated at 9.8 mg/L for the East Pasture, 3.3 mg/L for the West Pasture, 2.1 mg/L for Olema Marsh, 1.5 mg/L for Lagunitas Creek, and 0.06 mg/L for Tomasini Creek. All of the estimated means were skewed by episodic pulses in chlorophyll levels, particularly the East Pasture, which had levels averaging 69.0 mg/L compared to 13.3 mg/L for the West Pasture, 4.5 mg/L for Olema Marsh, 2.8 mg/L for Lagunitas Creek, and 1.6 mg/L for Tomasini Creek.

Higher concentrations of DOC in the East Pasture were directly related to the more intensive agricultural management of this pasture relative to the West Pasture, which was not as subject to heavy grazing, frequent ditching, irrigation, or manure spreading, although grass was cut annually for hay. Most of these pulses in DOC in areas other than the East Pasture probably correspond to temporal patterns in plant or algal decomposition. In terms of phytoplankton, higher "productivity" as measured by chlorophyll a probably resulted from the lack of hydrologic connectivity in the East Pasture, which led to more stagnant water conditions and longer residence times. In addition, the levees also shielded waters in the East Pasture, as well as the West Pasture and Tomasini Creek from the churning effects of the wind. Interestingly, both DOC and chlorophyll a levels were relatively low in Olema Marsh, which would have been expected to have high rates of both due to abundant plant decomposition, long water residence times, and lack of hydrologic connectivity within different portions of the marsh leading to more stagnant pools.

In contrast to concentrations, instantaneous loading rates for DOC did not appear to differ between the Project Area (median=0.02 mg/s), Reference Areas (median=0.27 mg/s), and Upstream Areas (median=0.13 mg/s). In general, mean instantaneous loading rates were only slightly higher than median rates, ranging between 1.4 mg/s for Reference Areas, 1.5 mg/s for the Project Area, and 2.4 mg/s for Upstream Areas. Within the Project Area (e.g., not including sampling stations upstream of the restoration area), the downstream sampling station of Lagunitas Creek at the Giacomini Ranch North Levee had the highest DOC loading rate (median=2.0 mg/s) with the diked, non-tidal East Pasture having the lowest (median=0.0 mg/s). Mean loading rates were skewed in all subsampling areas by sharp peaks in loading during certain sampling events, with loads averaging 0.1 mg/s for the West Pasture, 1.2 mg/s for Tomasini Creek and Olema Marsh, and 9.2 mg/s for Lagunitas Creek. With the exception of Lagunitas Creek, which had loading rates estimated of 60.5 mg/s in February 2006, peak values did not exceed 7.7 mg/s in the Project Area.

Chlorophyll a loading rates were also driven by pulses in loading, and these pulses did lead to some differences in instantaneous loading rates between Study Areas, with chlorophyll loading actually seemingly higher in the Reference Areas (est. median=0.05 mg/s) than in the Project Area (est. median=0) or Upstream Areas (est. median =0.01 mg/s). The disparity was even more striking with estimated mean loading rates, with Reference Areas averaging 1.7 mg/s; Upstream Areas averaging 0.8 mg/s; and the Project Area averaging 0.4 mg/s. Some of the differences between the Project Area and Reference Area results from the lack of any “loading” of chlorophyll from the East Pasture and several large pulses in loading in the mainstem of Walker Creek, despite the fact that concentrations were always relatively low to moderate in the creek.

Loading rates for DOC and chlorophyll a, as well as concentrations of these parameters, were similar between Reference Areas. There were no significant differences in DOC concentrations between Reference Area marshes, with medians ranging from 2.8 mg/L (Limantour Marsh) to 3.1 mg/L (Walker Creek and the Undiked Marsh). For chlorophyll a, median concentrations appeared a little lower for Limantour Marsh (1.6 mg/L) than for the Undiked Marsh (3.0 mg/L) and Walker Creek Marsh (3.1 mg/L), but differences were not statistically significant. Based on estimated means, pulses in phytoplankton productivity appeared to drive up levels in Walker Creek Marsh (17.6 mg/L) more so than in the Undiked Marsh (4.7 mg/L) or Limantour Marsh (4.5 mg/L). Sharp peaks in both DOC and chlorophyll loading drove up mean loading rates relative to the medians, particularly for Walker Creek Marsh. Median DOC loading rates varied only slightly between 0.23 mg/s at the Undiked Marsh to 0.29 mg/s at Limantour Marsh, but Walker Creek had a mean loading rate of 2.8 mg/s, which was much higher than the other marshes (0.65-0.83 mg/s). Estimated chlorophyll a loading rates for Walker Creek Marsh averaged 3.3 mg/s, compared to 1.3 mg/s for Limantour Marsh and 0.7 mg/s for the Undiked Marsh. Estimated median chlorophyll a loading rates were much lower, ranging from 0.2 mg/s for Walker Creek Marsh to 0.02 mg/s for the Undiked Marsh. While DOC and chlorophyll a concentrations were always among the lowest on the mainstem of Walker Creek relative to interior tidal channels, the creek displayed frequent pulses in DOC and chlorophyll a loading throughout the year.

Somewhat surprisingly, both DOC and chlorophyll a did not exhibit any clear seasonal or temporal patterns. In the East Pasture, pulses of DOC occurred throughout the year due to intensive agricultural management and activities such as ditching. There were fewer pulses in other Project Area sub-groups with those that did occur typically distributed throughout the year, although many took place during winter or wet season sampling events. For chlorophyll a, concentrations in the Giacomini Ranch and Olema Marsh were typically highest in the fall and summer, with occasional peaks in spring. While winds in Tomales Bay might generally dampen phytoplankton productivity in the Bay itself, the levees protected drainage ditches and ditched sloughs from the churning effects of the wind and allowed warmer temperatures and higher rates of solar radiation to increase primary production. Also, despite the drop in flows, there was probably no nutrient limitation on production during either the summer or fall in the Project Area.

DOC concentrations in Lagunitas Creek were somewhat uniform between sampling events, although loading was highest during high flow events due to the larger volume of water. Higher levels and loading rates of chlorophyll a in Lagunitas Creek occurred principally in the spring and fall, with a few higher values in summer. This temporal pattern, which differs somewhat from the Project Area, may relate to these seasons being periods when an optimal balance is achieved in nutrients, ambient air and water temperature, lower winds, and other factors, with nutrient inflow expected to be lower during summer and fall months.

The lack of temporal pattern extended to Reference Areas, with, for example, Limantour Marsh having the highest DOC values in the winter/wet season and spring sampling events and the Undiked Marsh having the highest values almost exclusively in fall with some winter/wet season high values. For chlorophyll a, concentrations were highest at Walker Creek in the spring and summer, with loading highest in the winter/wet season sampling events simply due probably to increases in flow volume, while, at Limantour Marsh, concentrations were highest in the winter, spring, and summer, with loading highest in the fall. The Undiked Marsh had peak chlorophyll a concentrations in the non-winter months, with loading rates highest in the spring and fall. Interestingly, in San Francisco Bay, temporal and concentration-related patterns in chlorophyll a have also recently shifted, with larger spring blooms occurring, as well as blooms in other seasons and an increase in baseline chlorophyll a levels (SFEI 2007).

Differences in reference marsh temporal patterns may relate to factors both inside and outside of the marsh. These factors may lead these systems to have what might be considered a very non-traditional pattern in DOC production and phytoplankton productivity. Internally, DOC is controlled by the timing and rates of vascular plant and algae die-off and decomposition and patterns in internal recycling and breakdown of decomposed plant materials in the waters and soil substrate. Outside of the marsh, upstream land use and management may affect the volume and timing of DOC import from riverine and terrestrial organic matter sources delivered to estuaries. These land use and management factors include reservoirs, agriculture, and rural residential developments. At Limantour Marsh, the Muddy Hollow reservoir may have affected timing of organic matter inputs from upstream reaches of Muddy Hollow Creek, with delivery increased during high rainfall periods when more waters flow out of the spillway. In conjunction with patterns in internal recycling of decomposing plant and plankton material, these factors could lead to pulses in DOC concentrations and, to some extent, loading throughout the year. Similarly, these factors can also affect timing and volume of nutrients delivered to downstream estuaries, which can promote phytoplankton productivity.

Primary productivity can be negatively affected by high turbidity rates, however, turbidity levels were similar between the Project and Reference Areas, which had higher levels than Upstream Areas. Turbidity levels averaged 22.7 NTU within the Project Area and 19.9 NTU within Reference Areas, with Upstream Areas averaging 13.4 NTU (Table 10). Among Project Area sites, the East Pasture had the highest turbidity levels (mean=36.6 NTU) with the West Pasture estimated at 13.3 NTU and Lagunitas Creek at 18.2 NTU.

The highest measured turbidity occurred at the downstream sampling station near the Giacomini Ranch North Levee in June 2003 with a value of 266 NTU. This value may have been an anomaly or the result of exchange with downstream Tomales Bay waters during an incoming tide or discharge of pasture waters from an adjacent pump, as values in upstream portions of Lagunitas Creek never exceeded a NTU of 26 on this same date. In general, turbidity fell below 50 NTU in Lagunitas and Fish Hatchery Creeks and 40 NTU in Tomasini Creek.

As with DOC and chlorophyll a, Reference Area estimates were substantially influenced by higher means for Walker Creek (25.8 NTU) than for the other marshes: Undiked Marsh (17.1 NTU) and Limantour Marsh (16.0 NTU). Surprisingly, the highest “turbidity” values did not occur in the winter or during wet season sampling events, but in other seasons. Turbidity is typically expected to be highest during the winter when sediment is being actively moved by creeks. The production of suspended particles may be due to events such as upstream dam releases, biological activity, cattle activity, and other activities within streams, ditches, and other water bodies.

- **West Pasture and Other Areas Much Less Heavily Impacted From a Water Quality Perspective Even Prior to Restoration**: One of the clear findings from our study was that the West Pasture and many of the Project Area sub-groups such as Tomasini Creek, Olema Marsh, and Lagunitas Creek were much less impacted than the East Pasture and often had water quality, nutrient, and pathogen conditions that were more equivalent to the Reference Areas than to the East Pasture. The East Pasture often almost all of the Basin Plan and USEPA objective exceedances in the Project Area and the striking dissimilarities between the Project Area and Reference Areas for many of the water quality parameters. In general, the other areas did exceed the Reference Areas in levels or loading of certain parameters, but, often, there was no significant difference between these areas and reference marshes.

- **What Represents "Ambient" Conditions?**: As was discussed earlier in this document, the Reference Areas represent a spectrum in historical and current land use and the magnitude of watershed development for agricultural and residential use. The Lagunitas Creek watershed has been developed for both agricultural and residential use, with most of the latter occurring in small communities scattered through the watershed, including the towns of Point Reyes Station, Inverness Park, and Inverness. The Walker Creek watershed also supports extensive agriculture, but is much less heavily populated, with only a few moderately populated communities and the rest of the population living on ranches or larger-acre properties. At one point, the Muddy Hollow Creek watershed was also farmed and was even the subject of a proposal to build a large ocean-front residential community, but with purchase of these lands by the Park Service, residential developments were shelved, and, today, there are only a few isolated homes still present in the area, with most of the use coming from recreational hikers and equestrians.

  Given the current extent of development within these watersheds, logically, Limantour Marsh, which lies at the terminus of Muddy Hollow Creek and Limantour Estero, would have been expected to have the lowest levels of nutrients and the best general water quality conditions. Walker Creek Marsh might have been expected to be a distant second: the creek does not support the numbers of people that Lagunitas Creek and many of these developments are associated potentially leaking septic systems. Admittedly, agricultural use has been linked in this watershed with impairment of the creek, and its condition has been further debilitated by improper closure of a mine within the upper portions of the subwatershed. Still, compared to the relative higher density of people and animals within the Lagunitas Creek watershed, Walker Creek might be expected to fall a distant second, but perhaps relatively close to Lagunitas Creek, which eventually flows out to Tomales Bay through the Undiked Marsh. The Undiked Marsh lies directly adjacent to Inverness Park and Inverness and is also influenced heavily by surface and groundwater flow – and associated pollutants -- from the Inverness Ridge.

  Results somewhat contradicted this informal hypothesis. Estimated average nitrate were just as high at Limantour Marsh as the other areas: concentrations were not significantly different, with Limantour Marsh averaging 0.82 mg/L; Walker Creek Marsh, 0.87 mg/L; and the Undiked Marsh, 0.89 mg/L. The situation for loading was somewhat similar despite the fact that streamflow volume in Muddy Hollow Creek is magnitudes of order lower than either Lagunitas or Walker Creeks. Nitrate loading averaged an estimated 1.02 mg/s at Walker Creek Marsh, compared to 0.31 for Limantour Marsh and 0.20 for the Undiked Marsh.

Similar trends occurred with phosphates. Estimated average concentrations of phosphates were lower in the Undiked Marsh (0.16 mg/L) than in either Walker Creek Marsh (0.26 mg/L) or Limantour Marsh (0.37 mg/L). Limantour Marsh also had higher estimated loading rates of phosphates (0.11 mg/s) than the Undiked Marsh (0.03 mg/s), although average rates were lower than those for Walker Creek Marsh (0.33 mg/s), which were driven up by some high loading values estimated for the mainstem of Walker Creek (range = 3.04 to 3.57 mg/s).

Interestingly, the pattern for fecal coliform in Reference Areas comes closest of all the potential pollutant sources measured to what might have been expected based on the degree of watershed development. The Undiked Marsh had much higher levels of coliform bacteria than Walker Creek watershed. The lowest levels and loading of coliform bacteria occurred in the Limantour Marsh. The geometric mean or medians for reference marshes were estimated at 23.1 mpn/100 ml for Limantour Marsh, 33.3 mpn/100ml for Walker Creek Marsh, and 478.6 mpn/100 ml for the Undiked Marsh. The differences between these marshes are even clearer from arithmetic means, with Limantour Marsh having a lower arithmetic mean (126.3 mpn/100 ml) than Walker Creek Marsh (812.8 mpn/100 ml). This pattern held true for loading, as well. Estimated instantaneous loading rates averaged 1.1 million mpn/s in the Undiked Marsh; 184,75 mpn/s in Walker Creek Marsh, and 257.8 mpn/s in Limantour Marsh. Chlorophyll a concentrations also appeared lower at Limantour Marsh (1.6 mg/L) than the other marshes (range of means = 3.1-3.2 mg/L), but the differences were significant.

These results suggest that, while all of these sites have been historically or are currently being impacted to some degree, reference site conditions – particularly conditions in marshes such as Limantour – should be used to guide interpretation of results for the Project Area and what degree of “improvement” might be realistically possible.

- **Downstream Water Quality Appeared to Improve Even When Project Area was Leveed**: One of the primary objectives for restoring the Giacomini Ranch and Olema Marsh relates to the considerable potential this area has to improve downstream water quality in Tomales Bay. Tomales Bay is considered impaired under Section 303(d) of the Clean Water Act for sediment, nutrients, pathogens, and mercury. Wetlands of all types have been shown in many cases to improve downstream water quality by filtering pollutants out of inflows, and these include both natural systems and wetlands specifically created to treat or refine wastewater (Mitsch and Gosselink 2001, Kadlec and Knight 1996). Agricultural and other types of management that involve construction of levees and installation of tidegates, culverts, and flashboard dam structures typically either reduce or eliminate the ability of wetlands to perform this function by disconnecting them from upstream sources. More than two-thirds of the inflow to Tomales Bay comes from Lagunitas Creek, which actually flows through the Giacomini Ranch, but levees have kept streamflow from spilling onto these historic floodplains except during moderate to large stormflow events. Tomasini Creek was also leveed to run along the eastern perimeter of the East Pasture. Within the Project Area, the remaining active floodplain for these systems was limited to a fringe of outboard marsh that developed on either side of the creek channels.

  For this reason, the Project Area was not expected to provide much in the way of downstream reduction in either concentrations or loading of nutrients or pathogens. The spatial locations of sampling stations on several of the creeks actually allow for some analysis of this hypothesis, with upstream locations on the outer perimeter of the Giacomini Ranch or Olema Marsh and downstream locations either midway through or at the downstream extent of these areas. Potential reduction in nutrients and pollutants was assessed for the predominant pollutants in the Project Area – nitrates and fecal coliform – which also had the most detections or values above the commercial laboratory detection limit.

  In general, floodplain systems are most effective at removing particulate forms of nutrients and other pollutants, because emergent vegetation “traps” the sediment or organic matter and removes it from water sheetflowing across the floodplain or marsh surface. Most inorganic nitrogen is transported as soluble nitrate, however, ammonium ions and organic nitrogen are often carried on sediment or organic matter: Estimates of sediment-bound nitrogen transport range as high as 51-57 percent in some systems (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). Retention rates for soluble nitrates on floodplains are very low, with rates estimated as only between 1-17 percent (Seitzinger et al. 2002, Van der Lee et al. 2004). Conversely, pathogens may be transported either bound to sediment or in solution, although during a recent study that included Lagunitas Creek and Walker Creek, most of the bacteria were in solution and not associated with suspended sediments (Lewis and Atwill 2007).

Most of these studies focus on the interaction between plants on floodplains and in off-channel or in-channel marshes and trapping of nutrients and pollutants, but pollutants can also be trapped within creek channels and bays by physical forces related to fluvial and estuarine sediment transport and circulation processes. Sediment laden with nutrients, organic matter, and pollutants are likely to deposit in areas where the creek gradient flattens or velocities decrease sharply. In addition, as has been discussed earlier, bathymetry, currents, and salinity, either alone or in combination, appear to drive concentrated zones of sediment deposition, which have been referred to as Estuarine Turbidity Maximum (ETM). Classically, ETM have been linked to the Null Zone observed in transitional regions of estuaries with classic estuarine or gravitational circulation (e.g., strong stratification of fresh and tidal flows) near the landward boundary of tidal influence, which occurs often around 2 ppt (Postma and Kalle 1955, Festa and Hansen 1976, Festa and Hansen 1978, Peterson et al. 1975 *in* Kimmerer 2004). In recent years, physical controls other than the Null Zone have been linked to ETM, including abrupt changes in bathymetry or shoaling (Schoellhammer 2001), ebb and flood tidal currents in river mouths (Ganju et al. 2004), and redistribution of dissolved and particulate fractions in intermediate rather than low salinity reaches (Rasheed et al. 1997). In addition to the effect that salinity has on stratification of estuarine waters and longitudinal gradients and currents, salinity can also play a direct role in determining patterns of sediment deposition through flocculation or aggregation of river-borne sediment particles caused by the increased electrostatic charge present at the landward edge of the “salt wedge” (Arthur and Ball 1979). The dynamics of Null Zones or ETM have not been specifically investigated on a system-wide basis in Tomales Bay, but ETM may exist at the mouth of Lagunitas, Walker, and other tributaries.

In keeping with this hypothesis that the Project Area would not be expected to have provided much water quality improvement prior to restoration, nitrate concentrations in Lagunitas Creek did not consistently show any decrease between the upstream sampling location at the Green Bridge and the downstream sampling location at the Giacomini Ranch North Levee. Nitrate concentrations averaged an estimated 0.96 mg/L at the upstream site and 0.87 at the downstream site, with medians very similar or equivalent – 1.0 mg/L and 0.87 mg/L, respectively. Loading also showed no statistically significant differences between upstream and downstream locations, although both the arithmetic mean and medians were seemingly lower at the downstream site (4.0 mg/s and 0.65 mg/s) than at the upstream site (14.5 mg/s and 1.47 mg/s). High variance from high loading during storm and other events may have reduced power of the test. Also, the levees may have precluded any filtering of nitrates by the small outboard marshplains present – or from depositing on the channel bottom -- by increasing flood flow velocities and, thereby, reducing the potential for retention in this portion of the system. A study on two small, at least partially diked deltaic marshes just northeast of the Giacomini Ranch showed that, in some marshes with well-developed channels, short water residence times resulting from channelization of short-duration, high-intensity flows may decouple these systems from the nutrient pathway during the winter, reducing their effectiveness in filtering contaminants (Chambers et al. 1994b).

In the West Pasture, where Fish Hatchery Creek was not necessarily leveed directly, but flowed within a leveed pasture, loading and concentrations did actually appear to drop between upstream sampling locations outside the Project Area and in the Project Area itself. Average nitrate concentrations dropped from 1.52 mg/L on Fish Hatchery Creek at Sir Francis Drake Boulevard to 0.84 mg/L on Fish Hatchery Creek midway through the West Pasture, which was less heavily grazed than the East Pasture. In terms of loading, similar trends occurred, with average loads dropping from 0.43 mg/s at the upstream Fish Hatchery Creek location to 0.04 mg/s midway through the West Pasture. Flood flows from Fish Hatchery Creek frequently overtop creek banks downstream of Sir Francis Drake Boulevard and sheetflow across the pasture, thereby probably leading to reductions in nitrates, although, occasionally, downstream concentrations and loading were higher, undoubtedly due to the influence of cattle grazing.

Average concentrations of nitrates also appeared to drop from upstream to downstream along the former Tomasini Creek channel, although the overall gradient pattern was much less clear than with Fish Hatchery Creek, with levels sometimes higher downstream. Average nitrate concentrations dropped from 1.88 mg/L on upstream Tomasini Creek at Mesa Road to 1.02 mg/L on Tomasini adjacent to the Shallow Shorebird Habitat and south of Railroad Point. Average loading rates also dropped in a downstream direction from 2.95 mg/s to 0.24 mg/s. However, based on median rather than mean loading rates – which were highly skewed by one very large sample during a storm event -- loading actually appeared slightly higher at the downstream sampling location (0.07 mg/s) than the upstream one (0.02 mg/s), although, more likely, this small difference probably equates more to an equivalency in loading rates between locations.

Unlike Fish Hatchery Creek, the decrease in nitrate concentrations, if not necessarily loading, on the former Tomasini Creek channel probably related more to in-channel deposition or dilution than nutrient trapping, as the fairly substantial levees constrict overbank flooding during most high flow events to a narrow band or floodplain along the inboard of the levees. Concentrations may have been diluted by tidal inflow and the copious amount of groundwater that flows from the base of the Point Reyes Mesa. Hydrodynamic modeling has shown that a fairly substantial source of additional freshwater in the form of groundwater from Point Reyes Mesa contributed to creek baseflow downstream of Mesa Road (KHE 2006a). While tidal and groundwater inflows decreased concentrations at the downstream location, it increased the volume of water and, therefore, may have increased loading rates. The situation is complicated by the fact that groundwater may not only have diluted nutrient concentrations in upstream flows, but also provided another source of nutrients and other pollutants to this system due to the presence of septic systems in the adjacent residential neighborhood. Methylene Blue Active Substances -- synthetic surfactants found in many types of laundry detergents as optical brighteners -- can be transported from septic system effluent into the ground water (Thurman et al. 1986) and were detected at least once in downstream Tomasini Creek waters.

Estimated average nitrate concentrations flowing into Olema Marsh (1.82 mg/L) exceeded those flowing out of the marsh (1.06 mg/L), which would suggest an upstream source for this nutrient. There was only once instance when concentrations were lower upstream than downstream, otherwise, they often differed by as much as 0.6 to 2.0 mg/L. Agricultural operations do exist upstream on tributaries to Bear Valley, but they are reduced in scope due to the fact that the Seashore now owns much of the land in this historically agricultural watershed. Some data from prior to this study show that one of those agriculturally influenced tributaries, Vedanta Creek, had lower nitrate concentrations (median = ~ 0.75 mg/L; Ketcham 2001). Within the park, the creek does run adjacent to a heavily used trail on which horses are allowed: during rainfall events, fecal matter undoubtedly runs off into the adjacent creek. Downstream of the park and other large private operations is a small rural residential development that may influence nutrient concentrations in Bear Valley Creek waters through septic-influenced groundwater inflow and surface water inflow from small creeks that drain off the Inverness Ridge.

Average nitrate loading rates in Olema Marsh also appeared higher upstream (1.23 mg/s) than downstream (0.29 mg/s). Average loading rates for the Bear Valley Marsh outlet were skewed by a very high value of 10.07 mg/s. Similar somewhat to Tomasini Creek, estimated median loading rates were dramatically reversed, with medians estimated as 0.05 mg/s for the upstream area and 0.13 mg/s for downstream area. While, overall, loading was lower at the downstream site than the upstream site, nitrate loading rates showed no clear upstream-downstream pattern during all of the individual sampling events, although, in May 2006, when loading was 10.07 mg/s at the upstream location, loading totaled only 0.14 mg/s at the downstream location. Loading rates for the upstream area may not be as accurate as those at the downstream location, because a very wide Bear Valley Marsh is abruptly funneled into two 6-foot culverts, and estimating flow volume is logistically difficult.

This disparity between means and medians may reflect the fact that trapping may be most efficient or even only occur during larger streamflow events, although this conclusion would seem contrary to what would be expected, given that nitrates are not particulate and that the structure of this system. In some senses, Olema Marsh is structured almost like a treatment-style wetland with defined and outflow locations that would seemingly function best under low velocity, longer retention time conditions. However, for some of the other creeks, this relationship between nutrient retention and higher flow events may hold true, particularly for particulate nutrients and those systems where pollutant retention derives principally from overbank flooding and trapping on floodplains.

Unlike nitrates, no clear pattern emerged between upstream and downstream concentrations and loading rates for fecal coliform on some of the major Project Area creeks, including Lagunitas Creek, Fish Hatchery Creek, Tomasini Creek and Bear Valley Creek in Olema Marsh. In some cases, variance in the data appeared to be large enough to potentially mask any potential differences and lessen power of statistical analyses (e.g., concentration and loading rates in Lagunitas Creek and loading rates in Tomasini Creek and Fish Hatchery Creek). For example, in Lagunitas Creek, estimated median concentrations appeared to drop from 955.3 mpn/100 ml at the Green Bridge to 356.9 mpn/100 ml near the Giacomini Ranch North Levee, and loading rates seemingly also dropped, with estimated median rates dropping from 12,430.6 mpn/s at the Green Bridge to 2,533.1 mpn/s at the North Levee, however, neither of these differences was strong enough to be deemed statistically significant.

In other cases, results appeared to point to actually an increase in concentrations, loading, or both at downstream locations, however, as with the other analyses, statistical results were not conclusive. In Fish Hatchery Creek, estimated median concentrations actually appeared to increase downstream (777.4 mpn/100 ml at the upstream location versus 2,459 mpn/100 ml at the downstream location). These increases may have resulted from the presence of cattle and inflows of fecal coliform into the West Pasture from other small drainages and groundwater inflow. Both median loading and concentrations appeared to increase at downstream locations in Olema Marsh: This suggests that there are some additional inputs to this marsh system other than the upper portions of the Bear Valley Creek watershed, such as septic-influenced surface water and groundwater flowing from the adjacent developed portion of Inverness Ridge into the west end of the marsh, wildlife use of the marsh, and potentially internal cycling.

- **The Importance of Episodic Events – Capturing Peak Export of Pollutants to Tomales Bay**: One of the clear findings from our study is the close relationship between rainfall, run-off, streamflow, and loading. While these relationships were not always distinct enough to be linear, with some exceptions, most of the high loading events occurred during winter or wet-season sampling events, with the highest values usually occurring during storm events. For example, estimated instantaneous loading rates for nitrates averaged 10.11 mg/s for Lagunitas Creek, but this average was skewed dramatically by loading during storm events, as evident by the estimated median loading rate of 0.66 mg/s: During an April 2006 storm, instantaneous loading rates of nitrates in Lagunitas Creek reached as high as approximately 220 mg/s. Research on other agricultural watersheds has also documented the highest export of nutrients and pathogens in stormflow, with levels generally higher in the wet season than the dry season (Vanni et al. 2001, Lewis and Atwill 2007). Ironically, storms are usually the least sampled part of the water year, due to the inherent planning and logistical difficulties: most water quality monitoring programs – including ours – operate on a set sampling schedule, with some programs attempting to capture storm events.

Complicating efforts to sample during storm events even further is the fact that concentrations and loading rates are not uniform throughout the storm event and may vary considerably in magnitude. Loading rates rise and fall and not always in direct response to streamflow . Ketcham (2001) performed a time series analysis of *E. coli* loading in Olema Creek during several storm events. During the so-called "first-flush event," in which ground conditions were finally saturated enough to generate substantial run-off into creeks, peak *E. coli* loading occurred approximately 2 hours after peak stream discharge, and loading rates decreased steadily thereafter even with a second run-off peak (Ketcham 2001). With the subsequent storm event, the lag in loading still persisted, although loading did increase slightly in response to a second run-off peak. During the very last storm, peaks in loading corresponded much more closely to streamflow peaks, with clear and discrete pulses with each increase in streamflow (Ketcham 2001). Therefore, these results suggest that timing of sampling during storm events may be key to accurately assessing the magnitude of loading to downstream portions of the watershed.

Olema Creek is an unregulated system. The complexities of loading increase considerably in regulated systems such as Lagunitas Creek. In Lagunitas Creek, dams capture much of the flow during the early part of the season from the upper portion of the watershed. During this period, most of the flow in the creek comes from subwatersheds below the dams, although there are occasional rises and falls in flow rates as spillways are adjusted. Once reservoirs reach capacity, which usually occurs after there has been sufficient rainfall to fill them, more stormwater is allowed to bypass reservoirs and flow downstream. In this system, not only are dams are affecting the volume and pattern of creek flows, they are affecting the volume and pattern of pollutant loading by trapping much of the early season flow and pollutant loads from more than 70 percent of the watershed. Ultimately, reservoir management may affect patterns of loading in Lagunitas Creek such that larger rainfall or run-off events may not necessarily correlate with the highest concentrations or rates of loading of nutrients and pollutants downstream as they might in unregulated watersheds.

To explore this hypothesis further, estimated instantaneous loading rates for nitrates and fecal coliform at the upstream Lagunitas Creek sampling site at the Green Bridge in Point Reyes Station were correlated with a number of factors, including streamflow, recent rainfall totals, and cumulative rainfall totals for the water year. Nitrates and fecal coliform were selected for analysis, because they have the most uncensored data or data that exceeded the commercial laboratory detection limits. Nitrate loading, but not concentrations, corresponded fairly well with instantaneous discharge or streamflow, regardless of the dynamics associated with flow capture, precipitation, and run-off patterns (Figure 17). These results support earlier findings by Smith et al. (1996), who concluded that the high flow regime accounts for most of the transport of nitrates in Lagunitas Creek, with concentrations not showing a linear relationship with flow rates. Nitrates are soluble and, for this reason, may be more readily mobilized than other nutrients and pollutants and may not always be strictly mobilized by rainfall events of sufficient magnitude and duration to generate substantial run-off. In a study of agricultural watersheds on the East Coast of the US, stream baseflow during the dry season was found to actually account for 25- to 37 percent of nitrate loading relative to only 3- to 13 percent of soluble reactive phosphorous (SRP; Vanni et al. 2001).

In contrast, fecal coliform loading at the upstream sampling site in Lagunitas Creek was not strongly associated with either streamflow or recent rainfall, but cumulative rainfall totals did show some relationship with loading, albeit seemingly not a linear one, regardless of regression results. In evaluating the loading data graphed against cumulative rainfall, a rather complicated pattern emerged based on groupings of sampling events (Figure 24). Coliform loading appeared lowest (1,000 – 10,000 mpn/s) in the summer and dry season fall sampling event; increased substantially during fall season wet events (~100,000 mpn/s); dropped back to lowest levels (1,000 – 10,000 mpn/s) during mid-year wet season events; and then started climbing exponentially once cumulative rainfall totals reached between 30 and 33 inches. This potential pattern could result from mobilization of readily available sources of coliform bacteria following the first rains in the fall, with loading rates then dropping to lower levels until rainfall reaches a sufficient volume to allow for more creek flows – and pollutant loads -- to bypass the upper reservoirs. The amount of data available does not allow for drawing any definitive conclusions, but these preliminary findings suggest that the dynamics of coliform loading on Lagunitas Creek are not necessarily simple and directly correlated with streamflow, as was found with nitrates.

Ultimately, this information suggests that timing is everything when it comes to capturing loading events that may represent the key periods when nutrients, pathogens, and other pollutants are exported from the upper watershed to Tomales Bay. In addition, patterns of peak loading may vary between systems, further complicating efforts to capture these important events. However, if these events are not sampled or sampled at the wrong time, estimates of pollutant loading from the upper watershed to Tomales Bay may be greatly underestimated and lead to an inaccurate understanding of nutrient dynamics within this system.

- **Do We Really Understand Nutrient Dynamics of Tomales Bay?** Nitrogen is typically considered the limiting factor in estuarine systems in terms of primary productivity of vascular plant and algal species, with phosphorous being abundant due to strong marine influences (Mitsch and Gosselink 2000, Day et al. 1989). However, many coastal estuaries now receive massive inputs of nitrogen and phoshorous as a result of urbanization and agricultural development that overwhelm these systems and lead to eutrophication issues and even potentially severe health problems for people and wildlife. While improvements in sewage treatment have reduced point source loading of these pollutants to coastal watersheds, nitrogen and phosphorous continue to be pollutants of major concern worldwide (Howarth et al. 2002). Despite advances in reducing point source input, nitrogen influxes continue to increase due to non-point sources such as fertilizer application and atmospheric deposition from fossil fuel sources (Howarth et al. 2002). In contrast, while still a pressing issue, phosphorous loading does not appear to have changed much in recent decades (Goolsby et al. 1999 *in* Howarth et al. 2002). Approximately one-third of US estuaries were recently characterized as exhibiting strong signs of nutrient over-enrichment: Tomales Bay was listed as being highly susceptible due to nitrogen loading or other factors, although not enough information was available to characterize its eutrophic status (Bricker et al. 2007).

  Ironically, despite this rather dubious honor, detailed analysis on watershed-scale nutrient dynamics on Tomales Bay is lacking, particularly when compared with voluminous amount of analysis conducted on systems such as San Francisco Bay, Chesapeake Bay, and other large estuaries. Because of the thriving oyster industry in Tomales Bay and threats to human health associated with past viral outbreaks and seasonal spikes in pathogen indicators, most of the attention from regulatory and other agencies and organizations has been focused on concentrations and loading of pathogen indicators.

  One research program – the LMER/BRIE -- did collect extensive data on nutrients in Tomales Bay and some of its larger watersheds between 1985 and 1996. A number of papers were published from this effort, but, in general, most of the focus – and corresponding data analysis – evaluated nutrient status (e.g., heterotrophic vs. autotrophic) of Tomales Bay and relationship of the estuary to nearshore waters through upwelling, biogeochemical reactions related to the products of primary production and respiration, and hydrodynamics of the estuary. For this reason, much of the data analysis strictly assessed dissolved sources of carbon and nutrients or nutrients that are freely transported in solution, even though data on particulate nutrients was available. In addition, analyses also concentrated on summer and fall sampling events, even though sampling was conducted year-round. The dry-season data better fit the needs of the study in that, during the dry season, when water exchange is slow, nutrient dynamics reflect internal chemical reactions, with the Bay essentially acting as a closed "incubation chamber" in which the whole-system chemical reactions can be assessed (Smith and Hollibaugh 1997b).

A few studies conducted under the LMER/BRIE program did assess particulate nutrient dynamics in addition to dissolved nutrients (Chambers et al. 1995, Smith et al. 1996). As discussed earlier, many nutrients, contaminants, and pathogens, however, are principally transported in water as bound or sorbed to sediment particles, particularly where erosion rates and sediment yields are high (Walling et al. 1997). In general, phosphorous is transported bound to sediment more than nitrogen (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). In agricultural watersheds, more than 50 – 90 percent of the phosphorous load is often exported as particulate (Vanni et al. 2001, Sharply et al. 1995 *in* Howarth et al. 2002). Most inorganic nitrogen is transported as soluble nitrate, however, ammonium ions and organic nitrogen are often carried on sediment or organic matter, with estimates of sediment-bound nitrogen transport as high as 51-57 percent in some systems (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). Unlike some of the other LMER/BRIE studies, Smith and colleagues (1996) did incorporate data from winter sampling -- including intensive sampling during storm events 1-3 times per day -- and moved further upstream to sample upper Lagunitas and Walker Creeks, although analysis, ultimately, did not include all years of data (Smith et al. 1996). Interestingly, while most of the focus under LMER/BRIE program was on dissolved nutrients, Smith and colleagues noted that, “suspended load transport represents the major net removal of C (carbon), N (nitrogen), and P (phosphorous) from the watershed” -- and, therefore, the largest source of nutrients delivered to the Bay (Smith et al. 1996).

Based on the data collected throughout the LMER/BRIE program, particulate nitrogen in Tomales Bay during this period averaged 0.11 mg/L, while particulate phosphorous averaged 0.02 mg/L (LMER/BRIE data). The particulate nitrogen mean is 27 percent larger than that of dissolved inorganic nitrogen as N (nitrates, nitrates, and ammonium) – 0.08 mg/L (N). During this same 11-year period, dissolved nitrate concentrations in the Bay averaged 0.06 mg/L as N and 0.28 mg/L as NO3- (LMER/BRIE data). Mean total dissolved phosphates, ammonium, and total ammonia concentrations averaged 0.07 mg/L PO4-P (0.20 as PO4-), 0.02 mg/L NH4+-N, and 0.03 mg/L as NH3+-N (0.04 as NH3+), respectively (LMER/BRIE data). Based on USEPA standards (NOAA/USEPA 1988), nitrate and phosphate levels in the Bay between 1985 and 1996 were low enough that waters met standards for promoting moderate aquatic diversity (e.g., <1 mg/L for nitrates and <0.1 mg/L for phosphates).

These results suggest that nutrient concentrations may actually be relatively low in Tomales Bay, despite Tomales Bay being characterized as highly susceptible to eutrophication in a recent national evaluation of estuarine health (Bricker et al. 2007). In comparison, recent sampling in Suisun Bay, the estuarine transition zone for San Francisco Bay located east of Marin County, and the central portion of San Francisco Bay consistently showed much more elevated levels of dissolved nutrients, with nitrate concentrations ranging from 0.40 mg/L NO3-N (1.77 mg/L as NO3-) to 0.97 mg/L NO3-N (4.3 mg/L as NO3-) depending on location and season (Wilkerson et al. 2006).

At least one factor advocates against drawing any definitive conclusions from this data. During most of the study period (1985-1993), northern California was experiencing drought conditions in which rainfall and run-off were approximately 25 percent and 55 percent, respectively, below the estimated mean values since 1880 (Fischer et al. 1996 *in* Smith et al. 1996). Drought conditions did abate during the second half of the study in 1994-1995, with rainfall approximately 20 percent above average (MMWD, unpub. data *in* Smith and Hollibaugh 1997). However, data from this wetter period was not necessarily incorporated into analyses for many of the studies, including the one by Smith and colleagues (1996) that assessed particulate nutrients. In general, drought conditions would be expected to generate less loading of nutrients from upper portions of the watershed to downstream portions of the estuary. They would particularly affect mobilization of particulate forms of phosphorous and nitrogen, which are usually almost exclusively exported during large storm and run-off events.

This would suggest that results from the LMER/BRIE study may underestimate to some degree nutrient levels within Tomales Bay, particularly particulate nutrients. Smith and colleagues noted that particulate nutrients remained the major source of nutrients exported from the watershed even during dry years, despite the fact that concentrations of particulate nutrients were more strongly dependent on flow than dissolved nutrients (Smith et al. 1996). Our study also has not adequately assessed particulate nutrients, which indicates that our results may underestimate the amount of nutrient loading in the Project Area, Upstream Areas, and Reference Areas, as well.

A full understanding of nutrient status and dynamics in Tomales Bay will require a better understanding of nutrient loading during storm events and the magnitude of loading from the particulate and dissolved nutrient sources. In addition, it will require a better evaluation of the fate of both dissolved and particulate nutrients once they flow from the upper watershed into the upper and lower portions of the estuary, including potential concentrated deposition zones for particulate nutrients and subsequent transformation of nutrients once they reach the estuary, both during winter and summer periods.

The fate of dissolved and particulate pollutants from the upper watershed is particularly pertinent given some of the results from our study and those of the LMER/BRIE program. While nutrient concentrations in Tomales Bay appeared generally low during the 11-year monitoring period (mean=0.28 mg/L NO_3^-), average nitrate concentrations in upper Lagunitas Creek and Walker Creek were much higher during the years they were sampled (1987 – 1995). Nitrate concentrations averaged 1.21 mg/L and 1.20 mg/L in Lagunitas and Walker Creek during this period, with 95th percentiles estimated at 3.62 and 4.22 mg/L, respectively (LMER/BRIE data). In addition, fecal coliform concentrations and loading from Walker Creek Marsh during our study were seemingly much lower than found in other studies, with Walker Creek Marsh actually having lower levels than the Undiked Marsh north of Giacomini Ranch. Most of the other studies have shown this subwatershed to have among the highest coliform levels (TBSTAC 2000 in Ghodrati and Tuden 2005, RWQCB 2001). Other than sampling periods, one key difference between those studies and ours is that their sampling station is located some distance upstream from Walker Creek Marsh itself. It is possible that some concentrated zones of deposition or ETM exist between these sampling areas on Walker Creek. This factor may also account for the strong disparity between concentrations of nitrates flowing from the upper watershed into the Bay, although simple dilution may also play a role. As noted earlier, reductions in nitrate and even potentially coliform levels and loading in the Project Area prior to restoration may potentially have resulted as much from in-channel processes, as floodplain processes.

The Expected Effect of Restoration on Salinity, General Water Quality Conditions, Nutrients, and Pathogens

One of the primary objectives in restoring the Giacomini Ranch and Olema Marsh is to improve downstream water quality conditions in Tomales Bay, as well as conditions and functionality of wetlands within the Project Area. Restoration is often heralded as having considerable potential to improve water quality conditions, but few projects have attempted to document this link between restoration and improvement of downstream water quality and ecosystem health.

Understandably, most of the early effort in improving water quality within degraded water bodies has focused on the other "R" – pollutant reduction. Just within the past decade, a number of studies have been completed that have evaluated the effectiveness of these efforts using long-term, comprehensive monitoring datasets. Sewage treatment upgrades and reductions in point-source discharges have also improved water quality conditions in many estuaries dramatically, with reduction in loading rates of certain pollutants in systems such as the Paxtuent River estuary and the San Francisco Bay estuary ranging from 40 to more than 80 percent (Testa et al. 2008, SFEI 2007). These improvements, however, have not eliminated water quality problems, (Howarth et al. 2002). Rather, they have simply shifted the focus (e.g., from point source to non-point source; Howarth et al. 2002) or been superseded by new and emerging water quality issues such as increasing atmospheric deposition of nitrogen from fossil fuel combustion, the longevity and plasticity of certain metals such as mercury, chlorination and its interaction with other chemical and minerals, and new pollutants such as new pesticides and herbicides, gasoline additives, and endocrine-disrupting pharmaceutical products.

Restoration is a less frequently used tool for water quality improvement, probably because fewer opportunities exist to effect measurable change. However, wetland managers and scientists have been advocating the use of restoration for quite some time. Based on a simulation model, Mitsch and Wang (2000) hypothesized that restoration of wetlands around the Great Lakes in Michigan and Ohio could reduce loading of 25 to 38 metric tons of phosphorous per year, which would represent from 12 percent to as much as 53 percent of the watershed's annual P export.

With restoration of the Project Area, we expect improvement not only in water quality conditions within the sites, but also in the quality of water exported downstream. As has been noted earlier, two-thirds of the freshwater inflow to Tomales Bay comes from Lagunitas Creek, which flows through the Giacomini Ranch.

Under the implemented alternative, agricultural management practices have been discontinued completely as of 2007, and agricultural infrastructure and conditions have been removed. The East and West Pastures of the Giacomini have been restored, along with Olema Marsh. Restoration involved complete removal of levees in the East and West Pastures along Lagunitas Creek and removal of tidegates and culverts. New tidal channels have been excavated in the East Pasture. Tomasini Creek has been realigned into one of its historic alignments midway through the East Pasture. Certain portions of the East Pasture have been lowered in elevation to increase hydrologically active floodplain and marshplain. Creek banks have been regraded to more stable profiles after removal of riprap, or floodplain terraces have been created. In Olema Marsh, an adaptive restoration approach is being undertaken, with initial excavation of a notch in a shallow berm to increase hydrologic connectivity of Bear Valley Creek and Olema Marsh with Lagunitas Creek and improve drainage of currently impounded waters.

General Water Quality Conditions, Nutrients, Pathogens, and Productivity in the Project Area

Project Area-Giacomini Ranch

Restoration of the Giacomini Ranch will reduce the number and magnitude of exceedances of Basin Plan and USEPA water quality objectives from actions within the Project Area. Discontinuation of agricultural management will remove actions that have been creating or exacerbating poor water quality conditions and reduce a direct source of nutrients and pathogens from the site. Breaching of levees, removal of tidegates and culverts, and other actions such as regrading Lagunitas Creek banks will increase connectivity between the Giacomini Ranch and Lagunitas and Tomasini Creeks. Creation of tidal channels into the interior of the East Pasture – where more of the historic tidal channels were eliminated and replaced with drainage ditches – will convey tidal water into the formerly diked non-tidal area and improve water circulation and exchange with Project Area creeks.

This increase of connectivity and exchange with tidally influenced creeks will increase salinities within the Project Area. While essentially either non-tidal (East Pasture and Olema Marsh) or muted tidal (West Pasture and Tomasini Creek), at least the Giacomini Ranch portion of the Project Area often had slightly elevated salinities regardless due to residual salts in the soils from historic tidal inundation prior to diking (KHE 2006a). With removal of levees and culverts, salinities will increase considerably within the Project Area (KHE 2006a), but many areas within the ranch will continue to have lower salinities due to extensive freshwater influence from the numerous creeks, small drainage, and emergent groundwater from the Inverness Ridge and Point Reyes Mesa. In addition, because of its position within the Estuarine Transition Zone, the Project Area will also continue to have highly variable salinity conditions on a seasonal basis, with salinities primarily fresh to brackish in nature in the winter, spring, and even into early summer.

The increase in exchange of Project Area waters with creeks will increase water circulation and decrease residence time, leading to an improvement in general water quality conditions. Waters will move in and out of the system with twice-daily tides, increasing exchange and replenishing oxygen supplies. Waters will not necessarily fully drain from the restored marshes. Natural gravel bars in Lagunitas Creek, including near the mouth of Tomasini Slough, will maintain some impoundment of waters in channels during even very low tide conditions, acting as mini-weirs or dams. In addition, very small earthen weirs were constructed at the mouths of some of the created tidal channels to retain subtidal conditions as habitat for the federally endangered tidewater goby, a resident estuarine fish species that favors brackish, low-velocity waters.

In addition to increased hydrologic exchange, elimination of frequent ditching will decrease production of organic matter whose breakdown generated the chronically hypoxic and anoxic conditions within waters of East Pasture ditches that resulted in consistent exceedance of Basin Plan dissolved oxygen objectives. Decomposition of organic matter may also be responsible for the occasional exceedance of oxygen objectives in the vegetation-choked Olema Marsh. With restoration, oxygen levels are expected to increase and become somewhat more stable, particularly in the East Pasture and Olema Marsh.

As with natural wetlands, oxygen levels will stil be expected to infrequently drop into hypoxic (low) conditions during summer nights when warm temperatures during the day boosts phytoplankton and algal productivity within shallower water features, causing spikes in oxygen demand or respiration at night that temporarily reduces available oxygen. These periods of high productivity are often accompanied by sharp elevations in pH greater than 8.5 that may continue to cause infrequent exceedance of Basin Plan pH objectives.

In general, restoration of the Giacomini Ranch will probably have the least effect on pH, with little change in pH conditions expected. Despite agricultural management, most of the pHs in the

Giacomini Ranch varied little between sites and seasons. Elimination of agricultural management and an increase in hydrologic connectivity and exchange will tighten the range of pHs somewhat and decrease the number of Basin Plan standard exceedances to some degree. However, as noted above, pH is still expected to exceed 8.5 on some occasions due to high primary productivity in marsh waters, and some of groundwater-fed drainages will probably continue to show slightly lower pH (<6.5) on occasion as they have done in the past. In addition, some areas may experience slight increases in general pH conditions with introduced or increased tidal influence, as tidal waters tend to be slightly more basic (~7.8).

Temperatures may shift within the Project Area somewhat. Increasing or establishing tidal exchange will reintroduce a source of warmer waters to the Giacomini Ranch, but, conversely, increased exchange may also act to decrease temperature in waters by decreasing residency time. When diked, infrequent to non-existent water exchange during warm spring, summer, and fall months, probably resulted in a steady climb in water temperatures throughout the season. Another factor controlling water temperature within the Giacomini Ranch is the direct, abundant, and perennial freshwater input from small drainages and groundwater inflow from the Point Reyes Mesa and the Inverness Ridge. These freshwater sources continually infuse colder waters into the Project Area and are probably responsible for the generally lower range of temperatures seen in the Giacomini Ranch, even when it was diked. In the long-term, these factors may offset each other to some degree and lead to relatively little change in the range of temperatures within the Giacomini Ranch.

With elimination of intensive dairying, infrequent pulses of nitrates, nitrites, ammonia, phosphates, and unionized ammonia in the East Pasture that exceed Basin Plan and USEPA objectives will be eliminated or practically eliminated over time. The substantial reduction in nutrient source loading with elimination or reduction in grazing intensity, along with discontinuation of manure spreading practices, will, over the long-term, eliminate exceedance of these objectives. As discussed earlier, low oxygen levels in ditches associated with ditching and the generation of decomposing organic matter that increased oxygen demand was probably, in large part, culpable for the frequent pulses in ammonia and phosphates and infrequent exceedance of nitrite and unionized ammonia objectives, particularly in the East Pasture. With increases in water column oxygen, some of the exceedances of Basin Plan standards will be eliminated or substantially reduced with ammonia and nitrites quickly converted to nitrate, and the soil-water interface will become anoxic less often and, thereby, release less of the normally soil-bound phosphates into overlying waters.

Discontinuation of intensive agricultural management practices will not eliminate all sources of nutrient loading to the Project Area. The ranch will receive more nutrient loads from Lagunitas Creek with the levees being removed, and the East Pasture will be more directly influenced by Tomasini Creek again. The West Pasture will continue to have influxes of nitrates and pathogens from Inverness Ridge drainages such as Fish Hatchery Creek and the 1906 drainage and possible septic-influenced groundwater emerging from the base of the Inverness Ridge and flowing into the West Pasture. In addition, the East Pasture will continue to be influenced by emergent groundwater from the base of the Point Reyes Mesa terrace and non-point surface run-off from the town of Point Reyes Station, both of which appear to have moderate- to high pathogen and nutrient loads. Nutrient loads are expected to decrease in at least one of the run-off sources on the north end of Point Reyes Station that traditionally received run-off from one of the former Giacomini Ranch feedlots, which is now unused.

Based on continued pollutant inflow and levels observed in reference marshes, nitrates will probably continue to exceed USEPA objectives for promoting maximum aquatic diversity (0.1 mg/L). Some of the very large pulses in concentrations observed, particularly in the East Pasture, will be eliminated, but, in general, nitrates concentrations will probably range between 0.5 to 1.2 mg/L, with increases in nitrate loading and concentrations during storm events. Nitrates averaged an estimated 0.86 mg/L in Reference Areas. The Project Area may continue to have slightly higher nitrate levels than Reference Areas due to the higher volume of freshwater –

and potential pollutant – inflow into the system and its more upstream location along the upper watershed-estuary gradient. Conversely, once pulses from point-source discharge and maintenance activities associated with former agricultural management are eliminated, phosphates within the Project Area may drop to slightly lower levels or ranges than Reference Areas, again due, in part, to the more landward location of the Giacomini Ranch along the estuarine gradient. Reference Areas actually had higher instantaneous loading rates of phosphates than either the Project or Upstream Areas, which may partly result from the closer proximity of these sites to the open water portions of the Bay and ocean. However, some pulses in phosphates will still occur in the smaller tidal creek channels during periods in the spring and summer when the soil-water interface becomes anoxic and encourages flux of phosphates into overlying waters.

For both nitrates and phosphates, loading rates from the system will increase with restoration to some degree due to increased hydrologic connectivity: previously, the East Pasture was completely diked and only contributed to downstream loading during moderate to extreme flood conditions or when the Giacominis occasionally pumped ditch waters into Lagunitas Creek. Loading rates for the East Pasture will increase considerably (from 0 under pre-restoration conditions), but loading rates for the West Pasture and Tomasini Creek may not appreciably change, because these areas were already functioning as muted tidal systems with both inflow and outflow of waters due to malfunctioning tidegates and flashboard dam systems.

Nutrient dynamics in the Giacomini Ranch will be affected not only by influx of new (and continuing) sources of nutrients from upstream and perimeter loading sources, but also by the rate at which moderate to excessively high nutrients in waters and soils can be expected to decrease over time without active removal of "hot soils." Few studies appeared to have addressed the issue of the timeframe over which nutrients and other pollutants in agriculturally managed soils and water such as pathogens decrease in response to removal or reduction in intensity of agriculture. In general, nutrients within waters are expected to either quickly convert into other nutrient forms – i.e., loss of nitrogen to the atmosphere through denitrification – or quickly be uptaken by plants and phytoplankton. However, flux out of nutrients and pollutants from soils into overlying waters could lengthen the timeframe over which nutrient concentrations will decrease within the East and West Pasture waters. Certain nutrients such as phosphates become soluble in soils and available for flushing into overlying waters when conditions become anaerobic or low in oxygen, which typically occurs during periods of persistent or repeated flooding or ponding. Other constituents such as metals are tightly bound under the reduced, slightly acidic to neutral pH conditions characteristic of flooded wetland soils. Within the East Pasture, it is likely most nutrients will be "lost" through plant uptake, with the moderately to excessively high nutrient concentrations documented in these soils (NPS, unpub. data) favoring establishment of weedy species that proliferate quickly under high nutrient conditions.

As with nutrients, removal or reductions in the number of cattle will substantially decrease coliform levels. Unlike nutrients, which are typically rapidly assimilated or converted, bacteria can persist for an extended period of time in both water and soils. In one study, *E. coli* -- another bacteria that has become more popular as a pathogen indicator -- lived in lake waters for at least 6 to 7 days, but in nutrient-rich river water, *E. coli* survived in excess of 3 weeks and was believed to persist for as long as 2 months in sediment (Palmateer and Huber 1985; Huron County Science Committee 2005). Under these conditions, coliform concentrations are expected to slowly decrease, particularly in the East Pasture, although pathogens will not be eliminated due to septic-influenced hydrologic inputs, use of the restored wetlands by wildlife, and inflow from upstream subwatersheds such as Fish Hatchery Creek, Tomasini Creek, Lagunitas Creek, and others.

As with many other water quality variables, discontinuation of agricultural management practices such as ditching will decrease elevated dissolved organic carbon (DOC) levels, which greatly exceed those found in nearby reference marshes. However, DOC loading may increase, at least in the East Pasture, simply due to the fact that the East Pasture will now have full-time hydrologic connectivity with downstream creeks. Plant decomposition will greatly increase with reintroduction of tidal waters into this formerly freshwater system and will, therefore, at least temporarily, accentuate the increase in export promoted by greater hydrologic connectivity.

Patterns of DOC flux may be more complicated than a simple consideration of hydrologic exchange. In research on restoring and mature marshes, some researchers have found that restoring marshes in Georgia consistently imported DOC and had some of the highest nutrient uptake rates (Childers et al. 1993). Conversely, older marshes had more variable patterns, although DOC export occurred during at least one-third of the samplings (Childers et al. 1993). Similar results have been observed in other systems Louisiana (Childers and Day 1990 and Wolaver and Spurrier 1988 *in* Childers et al. 1993). When it does occur, DOC export appears to correspond most closely with specific hydrologic conditions, including periods of low-tide drainage and during rainstorms when exposed (Wolaver and Spurrier 1988, Chalmers et al. 1985 *in* Childers et al. 1993). Given this, changes in DOC levels and loading may not be as predictable with changes in land management and infrastructure favoring lower concentrations and higher loading; accelerated decomposition rates favoring higher concentrations and higher loading (at least temporarily); while dynamics of marsh evolution may counter these trends by importing DOC. High levels of DOC, at least initially, could stimulate oxygen demand in newly restored areas and cause some episodes of hypoxia and anoxia.

Chlorophyll a levels also greatly exceeded those in reference marshes. With increased hydrologic exchange, levels should decrease to some degree due to the reduction in stagnant water areas. In addition, reduced point-source loading of nutrients from cattle and manure spreading will decrease nutrient levels available to phytoplankton, thereby bringing productivity measures such as chlorophyll a more in line with what might be expected in other estuarine systems. Temporal patterns in chlorophyll a levels may also shift due to the elimination of a perennial source of nutrients from cattle to a more flux in nutrients more closely associated with the wet season. This, combined with the fact that levees will no longer shield some of the Project Area water features from the churning effects of summer winds, may eliminate or at least substantially decrease blooms in summer and reinstate more a spring-fall pattern to productivity pulses.

Restoration will result in a temporary increase in turbidity as the newly reconnected system adjusts to altered hydrologic conditions, including potential slumping of banks on created or pre-existing channels in response to widening of channels to better accommodate flows. However, these are expected to drop rapidly after the first few years, as the marsh moves more toward a dynamic equilibrium in conditions, including establishment of more vegetation cover in areas that became unvegetated immediately following restoration.

Project Area-Olema Marsh

Some of the most complex changes that may occur with restoration comes with lowering of the water surface levels within Olema Marsh through improving hydraulic connectivity of Bear Valley Creek within Olema Marsh with Lagunitas Creek. The adaptive restoration approach proposed for Olema Marsh is expected to result in a dramatic lowering of water surface levels in this highly impounded marsh. Water surface levels have recently been perched almost 4 feet higher than the culvert invert for Bear Valley Creek at Levee Road for a number of reasons, including elimination of drainage from the western culvert, poor drainage from the eastern culvert due to low capacity and a berm near the outlet that acts as a funnel, and total submergence of the culverts at Bear Valley Road (KHE 2006b).

The first phase of the adaptive restoration program involved notching a berm and shallowly excavating a more defined flow path for waters within the marsh. These and subsequent actions may lower water surface levels as much as 1- to 4 feet (KHE 2006b). As waters drain down, approximately the upper 1- to 2 feet of the marsh surface, which appear to be a combination of granitic alluvium, former marsh muds, and peat, would be dewatered and exposed to air.

Through oxidation, the surface layer of areas with peat and organic mineral soils would begin to break down and decompose, causing a differential lowering of the marsh surface through subsidence or compaction. Subsidence rates are difficult to predict, but based on general elevations of the marsh soil surface from topographic surveys conducted, portions of Olema Marsh could subside by approximately 0.7 to 1.7 feet.

Oxidation of peat and mineral soils triggers a range of biogeochemical reactions, some of which have important implications for water quality. Oxidation of impounded soils, particularly peat soils or soils that were historically exposed to tidal influence, can dramatically affect nutrient conditions within soils. Rapid decomposition of peat and organic-rich mineral soils can generate a pulse in mineralization or production of inorganic nutrients, with pH often driving which nutrient forms are the most prevalent (Delaune and Smith 1985, Anisfeld and Benoit 1997, Portnoy 1999, Sommer and Horwitz 2001, Parsons and Martini-Lamb 2003). Oxidation often results in a lowering in soil pH because of the production of humic acids and other types of acids, and these acids can shift the nutrient pathway away from nitrification or the production of nitrates from ammonia. In addition, introduction of saltwater can decrease binding of ammonium in soils through the higher ionic strength of saltwater (Portnoy 1999). Nutrients produced through breakdown of organic matter or such as ammonium and phosphate can either remain in drained soils, or they can be flushed into overlying waters when soils are flooded again (Delaune and Smith 1985, Portnoy 1999). Often, these pulses are very sharp, but relatively short-lived, lasting a matter of weeks (Anisfeld and Benoit 1997, Parsons and Martini-Lamb 2003). Nutrient efflux into overlying waters may also be spatially variable, with areas exposed to tidal influence having higher rates of efflux because of cation exchange.

In addition to nutrient pulses, inundation of recently dewatered or drained soils can cause pH within overlying waters to plummet, at least temporarily. The severity of this reduction in pH depends on the soil substrate and the degree of current or historic tidal influence. The pH in overlying waters often drops lower in saline or tidally influenced soils (pH ~2-4 with pH 7 considered normal or neutral) than in freshwater wetland or peat soils (pH ~5.0), because oxidation of pyrite and other iron-sulfur compounds in tidally influenced soils leads to extensive production of additional acidic compounds (e.g., sulfuric acid and ferrous iron; Delaune and Smith 1985). In freshwater wetlands, acidity is primarily produced by breakdown of peat into humic acids. The peat underlying Olema Marsh is expected to be relatively fresh or low salinity in nature, at least within surface layers, because tidal influences have been largely precluded or at least limited since construction of Levee Road in the late 1800s. However, estuarine-derived muds probably underlie the peat in these areas at some unknown depth, with muds potentially still at or close to the surface in other areas. Therefore, pHs generated by breakdown of organic matter would be expected to be closer to 5 than 2-4. The persistence of acidic conditions within overlying waters depends to a large degree on the influx rate of waters high in carbonates such as seawater, groundwater, or streams, with acids typically quickly buffered in wetlands with some consistent source of water. Low pHs typically persist for longer periods of time in systems with no to very low sources of inflowing water, because acid concentrations greatly exceed that of available carbonates. Permanent Bear Valley Creek inflow, combined with persistent subsurface groundwater inflow from the Inverness Ridge, would be expected to buffer acids within a short time of being produced, although there could be some spatial variability within the marsh where lower pHs would persist.

Decomposition of peat soils can also affect water quality by releasing soluble, partly decomposed organic matter into overlying waters, thereby increasing oxygen demand and decreasing dissolved oxygen levels (Anisfeld and Benoit 1997). A similar phenomenon was observed in the East Pasture drainage ditches: organic matter was constantly introduced into ditch waters by frequent dredging, which disturbed both rooted and floating vegetation and undecomposed organic matter in ditch soils. In ditches, dissolved oxygen levels rarely exceeded 5 mg/L and were typically below 2 mg/L. Dissolved oxygen within Olema Marsh waters would be expected to drop in response to decomposition of peat soils, with effects being more prolonged than that for pH and possibly extending several years after restoration is completed.

These same biogeochemical processes have implications for contaminants, as well as nutrients. Under oxidized conditions, many marsh soils will release sediment-bound contaminants into overlying waters. Oxidation in and of itself does not necessarily lead to release of metals, but oxidation combined with a sharp decrease in pH as is often observed in saline soils can encourage a “pulse” of formerly sediment-complexed metals into the water column. Studies have documented releases of a variety of metals, including silver, aluminum, cadmium, chromium, copper, iron, manganese, nickel, lead, selenium, and zinc (Delaune and Smith 1985, Soukup and Portnoy 1986, Gambrell et al. 1991, Anisfeld and Benoit 1997). Release of contaminants such as metals appears to be higher from saline or saltwater wetland soils than freshwater wetland ones, probably because of the lower pHs often present in oxidized tidally influenced soils (pH ~3-4) than in freshwater wetland ones (~5.1; Delaune and Smith 1985). Soils high in humic acids or organic carbon also tend to bind metals (Syrovetnik and Neretnieks 2002), as well as organic contaminants such as DDT and chlorinated benzenes.

The potential for a pulse in metal or organic contaminants into overlying waters following draining and oxidation of Olema Marsh soils appears relatively minor given the relatively low probability of any historic or current exposures to organic contaminants or metals, even metals such as nickel, chromium, and valanium that are naturally high in the ultramafic or serpentine soils found in the Franciscan Formation, which is prevalent throughout the San Francisco Bay region and the eastern side of Tomales Bay, including the Bolinas Ridge (Hornberger et al. 1999) The sediment screening survey conducted in the Project Area in 2003 did show ubiquitously high levels of nickel and chromium in the Project Area, except in Fish Hatchery Creek (Parsons and Allen 2004). The upper portions of Fish Hatchery Creek, as well as Bear Valley Creek, drain completely off the Inverness Ridge, which is dominated by granitic rock such as quartz-diorite and granodiorite that probably contains naturally low levels of metals relative to the Franciscan Formation (G. Kamman, KHE, *pers. comm*.).

Over time, differential subsidence of peat and organic mineral soils would be expected to reach equilibrium with water surface levels, but while subsidence can occur relatively rapidly, the long-term effects of drainage on sediment nutrient pools and fluxes into overlying waters can persist for some time, with effects noted in some marshes even 10 years after marshes had been drained (Portnoy 1999). Within the short-term, assumed to be at least 10- to 15 years, a large degree of variability in water quality conditions is expected, primarily in nutrient loading to overlying waters as surface soils in Olema Marsh adjust to being dewatered. Pulses of phosphates from soils would not necessarily violate any Basin Plan or USEPA standards, because there are no phosphate standards, although the EPA has developed objectives for estuarine waters (NOAA/USEPA 1988). Pulses of ammonia could cause exceedances of the unionized ammonia objective, although periods of low pH would restrict unionized ammonia production. Depending on oxygen levels, ammonia could also be rapidly converted to nitrates either within the marsh or downstream of the marsh in Lagunitas Creek. Sharp pulses in nitrates caused by conversion from ammonia could cause exceedance of the USEPA objectives for nitrate concentrations exceeding 10 mg/L. Low oxygen levels would favor ammonia or potentially production of nitrites, a typically transient form of nitrogen that is toxic to people and wildlife and is regulated by the USEPA.

Declines in pH would be expected to be a much more transient issue and unlikely to persist for more than a few weeks to a month, given the steady influx of carbonate-rich waters into the Olema Marsh capable of buffering acids produced. These temporary declines in pH would exceed Basin Plan objectives for pH both in terms of ambient pH objectives that specify a range of 6.5-8.5 and project-related objectives of not causing more than a 0.5 change in pH. While pH changes would not be expected to extend much outside Olema Marsh itself, nutrient spikes would affect both the marsh and Lagunitas Creek, at least temporarily increasing loading rates to southern Tomales Bay. From an overall project perspective, these negative effects are buffered over the short-term by the marked improvement in water quality conditions in the Giacomini Ranch.

Over the long-term, restoration is expected to have a beneficial effect on water quality within Olema Marsh, as the marsh comes into equilibrium with changed water surface level conditions. Salinities could increase in Olema Marsh with restoration, as hydraulic connectivity with Lagunitas Creek is improved. It should improve dissolved oxygen conditions, which frequently become hypoxic due to long water residence times. While the restoration will change the structure of Olema Marsh, it is expected to remain largely a freshwater marsh with pockets of brackish marsh that will still be subject to flooding and, therefore, should continue to have beneficial effects on reducing nitrates. Ultimately, exceedance of USEPA nitrate standards for estuaries is expected to decrease in frequency and to only occasionally exceed objectives. Fecal coliform concentrations will decrease slightly, but with major sources of coliforms present both upstream on Bear Valley Creek and potentially on the perimeter from septic-influenced inflow from small drainages and groundwater, the degree of reduction possible may be limited.

Pollutant Retention and Effects on Tomales Bay

In the Giacomini Ranch, breaching of levees will increase the frequency of overbank flooding from both Lagunitas and Tomasini Creeks. This will not only affect nutrient and pollutant levels in the ranch itself, but will affect downstream loading of nutrients and pollutants to Tomales Bay. Much of the potential for reduction in pollutant loading depends on the frequency of overbank flooding and the degree to which sediment and associated pollutants are retained by the floodplain or its “trapping efficiency.”

In the Giacomini Ranch, the frequency of overbank flooding is predicted to drop from 3.5- to 7-year events in the East Pasture and 12-year-events in the West Pasture to 1.5- to 2-year events (KHE 2006a), thereby increasing the influence of Lagunitas Creek on the pastures and vice versa. In terms of Lagunitas Creek, the East Pasture will provide most of the flood storage, with inundated acreage estimated by hydrologic modeling at approximately 300 acres during a 2-year event compared to 83 acres in the West Pasture (KHE 2006a). Cumulative floodwater volume during a 2-year event – i.e., the total amount of water moving through an area during a 2-year event – was estimated at 2,050 acre-feet in the East Pasture (some of which includes flood flows for the now-rerouted Tomasini Creek) and 50 acre-feet for the West Pasture (KHE 2006a).

During these storm events, floodwaters would overtop levees and spill onto the floodplain, dropping a considerable amount of suspended sediment. To estimate how much sediment might be deposited on newly reconnected floodplains, sediment transport rates for different stream discharge or flow rates were derived from sediment yield rating curves for suspended sediment at the Lagunitas Creek near Point Reyes Station gauge (USGS Station 11460600) developed by H. Esmaili & Associates (1980) for Marin Municipal Water District. The mainstem of Lagunitas Creek at the Point Reyes gauge demonstrated the highest rates (if not total loads) of sediment transport at lower flows (streamflows < 1,000 cfs), thereby making the 2-year flood event the most appropriate modeled flow for analysis.

The potential movement of sediment onto floodplains in the Project Area has been restricted by poor connectivity between creeks and floodplains during smaller and more frequent flood events (< 10-year flood events). Smaller flow events such as these often constitute the “dominant discharge” streamflows at which most of the sediment transport within many systems occurs, at least on average. During the 1979-1980 study, the rate of sediment transport in the lower portions of Lagunitas Creek just upstream of the Project Area showed signs of declining at the 1-year flood event, although the total load continued to increase with streamflow at a slower rate, with some of the most extensive sedimentation in recent decades observed after the 100-year flood event in 1982 (H. Esmaili and Associates 1980; Anima et al. 1988). Based on the sediment rating curve developed by H. Esmaili & Associates (1980), approximately 50,000 tons per day of suspended sediment would potentially move through the Project Area during a 2-year flood event.

This estimate assumes that the bedload being transported in Lagunitas Creek largely remains within the creek channel and that most of the sediment deposited on floodplains and marshplains would be suspended sediment such as fines (silts, clays) and medium-grained sands (Dunne and Leopold 1978). Only a portion of floodwaters carrying sediment during flood events end up on the floodplains or marshplains, with some being deposited in lower elevation off-channel features such as oxbows and secondary channels or within the active channel itself (Heimann 2001).

Sediment yield for the stream discharge associated with the 2-year flood event (3,531cfs; KHE 2006a) at the Point Reyes Station gauge on Lagunitas Creek was then factored by the percentage of cumulative flood volume of waters moving through the East and West Pasture floodplains to estimate the proportion of sediment in tons per day likely to be deposited on floodplains during overbank flooding. As with bedload sediment transport, suspended sediment loads are likely to be variable both vertically and horizontally within floodwater flows, however, for the purpose of this analysis, suspended sediment was assumed to be relatively uniformly distributed throughout the water column. In some systems, sediment deposition on floodplains has shown a strong linear relationship with both cumulative suspended sediment load and cumulative streamflow, with these variables explaining up to 82 percent of the variability in floodplain sediment deposition (Heimann and Roell 2000). In other systems, deposition of sediment appears to display more of a non-linear relationship in which at some specific threshold of flow velocities become high enough that most of the sediments are transported hrough floodplains rather than retained. In a study on Missouri creeks, Heimann (2001) found that more suspended sediment deposition occurred under smaller floods such as 5-year events than larger ones such as 25-year events, because flood flow velocities on the floodplain were lower.

Based on cumulative floodwater volume, the percentage of suspended sediment from Lagunitas Creek potentially diverted through the East and West Pastures would represent 20 percent of the total load or approximately 9,830 tons/day. Almost 98 percent of this sediment (~ 9,600 tons/day) would move preferentially into the East Pasture rather than the West Pasture. Based on hydraulic modeling, stream power would drop sharply once floodwaters crest the creek bank, causing most, if not all, of the sediment to deposit in the southernmost portions of the former pasture (KHE 2006a). The sudden loss in stream power suggested by hydraulic modeling once floodwaters crest the levees would suggest that trapping efficiency, at least under smaller flows, would be at the higher end high and could result in approximately 9,525 tons/day of sediment being deposited on the Giacomini Ranch floodplains. Increased rates of floodplain deposition could have a beneficial effect on the Bay by reducing sediment and potential pollutant delivery by as much as 19 percent.

In addition to being a water quality pollutant in and of itself – Tomales Bay has been declared impaired for sediment – suspended sediments are often associated with nutrients such as ammonium, organic nitrogen, and phosphate; pathogen indicators such as fecal coliform and *E. coli*; and contaminants such as metals. As has been discussed elsewhere in this document, In general, phosphorous is transported bound to sediment more than nitrogen (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). In agricultural watersheds, more than 50 – 90 percent of the phosphorous load is often exported as particulate (Vanni et al. 2001, Sharply et al. 1995 *in* Howarth et al. 2002). Most inorganic nitrogen is transported as soluble nitrate, however, ammonium ions and organic nitrogen are often carried on sediment or organic matter, with estimates of sediment-bound nitrogen transport as high as 51-57 percent in some systems (Meybeck 1982, Haith and Shoemaker 1987, Walling et al. 1997). In contrast, recent research on fecal coliform loading in Lagunitas Creek, Walker Creek, and three other northern California estuaries revealed that, while particulate coliforms had the highest bacterial counts, they represented a small fraction of the overall load, making the dissolved load comparatively much higher (Lewis and Atwill 2007).

The percentage of material deposited on floodplains versus transported through these systems depends on a number of factors, but trapping efficiency is often higher under smaller floods such as 5-year events than larger ones such as 25-year events, because flood flow velocities on the floodplain are lower (Heimann 2001). The optimal flow at which trapping efficiency of the Giacomini Ranch floodplains is maximized is unknown. However, some estimates of potential instantaneous loading rates during smaller flood events can be derived from instantaneous loading rates calculated on the falling limb (~5,000 cfs) of a 2.25-year flood event in 2006. Calculated instantaneous loading rates during this flood event totaled approximately 10 million MPN per second (MPN/s) for fecal coliform, 220 milligrams per second (mg/s) for nitrates, and 40 mg/s for total dissolved phosphates. Because samples were collected in Lagunitas Creek at the Green Bridge, which is at the upstream boundary of the Project Area, these numbers do not include additional loading that would have occurred during this same event from Olema or Bear Valley Creeks, which are located downstream of the Green Bridge.

During a storm event of this magnitude, approximately 50,000 tons/day of suspended sediment would be conveyed in Lagunitas Creek based on estimates from the sediment rating curve by H. Esmaili & Associates (1980). A study on 11 natural (versus constructed) wetlands in the United States yielded a median trapping or removal efficiency rate for Total Suspended Solids (TSS; suspended sediment and other materials) of 76 percent, with a maximum removal rate up to 95 percent (Strecker et al. 1992 *in* Kadlec and Knight 1996). Based on the less conservative estimates of 95 percent trapping efficiency on floodplains, suspended sediment loads within Lagunitas Creek could be reduced as much as 19 percent or slightly more than 9,500 tons/day.

There are no definitive numbers for the percentage of pathogens likely to be retained on floodplains, but, as with sediments, estimates for coliforms generally appear to be high, with natural wetlands receiving untreated or partially treated municipal or stormwater discharges having a 94.2 to 99.9 percent removal rate, even with abundant use by wildlife (CH2MHill 1991 *in* Kadlec and Knight 1996). Retention efficiency generally exceeds 90 percent with coliforms when influx concentrations are high (Kadlec and Knight 1996). During this storm, flows of approximately 5,000 cfs were sustained for at least one hour. Using an estimate of 90 percent retention on Giacomini Ranch floodplains (Kadlec and Knight 1996), instantaneous coliform loading rates in Lagunitas Creek could be reduced by as much as 17.1 percent or 1.72 million MPN/s or 6.19 billion MPN during just that one hour of flooding. In addition, using an estimate of 20 percent retention for phosphates (Kadlec and Knight 1996), instantaneous phosphate loading rates in Lagunitas Creek could be reduced as much as 3.8 percent or 1.5 mg/s or 5,400 mg during just that one hour of flooding.

During the flood event described above, calculated instantaneous loading rates totaled approximately 220 mg/s for nitrates. However, as discussed several times in this document, nitrates may not be as readily retained by floodplains, although some portions of the Project Area showed downstream nitrate reductions. In general, nitrates have been found to have very low rates of retention (2 – 3%) on floodplains unlike other forms of nitrogen such as organic nitrogen and ammonia (van der Lee et al. 2004). The proportion of nitrogen removed from through a network of streams in an East Coast watershed ranged from 37 – 76 percent, but these numbers included ammonia and organic nitrogen (Seitzinger et al. 2002). Assuming a trapping efficiency rate of approximately 3 percent, the instantaneous loading rate of nitrate onto floodplains during the 2006 flood event would equate to roughly a 0.6 percent reduction in nitrate loads in Lagunitas Creek or a decrease of approximately 1.25 mg/s or a total of approximately 4,500 mg during that one hour of flooding. As was discussed earlier under the Summary and Discussion section and other portions of the document, some nitrate retention did appear to occur with Project Area streams and associated wetlands even under diked conditions, although some of this may have been deposited in the stream channel, not floodplains, due to estuarine sediment transport processes.

In addition to water quality improvements related to reconnecting Lagunitas Creek with its floodplain, realigning Tomasini Creek near the Hunt Shack will likely result in much lower loads of nutrients and pathogens being routed through the East Pasture, at least from the Point Reyes Mesa residential development. It will also decrease the potential for these more polluted waters downstream of the Hunt Shack to be exchanged with Tomales Bay, because flood flows, which are more likely to pick up and convey “on-site” nutrient loads to downstream sources, will be diverted into the East Pasture. Tidal action can also cause exchange of waters, but the retained tidegate/flashboard dam on the now backwater slough channel tends to minimize outflow to some degree by truncating the lower part of the tidal range.

The quality of waters within the rerouted portion of Tomasini Creek will be improved through overbank flooding and related deposition of sediment, nutrients, pathogens, and contaminants onto the East Pasture floodplain. While Tomasini Creek has high concentrations of nutrients and coliforms just as do most of the other creeks and drainages, Tomasini Creek also is influenced by historic or potentially ongoing leakage from the now-closed West Marin Landfill, located upstream in the Tomasini Creek watershed. The landfill reputedly does not have the liner now required of all landfills and violates state regulations requiring a minimum of 5 feet between the bottom of the landfill and the groundwater table. The RWQCB documented the presence of leachates and cation/anion salts among other contaminants in Tomasini Creek more than one mile downstream from the landfill and just upstream of the Project Area boundary (David Elias, RWQCB, *pers. comm*.). A sediment screening study conducted in the Project Area in 2003 found detectable concentrations of cadmium within creek sediments just upstream of Mesa Road, the only detection of cadmium within the Project Area (Parsons and Allen 2004). However, cadmium levels did not exceed standards associated with frequent or infrequent toxicity to aquatic organisms (Parsons and Allen 2004).

Rerouting of Tomasini Creek into the East Pasture will increase loading of not only nutrients and pathogens, but more toxic contaminants that are not typically a concern in rural areas such as Tomales Bay: the landfill reputedly accepted wastes for a while from other areas in the San Francisco Bay region. Without more data, it is difficult to predict the magnitude of the problem posed by the landfill. However, wetlands and their reduced or anaerobic soil environments are extraordinarily efficient in trapping and binding contaminants, as well as nutrients and pathogens, for long periods of time, as long as wetland conditions are not radically altered (e.g., dewatered). By routing flows onto East Pasture floodplains, these contaminant, nutrient, and pathogen loads are diverted from reaching Tomales Bay and, thereby, decreasing water and sediment quality conditions in the southern portions of the watershed. In terms of minimizing impacts to aquatic life, floodplains are a more stable reservoir for contaminants than stream channels and bays, which are subject to more frequent erosion and redistribution of contaminated sediments.

Assessing the Success of Restoration in Improving Wetland and Watershed Health in Tomales Bay

Ultimately, monitoring of water quality and other hydrological variables will become part of a larger evaluation of the success achieved in restoring the Giacomini Ranch and Olema Marsh. The overall Long-Term Monitoring Program also includes monitoring of vegetation, zooplankton, benthic invertebrates, fisheries, and birds. This program focuses on assessing improvements not only in physical and biological conditions and wetland functionality within the Project Area relative to conditions existing prior to restoration, but also on the evolution of the restored wetlands and how close they move over time to being physically, biologically, and functionally equivalent to reference marshes or the Reference Areas. While the restored wetlands can play many key roles in this watershed, including support for many common and rare wildlife species, one of the most important roles that it can play is in improving downstream water quality in Tomales Bay for both wildlife and humans. Assessing water quality improvements, then, both within the Project Area and at its downstream boundaries represents an integral and crucial component of the overall monitoring effort. The value of this program would be greatly enhanced if monitoring and analysis efforts were conducted simultaneously with detailed evaluation of water quality conditions in both the upper watershed and Tomales Bay itself.

Based on evaluation of the preliminary data, predicted changes with restoration, and results from some of the progress criteria analyses proposed in the Long-Term Monitoring Program Framework: Part I (Parsons 2004), it appears that some water quality monitoring variables might be more capable of discerning change between pre-restoration and restored conditions and the direction of the evolutionary restoration trajectory (i.e., are restored wetlands becoming more like reference marshes?) than others. Below is a summary of recommendations on whether variables should continue to be included in progress criteria (or be incorporated if they were not recommended for inclusion in the framework plan). As was discussed in that document, even if variables are not included in the progress criteria, they may still be monitored for informational purposes.

- ***Salinity – Monitor: Do Not Include in Progress Criteria***: While most of the Project Area is expected to develop into a tidal marsh system that resembles the reference marshes, the pattern of salinities between these two Study Areas may never totally converge, because of the fact that the Project Area receives more direct, abundant, and perennial freshwater inputs from small drainages and groundwater inflow from the Point Reyes Mesa and the Inverness Ridge. Currently, 40 percent of the Project Area salinities exceed the 5^{th} and 95^{th} percentiles in Reference Areas, with most of those exceedances (39 percent) coming from salinities below 0.68 ppt, the 5^{th} percentile, rather than above the 95^{th} percentile, 36 ppt (Figure 31). This wide range of variability is reflected in the coefficient of variation for Reference Areas, which was 0.54: variables with a CV of less than 0.2 are considered to have low variability.

  The 5^{th} and 95^{th} percentiles for salinities in the Project Area are estimated at 0.1 and 29 ppt, so the range is actually not that dissimilar from the Reference Areas even prior to restoration. With restoration, mean salinity and the upper range of salinities within the Project Area should increase somewhat with more direct tidal influence and the discontinuation of irrigation with freshwater in the East Pasture during the summer, but, due to the abundant freshwater inflow from creeks and groundwater, salinities will probably never completely converge with that of the Reference Areas. This variable will be monitored, but kept out of the Progress Criteria, as recommended in the Framework Plan (Parsons 2004).

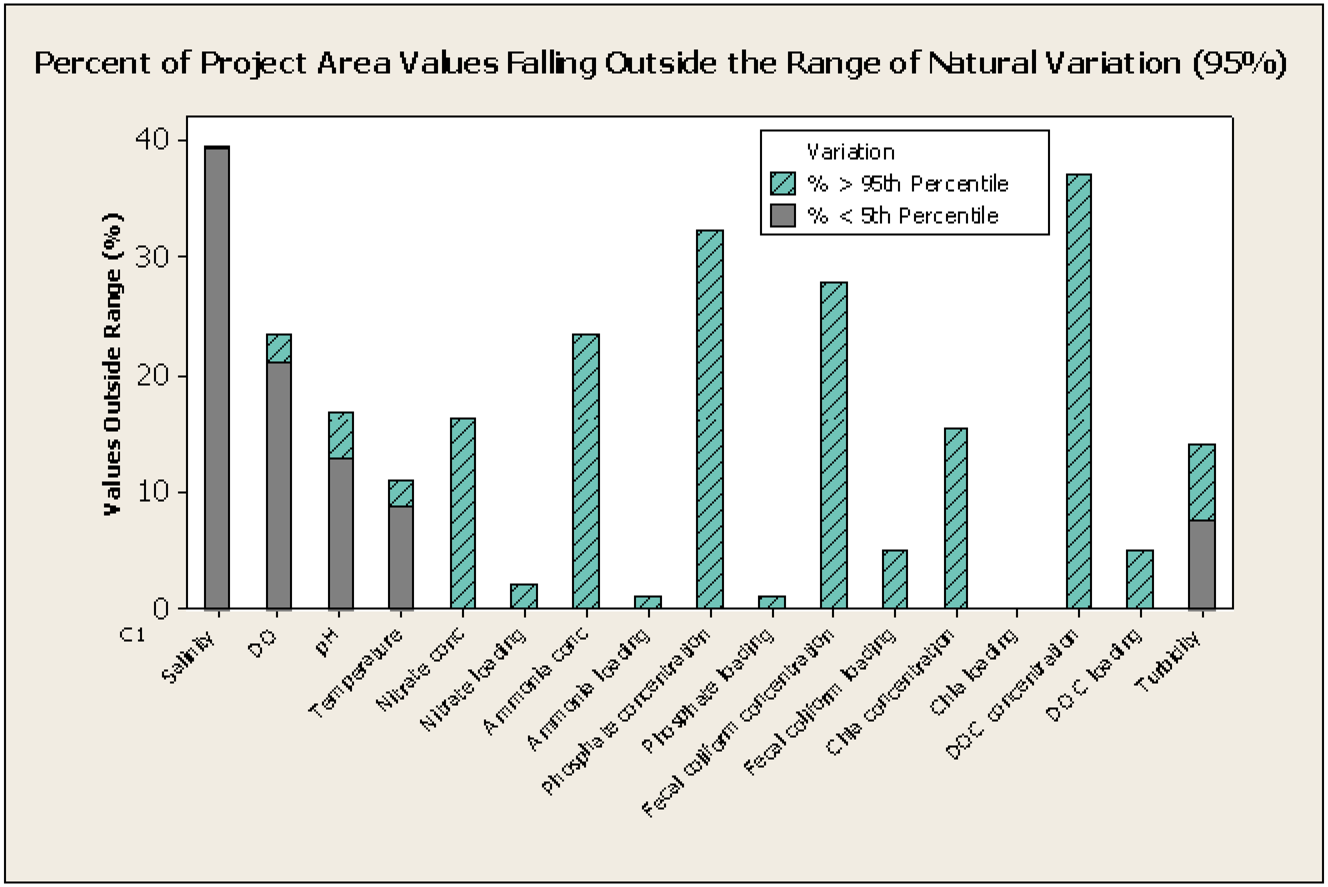


FIGURE 31. Percent of values falling outside the range of natural variation in Reference Areas (5^{th}, 95^{th} percentiles).

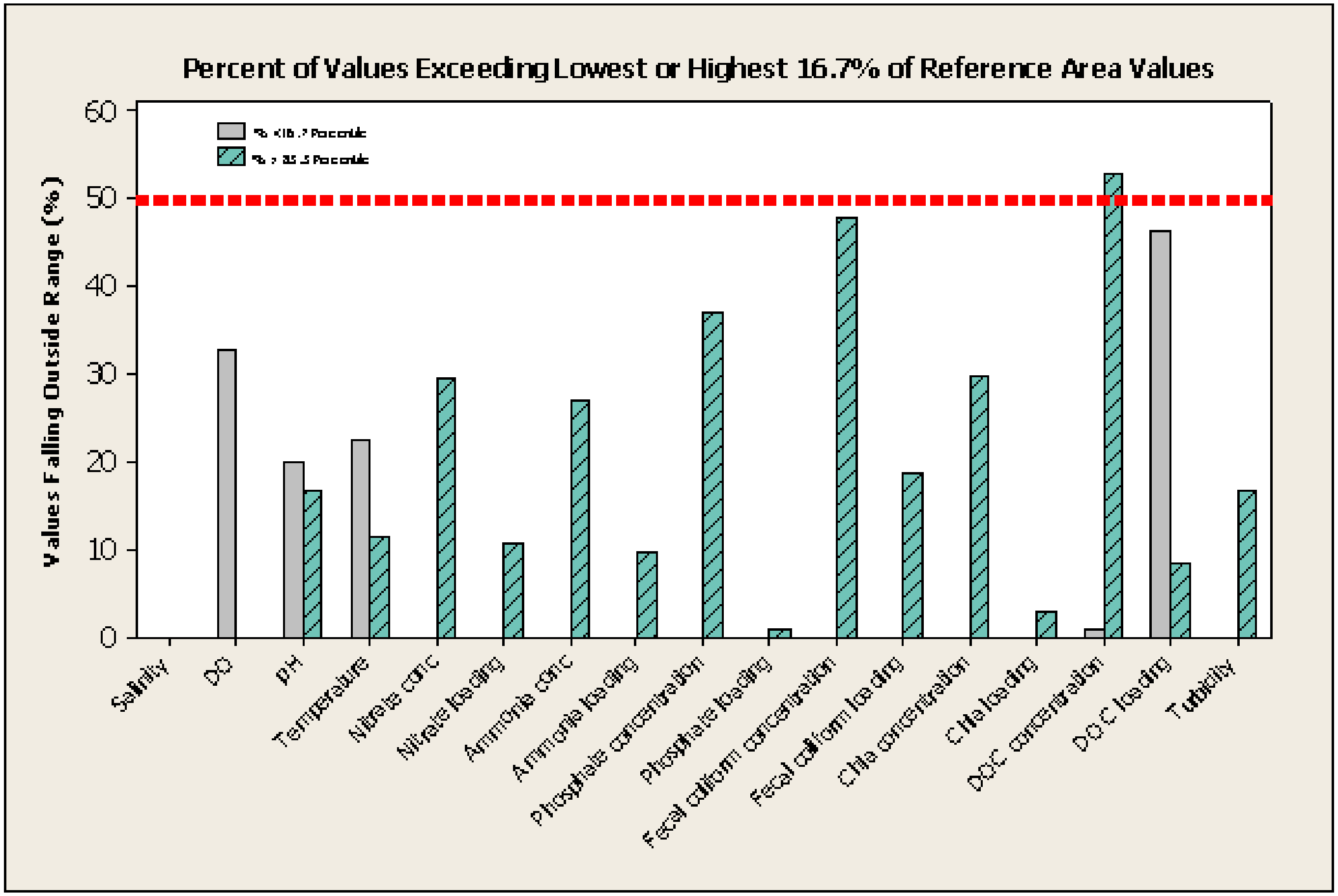


FIGURE 32. Percent of values either exceeding lowest or highest 16.7% of Reference Area values. Red line on graph indicates success criteria threshold of Project Area being required to have more than 50% of its value above the lowest or highest 16.7% of Reference Area values.

- ***Dissolved Oxygen - Include in Progress Criteria***: Approximately 23 percent of the Project Area dissolved oxygen values exceeded the natural range of variability observed in Reference Areas (Figure 31). Most of these exceedances (21 percent) came from oxygen values that fell below the 5th percentile of values in Reference Areas (4.2 mg/L), which falls below Basin Plan standards of 5 mg/L. Approximately 33 percent of oxygen values fell below the lowest 16.7 percent of values in Reference Areas (5.9 mg/L; Figure 32). As part of the progress criteria, 50 percent or more of the Project Area values must be above the lowest 16.7 percent (or, in some cases, the highest 16.7 percent) of values. Therefore, the Project Area actually already met this criterion, although 68 percent of the levels measured in the East Pasture fell below the lowest 16.7 percent of values, so the East Pasture would not have met this criterion. Within reference marshes, oxygen concentrations were somewhat variable – coefficient of variation was 0.37 – although not nearly as variable as sub-group sampling areas within the Project Area. (CVs below 0.2 are considered to have low variability). While Short et al. (2000) advocated eliminating monitoring variables with a CV greater than 0.2, this variable seems important to retain due to the very direct effects that restoration is expected to have on oxygen levels though increasing water exchange and eliminating management practices such as ditching that increased biological oxygen demand (BOD). Therefore, while the Framework Plan (2004) listed this as a variable just to be monitored, it should be incorporated into Progress Criteria.

- ***pH – Include in Progress Criteria***: Approximately 17 percent of pH values exceeded the natural range of variation in Reference Areas (Figure 31). However, this actually represents a relatively low deviation from "natural" conditions considering that 10 percent would be expected to be above or below the 5th and 95th percentiles. Of exceedances, approximately 13 percent of the 17 percent came from values that fell below the 5th percentile of 7, which occurred in areas influenced by groundwater or in areas where there was extensive breakdown of organic matter after ditching or seasonal vegetation die-off.

  The range for pH in Reference Areas was rather tight, with the 95th percentile estimated at 8.4. This tight range is reflected in the small coefficient of variation (0.06), where CVs below 0.2 are considered to have low variability. More than 83 percent of the values measured in the Project Area prior to restoration fell below the highest 16.7 percent of values or 83.3rd percentile recorded in the reference wetlands (pH=8), well above the 50 percent threshold established as part of progress criteria (Figure 32). While low pH can negatively affect aquatic organisms and has implications for nutrient cycling, progress criteria focused on the higher end of the pH range, because high pH can increase the potential for the production of toxic unionized ammonia when temperatures are high and ammonia is present in sufficient quantities. In addition to strong overlap in pHs between the Project Area and Reference Areas, the Project Area actually had fewer exceedance of Basin Plan standards than Reference Areas. Approximately 11 percent of the pH values recorded in reference marshes exceeded 8.5, the upper Basin Plan limit, while pH never fell below 6.5. In comparison, in the Project Area, pH fell below 6.5 during approximately 2 percent of the sampling periods and exceeded 8.5 approximately 3 percent of the time.

  The Framework Plan (2004) categorized pH as a variable to be monitored, but not incorporated into progress criteria. While the low CV might advocate for incorporating pH in progress criteria, the strong overlap in the range of value between the Project Area and Reference Areas – and the fact that it actually had fewer exceedances of Basin Plan standards -- would seemingly argue against its inclusion. As with salinity, the lower range of pHs in the Project Area at least partially reflects the influence of groundwater on pH conditions and so, therefore, will probably never totally converge with that of Reference Areas.

However, while current pH conditions are not an issue, restoration of Olema Marsh through lowering water levels and increasing hydrologic connectivity may result in some short-term dramatic changes in pH (see discussion on *The Expected Effect of Restoration on Salinity, General Water Quality Conditions, Nutrients, and Pathogens*). Similar short-term fluctuations in pH may also occur in the Giacomini Ranch as large expanses of pasture grasses and herbs began to die off and decompose in response to encroaching saltwater. Over the long-term, pH fluctuations resulting from these conversion-associated factors would expected to taper off, with median and mean pH increasing and returning to ranges somewhere in between pre-restoration and Reference Area conditions. However, the rebound in pH may also ultimately be affected by factors unrelated to the restoration such as climate change, which could increase acidity of ocean and estuarine waters. Because of the potential for temporary destabilization in pH conditions after restoration, pH should be included in progress criteria, at least through Year 7 to 10 of the monitoring program, with longer term monitoring conducted to assess potential changes due to climate change.

- ***Temperature - Include in Progress Criteria***: Temperature is an important parameter to monitor, at least for this project, because of the impacts that temperature can have on salmonids, which are an extremely important and threatened resource in this watershed. The importance that temperature has for the type and use of habitat that the Project Area is expected to provide after being restored remains somewhat more questionable.
The Project Area -- and the reference marshes that have the type of habitats that most of the Project Area is expected to eventually develop – represent transitional habitats for salmonids moving upstream in the watershed to spawn and young salmon or smolts in the process of increasing in size adjusting to higher salinity waters as they outmigrate to the ocean. The length of time that these fish spend in estuarine habitats would be expected to be fairly variable, so temperature may not play as key a role as it would in upstream rearing areas, particularly as most of the higher temperatures recorded in reference marshes occurred during the mid- to late summer months, when salmon would not necessarily be expected to be present or would be present in much lower numbers.

  Prior to restoration, only 11 percent of Project Area temperature values fell outside the range of natural variation in Reference Areas, which is essentially equivalent to that of Reference Areas (10 percent; Figure 31). Only 12 percent exceeded the highest 16.7 percent of values or the 83.3rd percentile in Reference Areas (23.1 degrees Centigrade), which obviously falls below the number exceeding that value in Reference Areas (16.7 percent; Figure 32). There were actually fewer exceedances of lethal and sub-optimal temperature thresholds for salmonids in the Project Area than in Reference Areas, with 17.8 percent of exceeding 22 degrees Centigrade, the suboptimal limit, compared to 15 percent in the Project Area. The range of temperatures in the Project Area – 5th and 95th percentiles estimated at 8.7 and 24.9 degrees Centigrade – was actually slightly lower than that of Reference Areas – 9.75 and 27 degrees Centigrade. Some of this variation is to be expected based on position within the watershed: the Project Areas further upstream along the watershed-estuary gradient than do the other Reference Area marshes. Also, levees in the Project Area have minimized or eliminated the influence of warmer tidal waters and accentuated the influence of freshwater from fluvial and groundwater sources, which -- at least when flowing -- is typically cooler than marine waters.

  As was discussed earlier in reference to changes expected with restoration, removing levees and tidegates will increase influence of warmer tidal waters, but increased hydrologic exchange will serve to reduce the amount of stagnant water that heats up due to solar radiation. In addition, the extensive freshwater influence in the Project Area from creeks, small drainages, and emergent groundwater will continue to introduce sources of cooler water to the Project Area. Therefore, while the range of temperatures and mean temperature of waters in the Project Area may shift upwards slightly, temperatures may never completely converge with those of the Reference Areas, which are further downstream in the Estuarine

Transition Zone system and, with the possible exception of the Undiked Marsh, are less significantly influenced by flow from small drainages and groundwater.

Temperature, then, is not currently a problem in the Project Area, and it was not included in progress criteria in the Framework Plan (2004), but it should continue to be monitored to allow for evaluation of the potential for salmonids to use this portion of the estuary as transitional habitat during upstream migration and outmigration to the ocean.

- ***Nutrients - Retain in Progress Criteria***: While monitoring of nutrients is more costly than that of field parameters such as oxygen levels, temperature, and pH, clearly, one of the most important differences between the Project Area and Reference Areas was the high level of nutrients found in both intensively and more passively managed portions of the Project Area.

  Nitrates are obviously the primary dissolved nutrient in this system: they are consistently detected in waters of all the monitoring study areas and are significantly higher in the Project Area, particularly the East Pasture, than Reference Areas with 16 percent of the Project Area values exceeding the 95th percentile of levels in Reference Areas (2.3 mg/L; Figure 31). The number of concentration-based values falling outside the natural range of variation only increased with some of the other nutrients, ranging from 24 percent to 32 percent. Conversely, loading estimates for the Project Area typically fell below what might be expected given the high concentrations, because the East Pasture essentially did not contribute to downstream loading, because it was leveed and only infrequently connected to Lagunitas Creek. In terms of Basin Plan standards, almost all of the exceedances of Basin Plan and USEPA water quality standards came from the Project Area, with the East Pasture accounting for most, if not all, of these exceedances. Despite this, the Project Area still met the progress criteria of having more than 50 percent of values fall below the highest 16.7 percent of values or 83.3rd percentile for nutrients in reference marshes, with percentages ranging from 63 to 99 percent (Figure 32). This might have been at least partially due to the fact that nutrient levels also varied dramatically in Reference Areas, with coefficient of variations for concentration-based parameters ranging from 0.52 (total ammonia) to 0.78 (nitrates).

  Nutrients will be an important parameter to monitor as the restoration unfolds. While removal of cattle and discontinuation of manure spreading will eliminate these direct point source discharges, reconnection of the Project Area with Lagunitas and Tomasini Creeks through removal of the levees will increase nutrient loading from upstream watershed sources. In addition, loading from non-point stormwater run-off and septic-influenced groundwater on the perimeter of the Project Area will continue. Wildlife will also use the Project Area in greater numbers. Underlaying all of this are nutrient fluxes associated with historically high levels of nutrients in Project Area soils, which may move into Project Area waters, although they will eventually become reduced over time as nutrients become assimilated by plants or transformed by biogeochemical processes. Perhaps, one of the most compelling reasons to monitor nutrients comes not from how restoration will change nutrients in the Project Area, but from how restoration in the Project Area will change nutrients in Tomales Bay. Both of these factors advocate for continued inclusion of nutrients in progress criteria, although change may be harder to detect for some nutrients than others, because of the inherent variability in nutrient data as evidenced by the CVs.

- ***Pathogens and Fecal Coliform Indicators - Retain in Progress Criteria***: In addition to nutrients, pathogens are one of the more pressing issues in the Project Area and Tomales Bay as a whole.

  More than 28 percent of the Project Area fecal coliform levels exceeded the 95th percentile of values in Reference Areas (6,201.3 mpn/100 ml; Figure 31). Approximately 49 percent of the samples from the Project Area exceeded the highest 16.7 percent of coliform levels or 83.3rd percentile in reference marshes (1,482 mpn/100 ml), which comes close to not meeting the progress criteria for this parameter (Figure 32). Variability for this parameter is not only high in the Project Area, but in Reference Areas: The coefficient of variation for this parameter greatly exceeds 1.

In general, all monitoring study areas violated Basin Plan standards for beneficial use objectives, particularly those for shellfish harvesting and municipal water supply (20-43 mpn/100 ml), but Project Area levels consistently to regularly exceeded water contact and non-contact water recreation standards (200-2,000 mpn/100 ml) and the newer TMDL standards (96-200 mpn/100 ml) for Lagunitas Creek. The importance of some of the other Project Area sub-sampling or sub-groups to downstream coliform loading is apparent in that loading rates exceeded the 95th and 83.3rd percentiles in reference marshes approximately 5 percent and 19 percent of the time, respectively, even with the East Pasture being leveed and not actively contributing to downstream loading (Figures 31-32).

Removal of cattle and discontinuation of manure spreading has eliminated a direct source of pathogens in the Project Area. However, as with nutrients, there will continue to be influxes of pathogen indicators such as fecal coliform even with restoration from perimeter freshwater sources such as small creeks, drainages, and septic-influenced groundwater, as well as increased use by wildlife. In addition, reconnection of Lagunitas Creek and Tomasini Creeks will increase loading of pathogens from upstream watershed sources. Again, one of the more important reasons to continue to monitor coliforms and pathogens comes not so much from how the restoration will change the Project Area and improve site conditions, but how the restored Project Area will change conditions in the upper portions of the Tomales Bay estuary. These factors advocated for continued inclusion of fecal coliform in progress criteria.

- ***Productivity-Related Measures – Retain in Progress Criteria***: In addition to water quality improvement, support of the estuarine food web through production of detritus, phytoplankton, and higher order organisms is another important function of coastal marshes. Nutrient enrichment of coastal waters has destabilized the delicate balance in this web by leading sometimes to overproduction of some of the elemental components such as dissolved organic carbon (DOC) and chlorophyll a.

  Some of these issues are evident in the Project Area. Approximately 15 percent of the Project Area chlorophyll a values exceeded the 95th percentile in Reference Areas (30 mg/L), while more than double that percentage exceeded the highest 16.7 percent of values or 83.3rd percentile in reference marshes (8.3 mg/L; Figures 31-32). This disparity becomes even more striking with DOC. Approximately 37 percent of Project Area DOC levels exceeded the 95th percentile in Reference Areas (6.1 mg/L), while more than 53 percent exceeded the 83,3rd percentile in reference marshes (4.4 mg/L; Figures 31-32). DOC concentration was the only parameter that failed to meet the 50 percent threshold for this progress criterion. As with nutrients, loading of DOC and chlorophyll a fell easily within the natural range of variation due in large part to the fact that the East Pasture did not regularly contribute to downstream loading (Figures 31-32).

  With primary productivity measures, then, progress criteria would actually hope to capture an eventual decline in DOC and chlorophyll a to levels more in balance with non-eutrophic systems, although DOC may increase temporarily due to elevated decomposition rates during pasture conversion. Over time, these parameters would be expected to stabilize somewhere in the range of natural variation observed in Reference Areas and provide support for both resident and non-resident aquatic organisms. To some degree, determining whether this convergence has been achieved will be clouded by the high variability in these parameters even within reference marshes: CV exceeded 1 in both cases.

In marked – and surprising – contrast to DOC and chlorophyll a, turbidity -- which is linked to chlorophyll a measures of productivity in that high turbidity levels can dampen phytoplankton productivity – in the Project Area showed similar data dispersion to that of Reference Areas, with only 14 percent exceeding the 5th and 95 percentiles or 4 percent more than actually occurred in reference marshes (Figure 31). Approximately 17 percent of turbidity values in the Project Area exceeded the 83.3rd percentile in Reference Areas, which is again essentially equivalent to the current distribution of values in reference marshes (Figure 32). Restoration will result in a temporary increase in turbidity as the newly reconnected system adjusts to altered hydrologic conditions, however, turbidity values are expected to drop rapidly after the first few years. While pre-project conditions would suggest that turbidity would not necessarily be a good indicator of restoration progress, the temporary increases in turbidity expected in the early part of the restoration process support its continued inclusion at least until Year 7 of the monitoring program.

Other Recommendations

The results from the pre-restoration portion of this monitoring program also lead to some other conclusions and/or recommendations, some of which should be incorporated into post-restoration monitoring to improve effectiveness of this program.

- ***Frequency and Extent of Storm Sampling Increased***: The number of storm events monitored should increase, and more effort should be made to capture these events at Reference, as well as Project Area, creeks, drainages, and groundwater outflow locations. Storm sampling efforts have increased since 2005, but only at Project Area and, in some events, Undiked Marsh sampling sites. This may not have had a large effect on means for pre-restoration monitoring data – only two storm events were sampled separately during that period, with other wet season and storm sampling events during that period occurring as part of the regularly scheduled monitoring that includes sampling at all marshes. However, it may affect analysis of post-restoration results as the frequency of monitoring storm sampling events has increased since 2006. In general, logistical complexity of sampling all areas within a single day – quarterly monitoring usually requires four to five days of sampling – has forced us to devote our resources to monitoring the Project and Upstream Areas. In addition, as has been discussed in this document, timing is everything when it comes to storm sampling, and no sampling effort can capture peak loading on all drainages at once, particularly as it does not always coincide with peak streamflow. This logistical conundrum will not be easy to redress in future sampling events, so we may need to reassess how we will analyze our data.

- ***Particulate Nutrients Assessed as Well as Dissolved***: Based on extensive research conducted in other watersheds, a substantial portion of the nutrients flowing into the upper portion of Tomales Bay from the upper watershed would be expected to be particulate and mobilized almost exclusively in response to storm events generating increases in run-off and streamflow. Lower particulate levels observed in the LMER/BRIE study between 1985 and 1993 may be at least partially due to the fact that, because levels are highly associated with run-off, the drought conditions that occurred during the sampling period may have greatly reduced downstream transport. Despite this, Smith and colleagues, who analyzed particulate data from Lagunitas and Walker Creeks, still postulated that particulate loading was the dominant pathway by which nitrogen and phosphorous were removed from the watershed and transported downstream, even during drought periods (Smith et al. 1996). Unfortunately, we cannot compare results of the LMER/BRIE data with results from our study, because most of our laboratory analyses to date have focused on dissolved nutrients (e.g., nitrates, nitrites, total dissolved phosphates), with the possible exception of total ammonia, which is characterized as representing both dissolved and particulate ammonia fractions as samples are not filtered prior to analysis. A complete understanding of the nutrient dynamics of at least the upper portions of the Tomales Bay estuary requires that particulate, as well as dissolved, nutrient factions be assessed. Since 2007, Total Phosphorous has been incorporated into the monitoring program to try and capture some of the particulate and organic phosphorous fractions in combination with the dissolved one. However, more investigation should be conducted into the logistical feasibility of assessing particulate fractions separately.

- ***Lower Detection Limits***: Analyses of Total Ammonia and Total Dissolved Phosphate data were confounded, to some degree, by the fact that commercial laboratory detection limits may not be capturing the presence of low levels of these nutrients. In efforts to improve data resolution, we have begun to have our nutrient samples analyzed by the laboratory of Dr. Francis Wilkerson at San Francisco State University's Romberg Tiburon Center for the Environment. With their analytical techniques, detection limits can be reduced from 0.2 mg/L to below 0.01 mg/L for nitrates, nitrites, ammonia, and orthophosphates. This laboratory only processes dissolved nutrients, however, the lower detection limits should reduce the amount of estimation needed using the survival/reliability analysis statistical techniques that were employed to analyze these data sets for this report.

- ***Re-Evaluation of Reference Area Suitability***: As part of the post-restoration monitoring, some consideration must be given to the fact that Limantour Marsh and, potentially to some extent, the Undiked Marsh may change in response to restoration efforts conducted adjacent to these systems. Particularly in the case of Limantour Marsh, removal of the Muddy Hollow Pond and restoration of the formerly estuarine area behind the dam will result in increased tidal prism, changes in fluvial and tidal processes and conditions, and changes in sediment transport and depositional patterns, among other variables. These changes will have effects on the downstream marsh that formed largely after the pond was constructed. For this reason, Limantour Marsh will probably not represent a viable reference marsh condition for evaluation of future changes in the Project Area.

  To some extent, the same is true of the Undiked Marsh in that restoration of the Giacomini Ranch may affect the undiked marsh directly north of it. However, even though the scale of restoration is larger in the Project Area than at Muddy Hollow Pond, the degree of change in downstream areas might still be expected to be of a lesser magnitude, because restoration of the Giacomini Ranch did not create a large, unvegetated, subtidal basin directly upstream of the existing marsh as did removal of the Muddy Hollow Pond dam. While subtidal ponding of the Giacomini Ranch has increased with restoration, removal of levees has not resulted in a large expanse of unvegetated mud flat, but simply greater hydrologic connectivity with former densely vegetated pasture lands that are essentially at or only slightly below adjacent undiked marsh elevations.

  In addition, after a year of monitoring, most of the sampling site locations in the Undiked Marsh were moved north to reduce the potential for the restoration project to directly affect these areas. While selecting new marshes would ultimately be the best option for ensuring that Reference Areas continue to represent ambient conditions, there are few tidal marsh systems in Tomales Bay and adjacent watersheds that are comparable to the Project Area in terms of scale and watershed landscape position. Ultimately, if data continues to be collected from the Undiked Marsh, results will need to be carefully evaluated to ensure that they do not reflect potential changes from restoration rather than the range of variation expected due to intra-annual or inter-annual patterns in climate and other factors.

- ***Determining Effects of Climate Change***: When the Giacomini Wetland Restoration Project was in the early planning stages, the issue of climate change rarely even arose in planning discussions and public meetings. Since then, however, the plethora of papers published since 2001 on global warming and climate change has intensified the importance of this controversial issue with increasingly dire predictions regarding the rate of sea level rise and other associated effects. This issue is particularly important for coastal ecosystems, which are among the most vulnerable to the effects of climate change, including sea level rise, higher rates of wave and wind-induced erosion, decreases in water pH from acidification, and changes in estuarine circulation and salinity patterns. Given recent estimates for the rate of sea level rise, scientists currently predict that we could close more than 22 percent of the world's wetlands to global warming (San Francisco Bay Joint Venture 2008). Combining these climate change-associated losses with continued development and reclamation of wetlands worldwide increase loss of wetlands internationally to 70 percent (San Francisco Bay Joint Venture 2008). For wetlands such as Giacomini, persistence into the future will depend on countering of the submergence effects of sea level rise by continued sediment inputs from the upper watershed that will build marshplain elevations and thereby be more likely to maintain vegetated marsh. Preservation of coastal marshes is important not only for the so-called traditional "functions" that these systems perform, but because these types of wetlands may play a disproportionately larger role than other systems in ameliorating the effects of climate change by sequestering a considerable amount of carbon generated by global warming (Trulio et al. 2007).

Because hydrologic factors will be among those most affected by climate change, the Long-Term Monitoring Program needs to ensure that it addresses variables that will capture changes in this system that potentially are associated with climate change. These variables include monitoring of water level, the landward extent of high tides, frequency of marshplain inundation by high tides, wind speed, salinity, and pH, with monitoring conducted regularly enough to evaluate changes in spatial and temporal patterns. From a landscape perspective, assessment of changes in the extent of subtidal, intertidal mudflat, and vegetated intertidal marsh will be important, with special attention paid to changes in types of vegetated intertidal marsh (e.g., low marsh, mid marsh, high marsh, etc.). Monitoring should not only focus, though, on how climate change will affect these wetlands, but on how these wetlands may affect climate change. Through more detailed monitoring of carbon accumulation in soils, this program could also contribute to a broader scientific understanding of how restoration of coastal marshes can change local rates of carbon sequestration -- or release into the atmosphere – to guide future restoration project decision-making processes.

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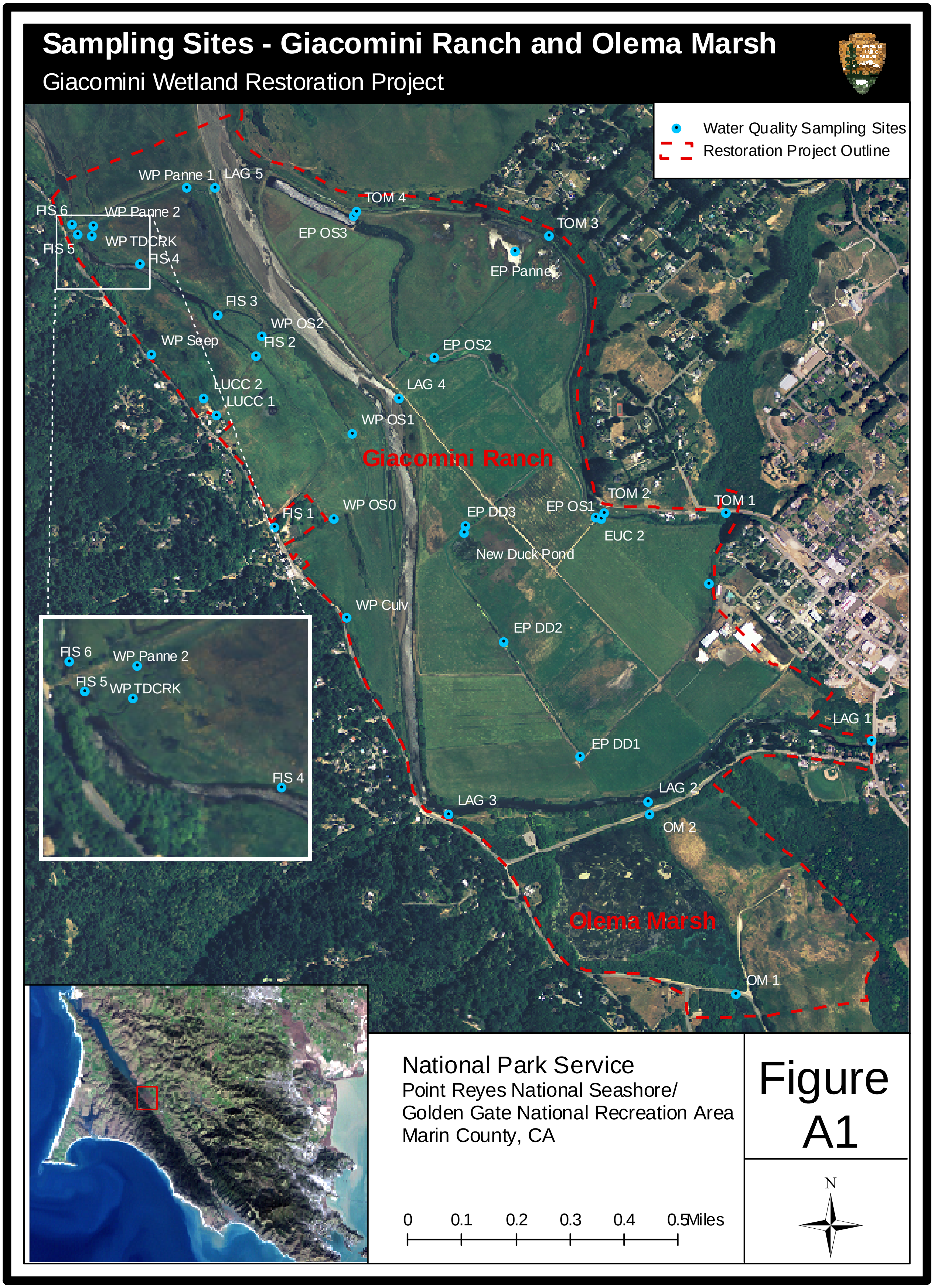
APPENDIX A

Water Quality Monitoring Site Maps

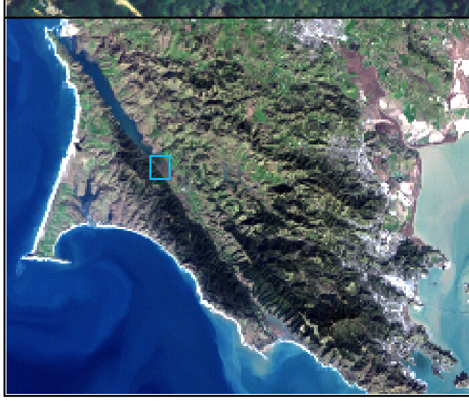


Sampling Sites - Giacomini Ranch and Olema Marsh
Giacomini Wetland Restoration Project
Water Quality Sampling Sites
Restoration Project Outline
WP Panne 1
LAG 5
FIS 6
WP Panne 2
TOM 4
EP OS3
TOM 3
FIS 5
WP TDCRK
FIS 4
EP Panne
FIS 3
WP OS2
FIS 2
WP Seep
EP OS2
LUCC 2
LAG 4
LUCC 1
WP OS1
Giacomini Ranch
TOM 2
TOM 1
EP OS1
FIS 1
WP OS0
EP DD3
EUC 2
New Duck Pond
WP Culv
EP DD2
LAG 1
EP DD1
LAG 2
LAG 3
OM 2
Olema Marsh
OM 1
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0
0.1
0.2
0.3
0.4
0.5
Miles
N

Figure A1

Sampling Sites - Undiked Marsh

Giacomini Wetland Restoration Project



National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA

0 0.05 0.1 0.15 0.2 Miles

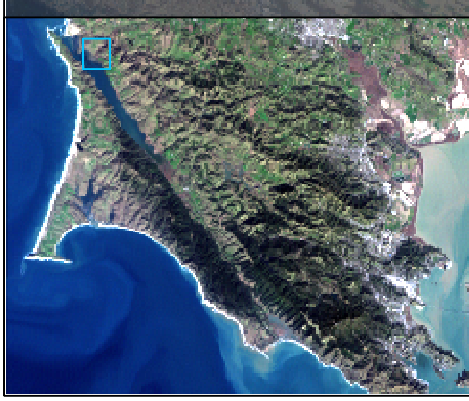
Figure A2

N

Sampling Sites - Walker Creek Marsh

Giacomini Wetland Restoration Project

Water Quality Sampling Sites

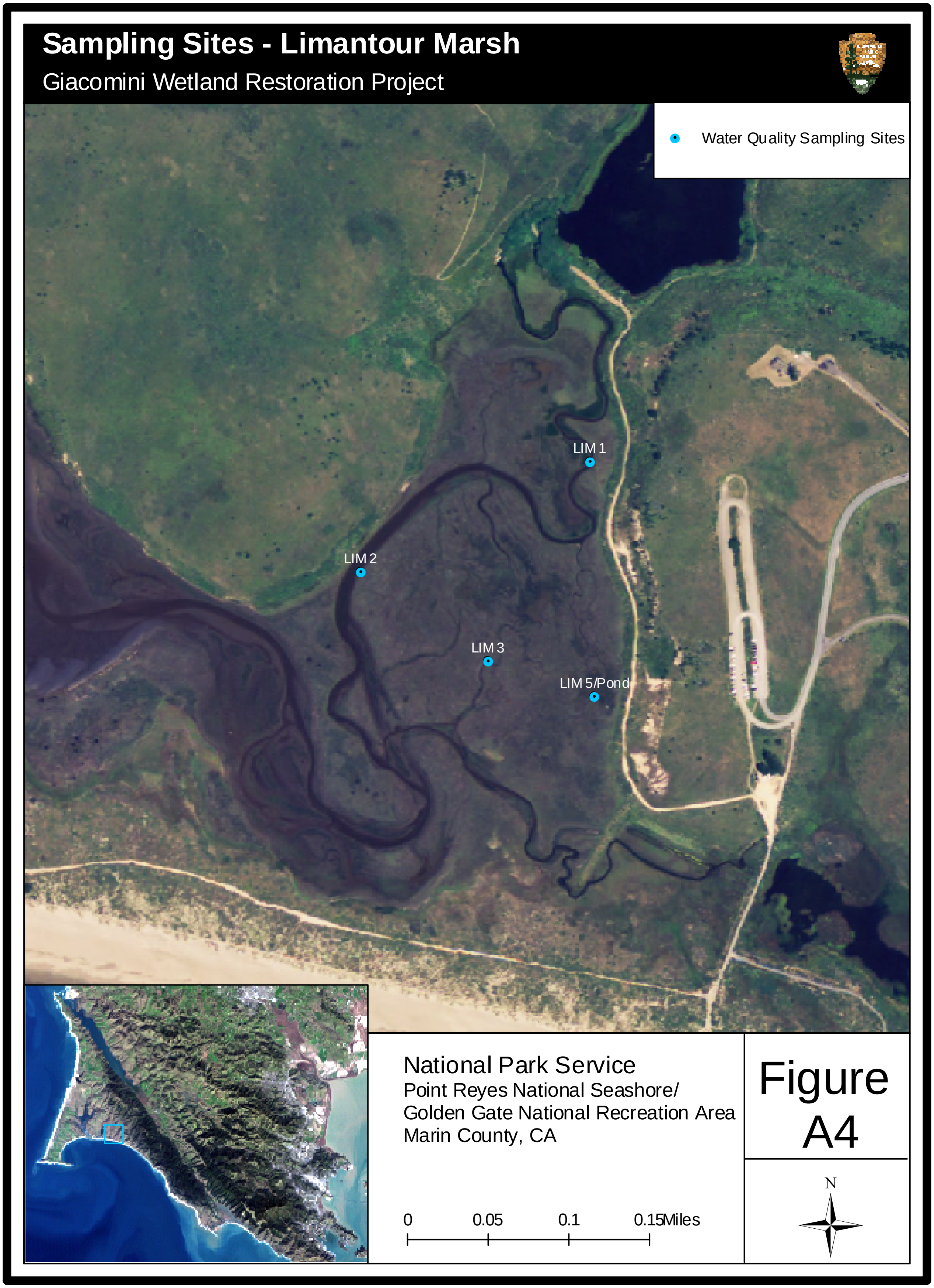


National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA

0 0.1 0.2 0.3 Miles

Figure A3

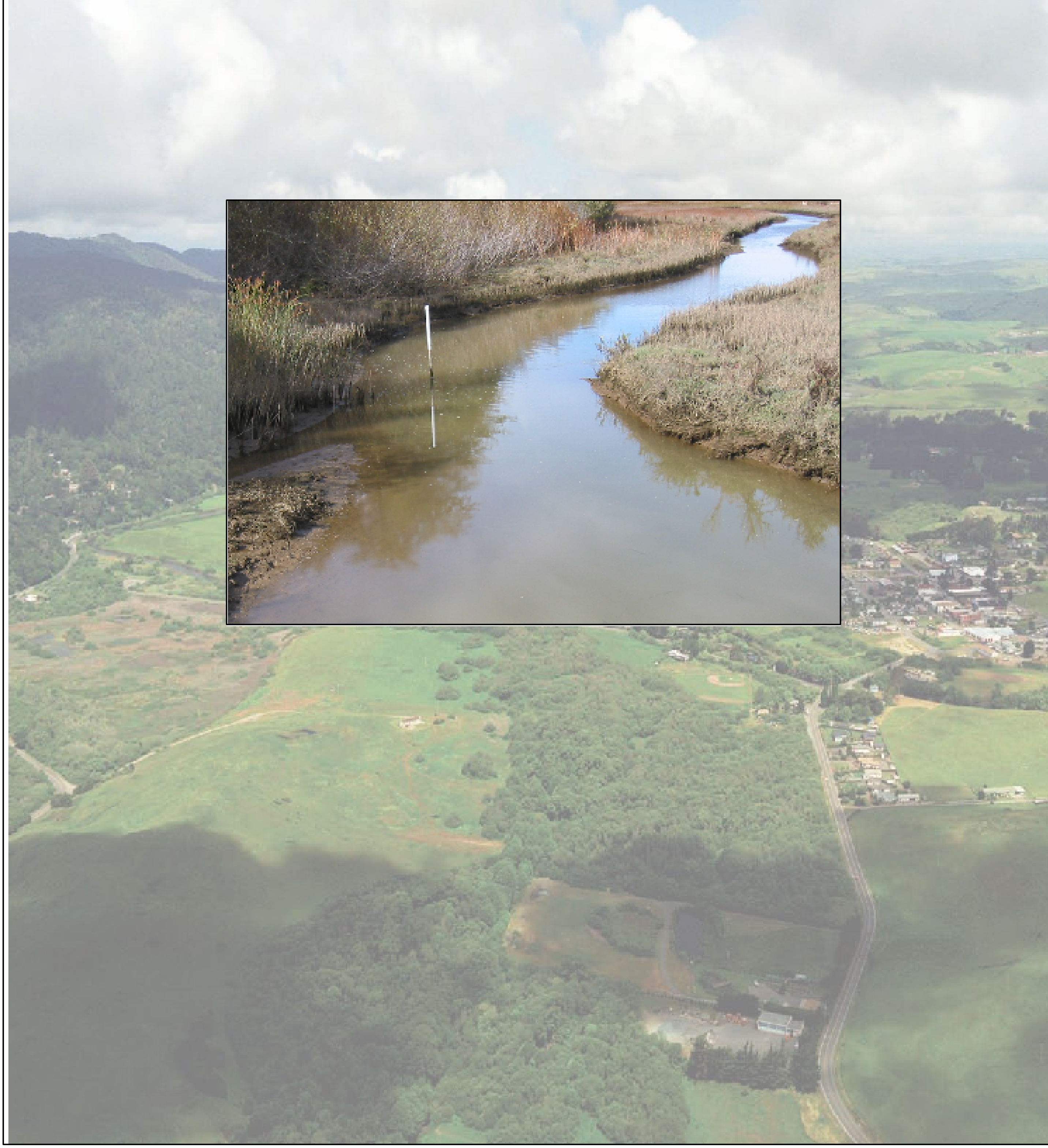
N



Sampling Sites - Limantour Marsh
Giacomini Wetland Restoration Project
Water Quality Sampling Sites
LIM 1
LIM 2
LIM 3
LIM 5/Pond
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA
0
0.05
0.1
0.15
Miles
N
Figure A4

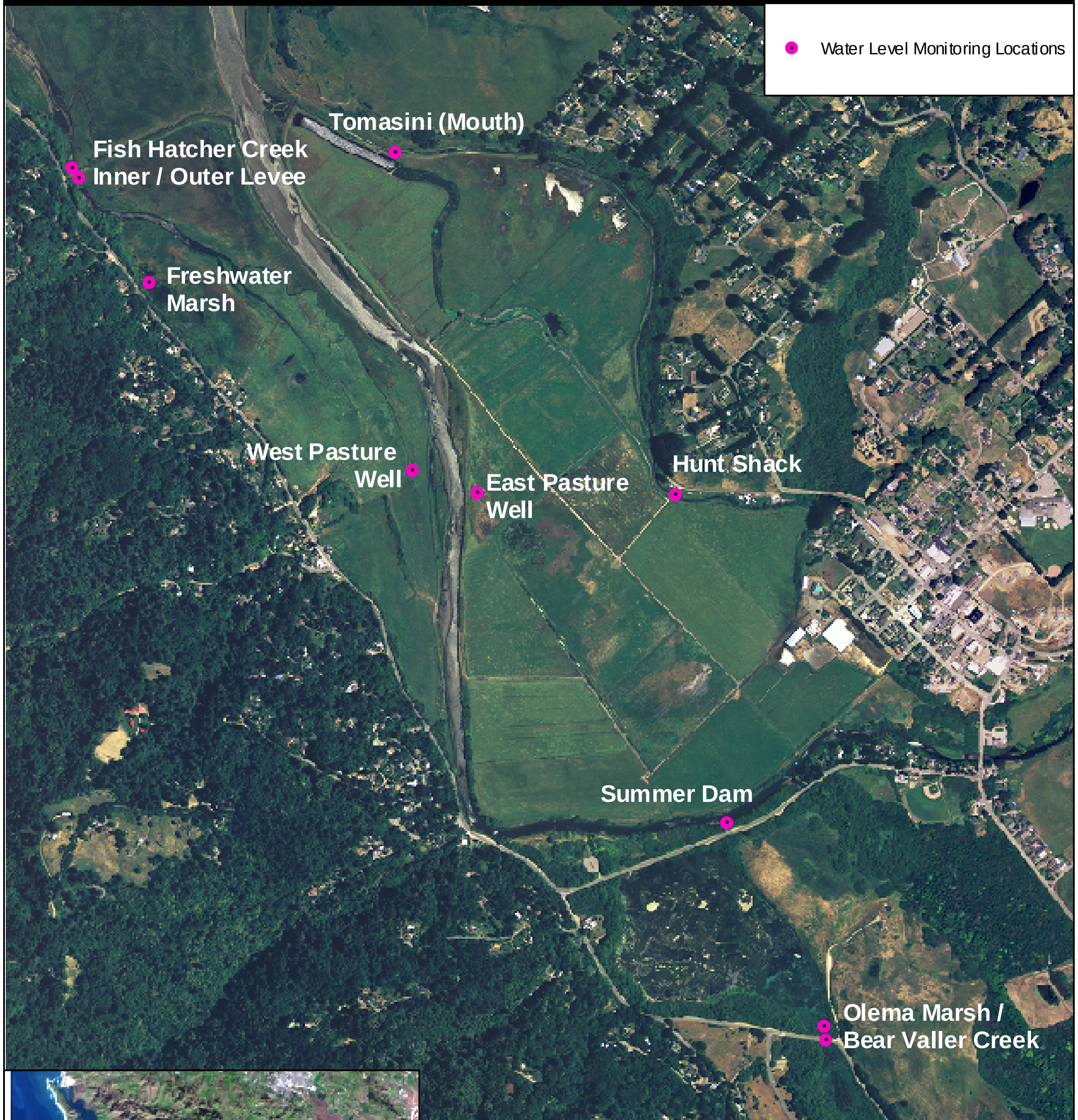
APPENDIX B

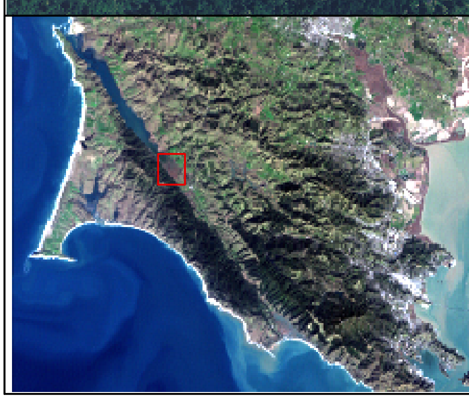
Surface Water Level Monitoring



Surface Water Level Monitoring Locations

Giacomini Wetland Restoration Project



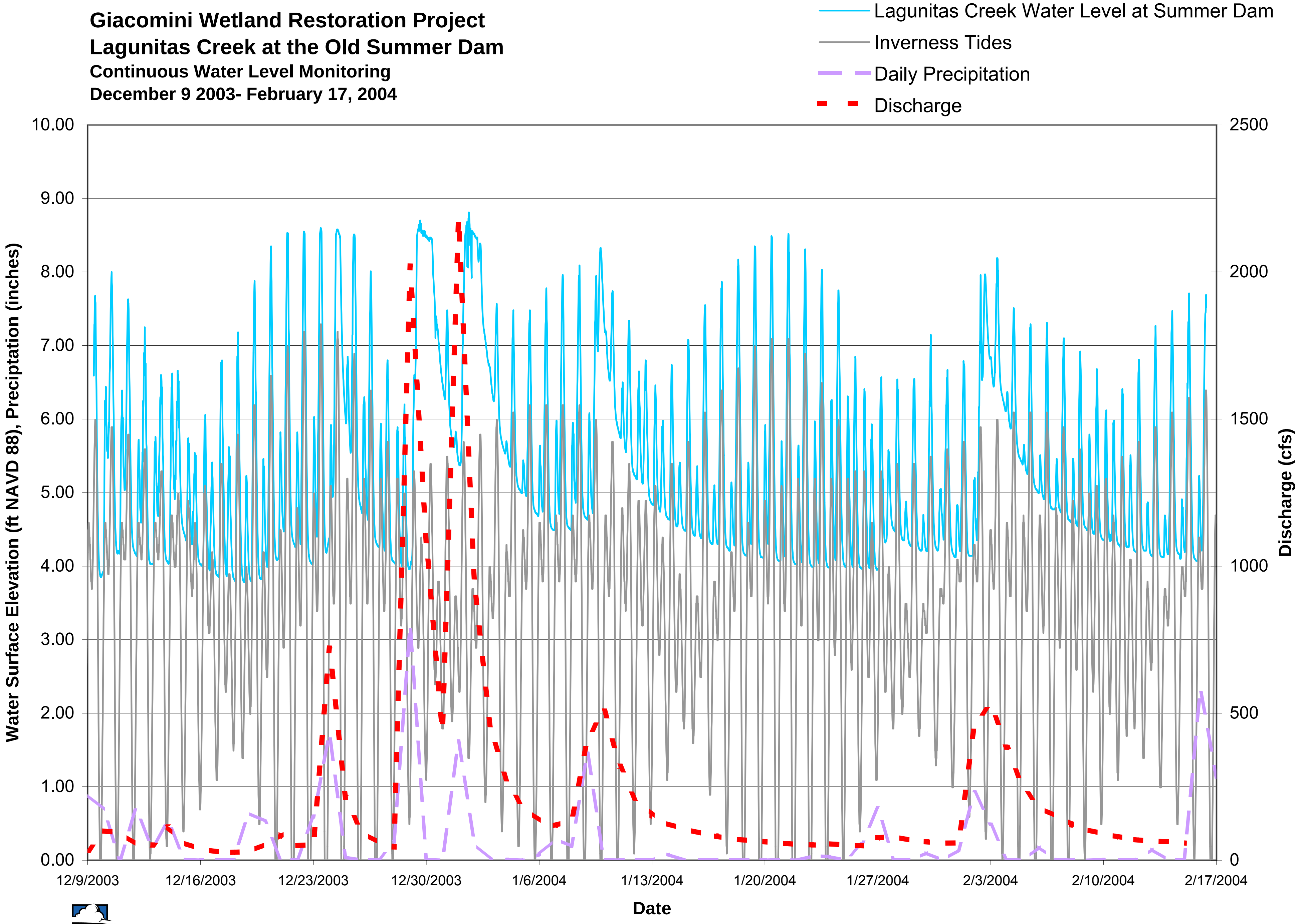


National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA

0 0.1 0.2 0.3 0.4 0.5 Miles

Figure B1

N



Kamman Hydrology & Engineering, Inc. Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

Figure B2

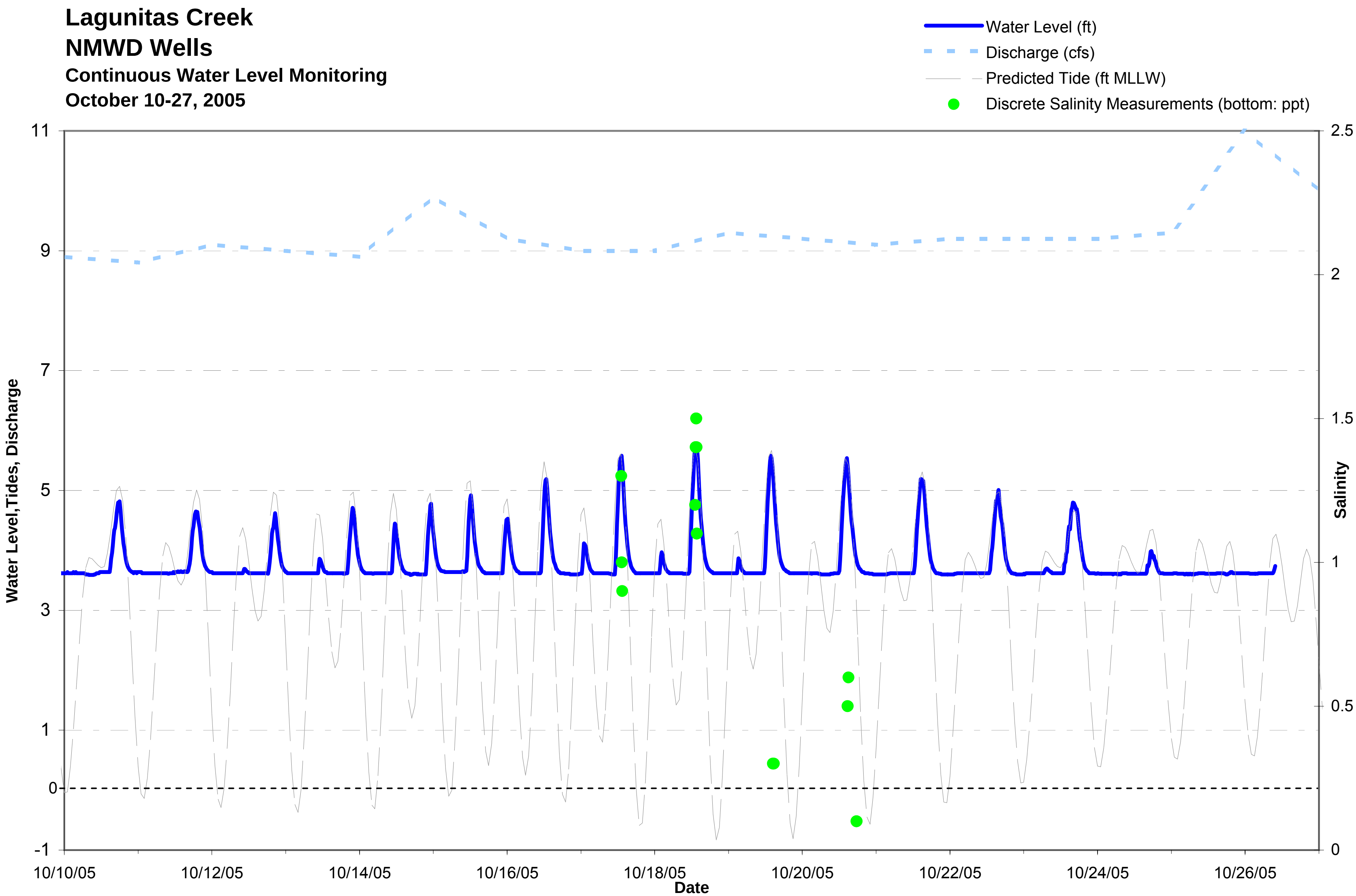


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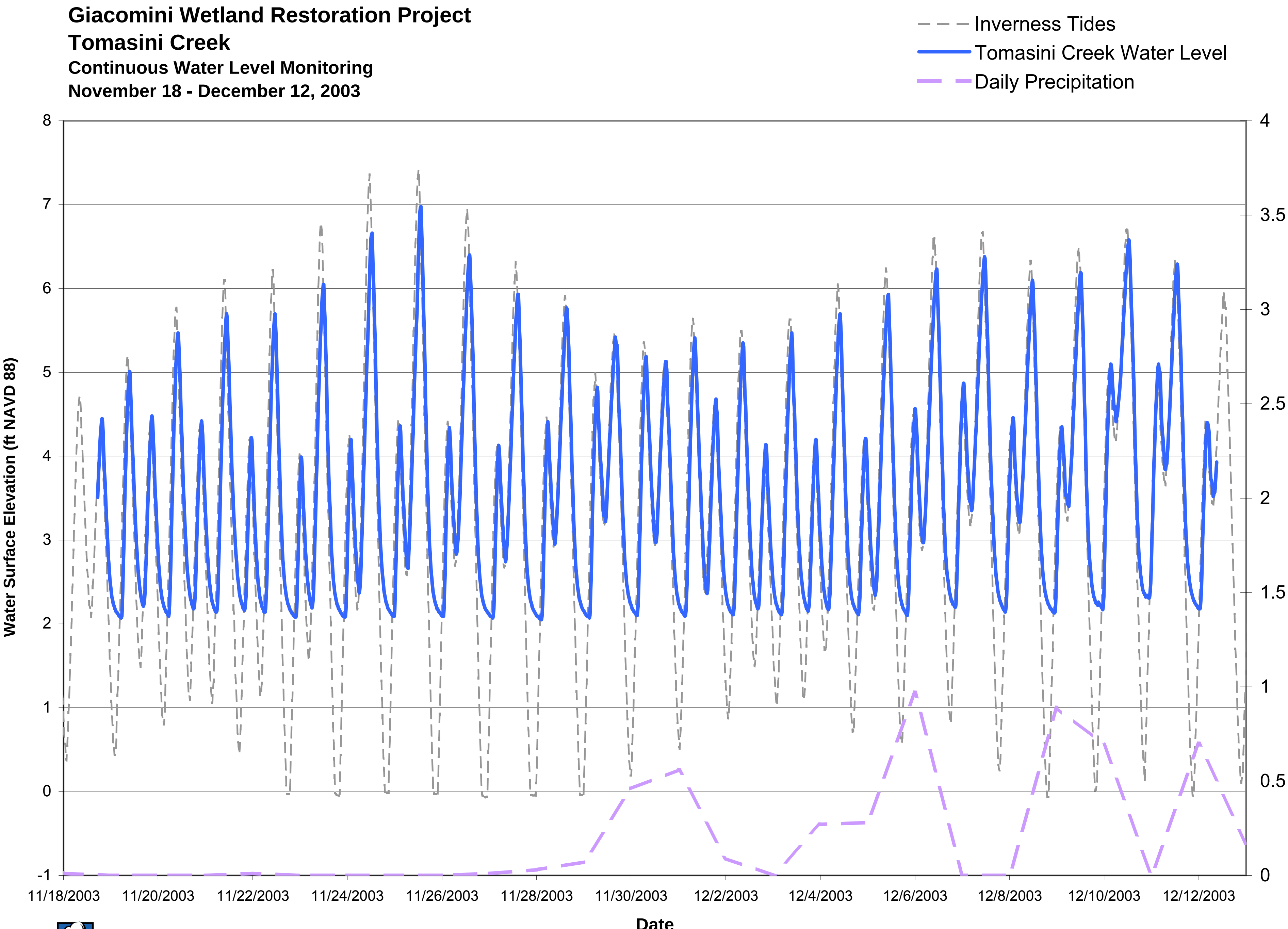
Figure B3



Kamman Hydrology & Engineering, Inc.

Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

Figure B4

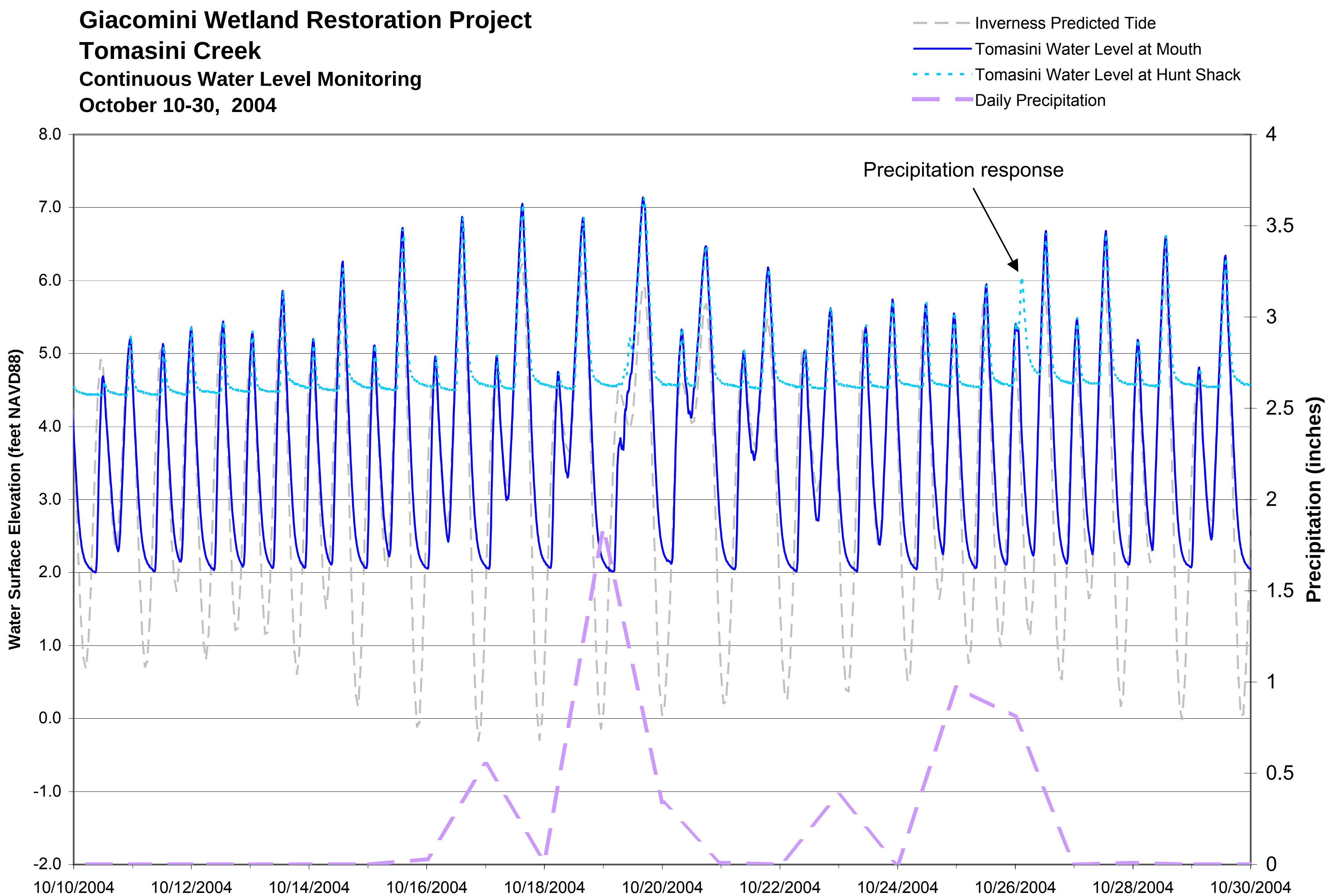


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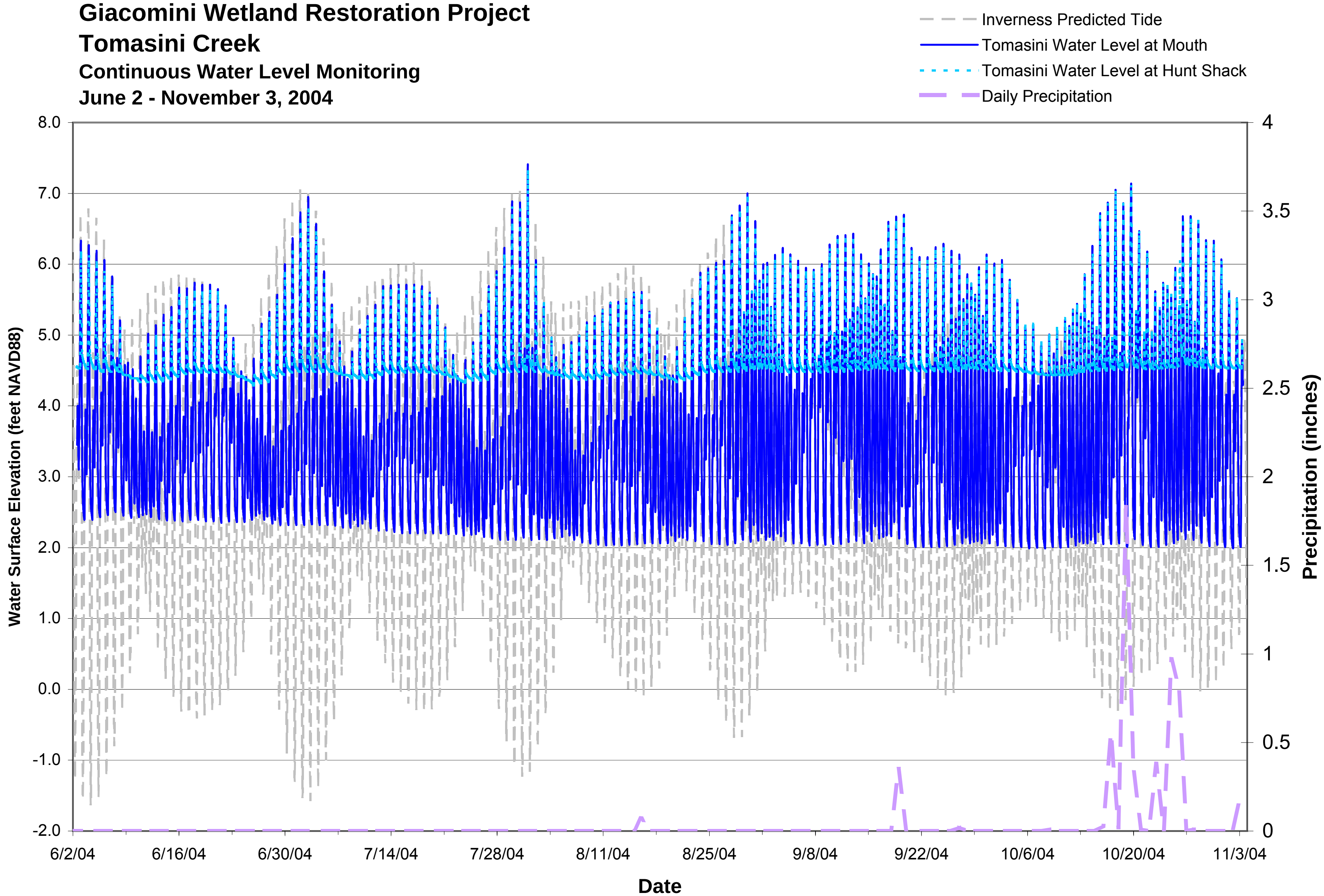
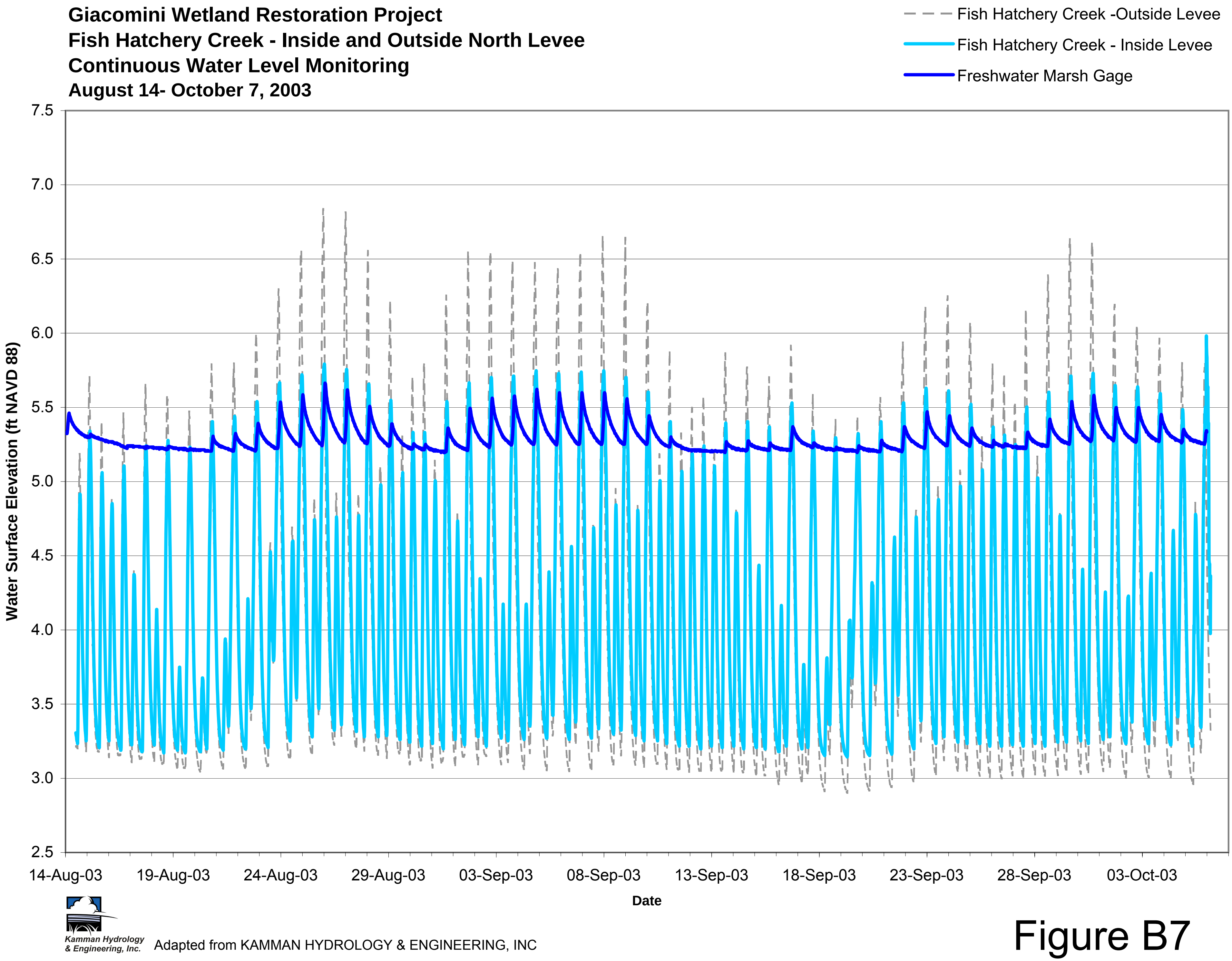
Figure B5



Kamman Hydrology & Engineering, Inc.

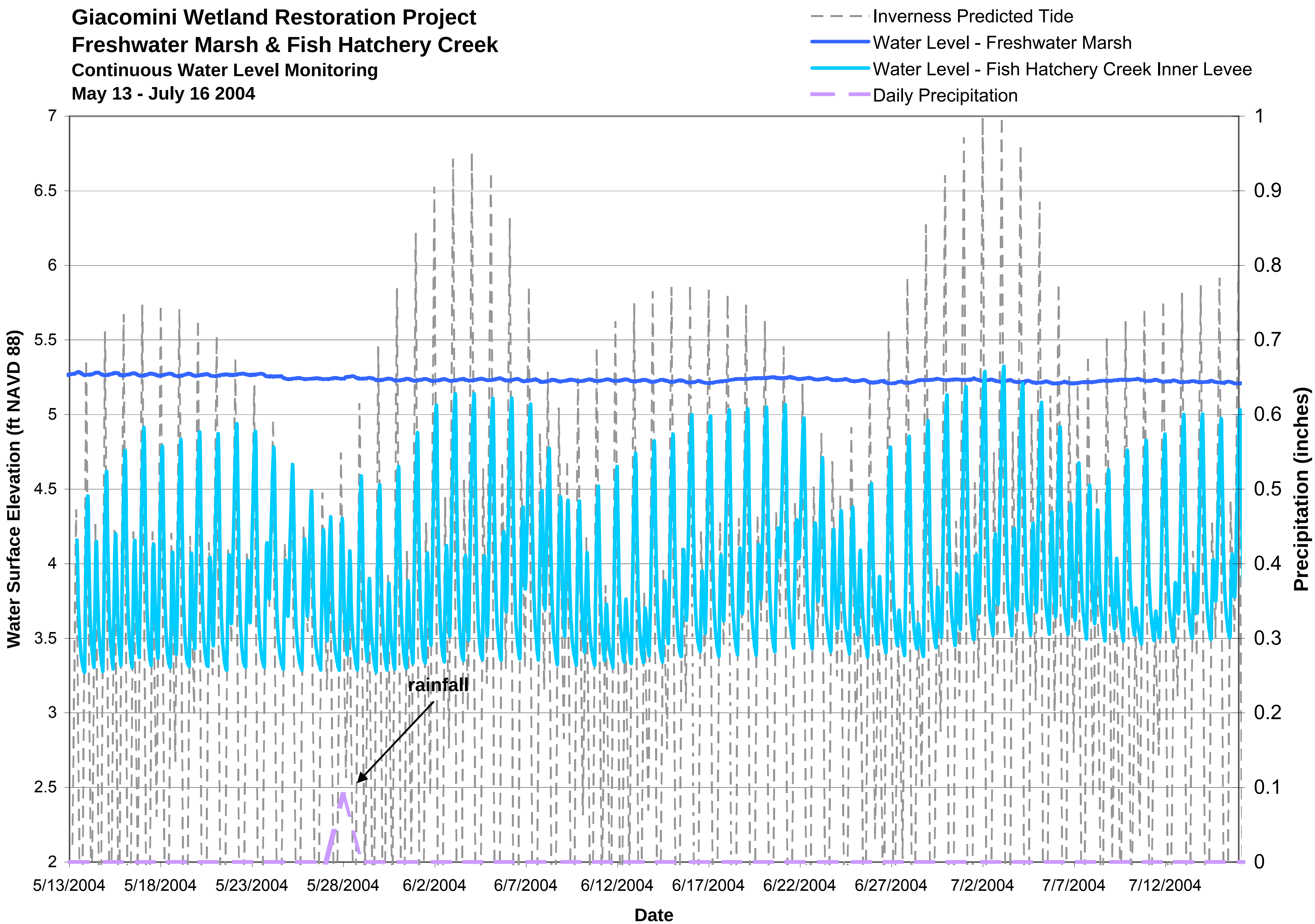
Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC

Figure B6



Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC

Figure B7



Kamman Hydrology & Engineering, Inc.

Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

Figure B8

Giacomini Wetland Restoration Project
Bear Valley Creek and Olema Marsh
Continuous Water Level Monitoring
January 6 - May 6, 2005

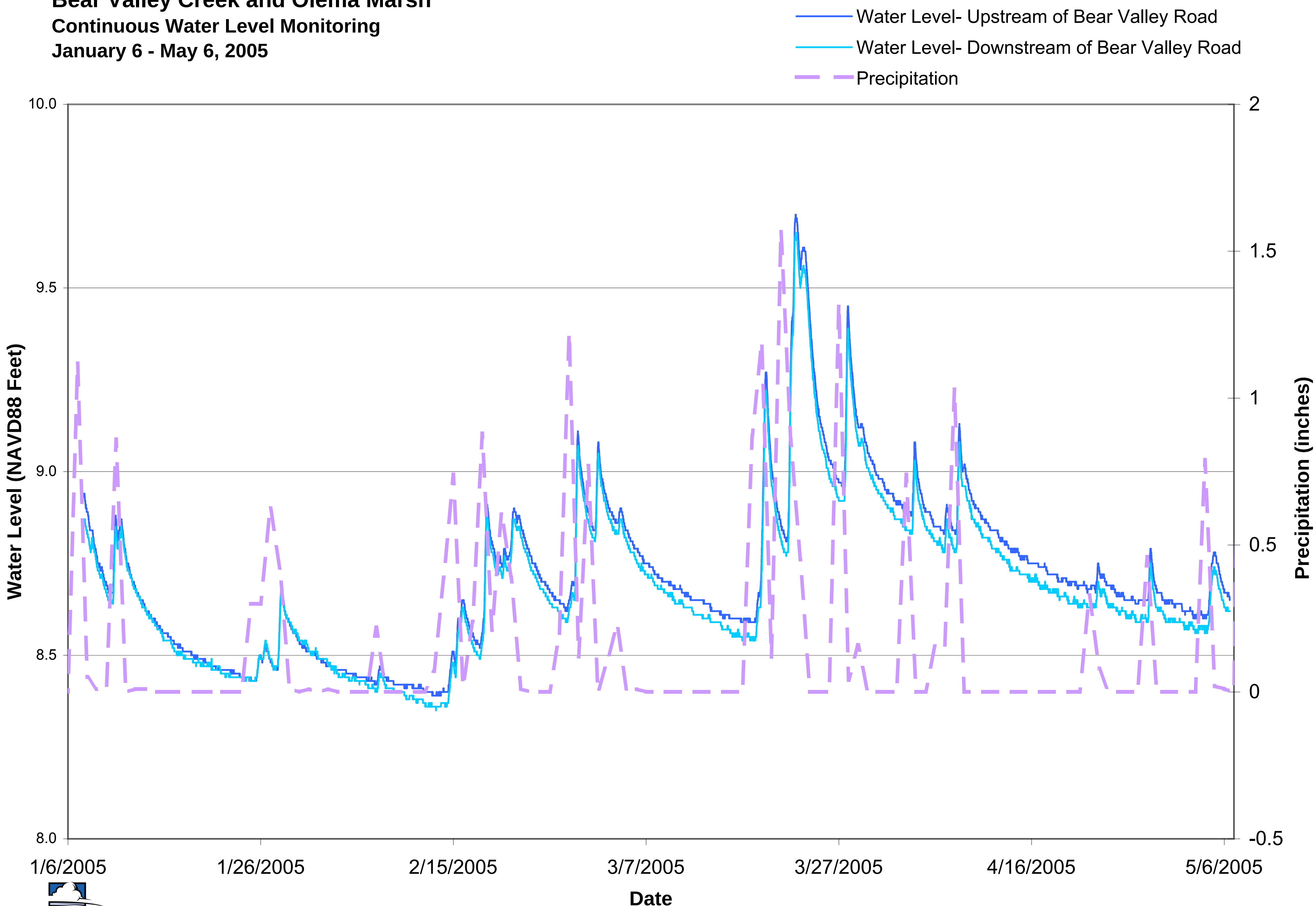


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Figure B9

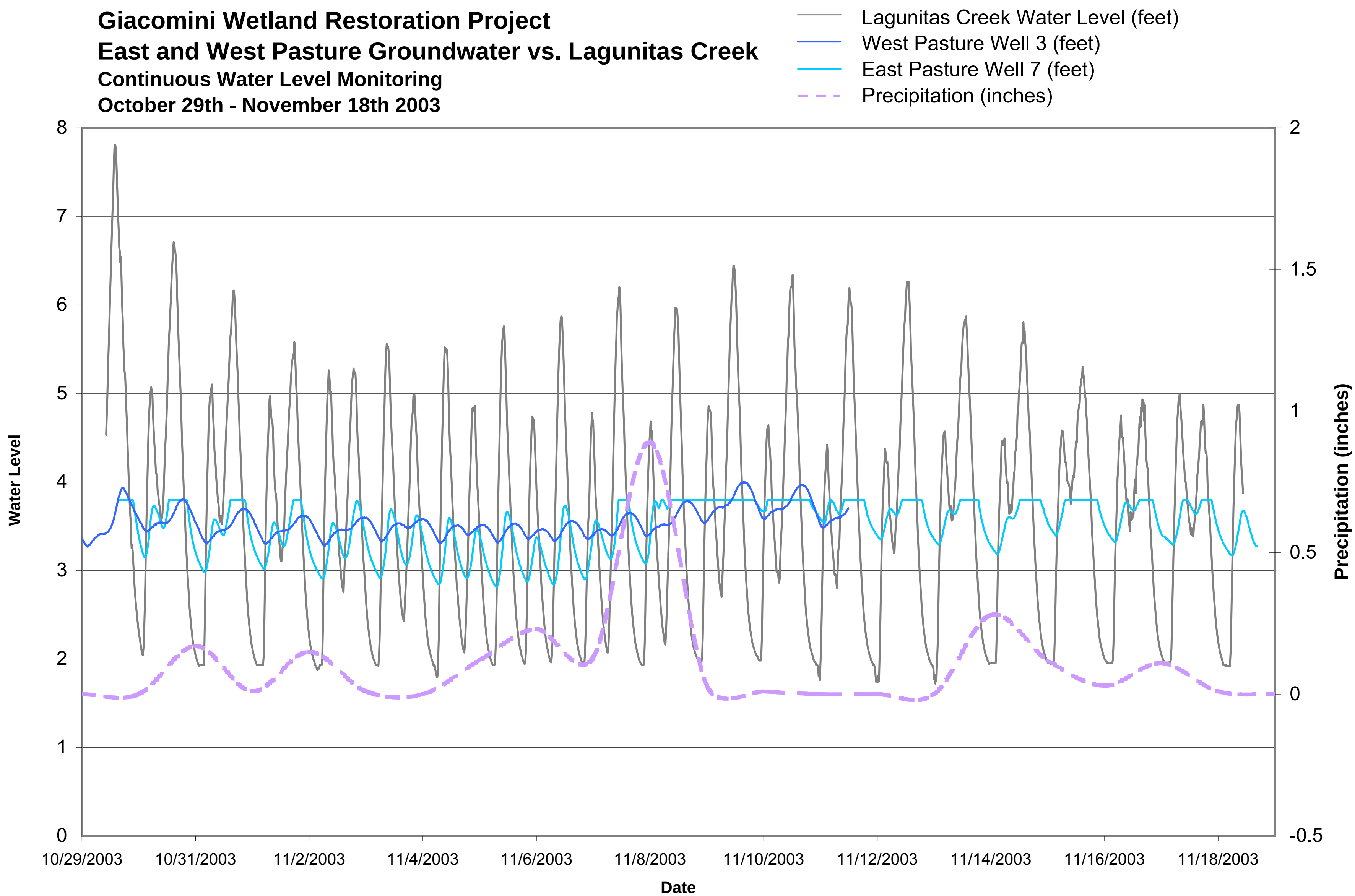

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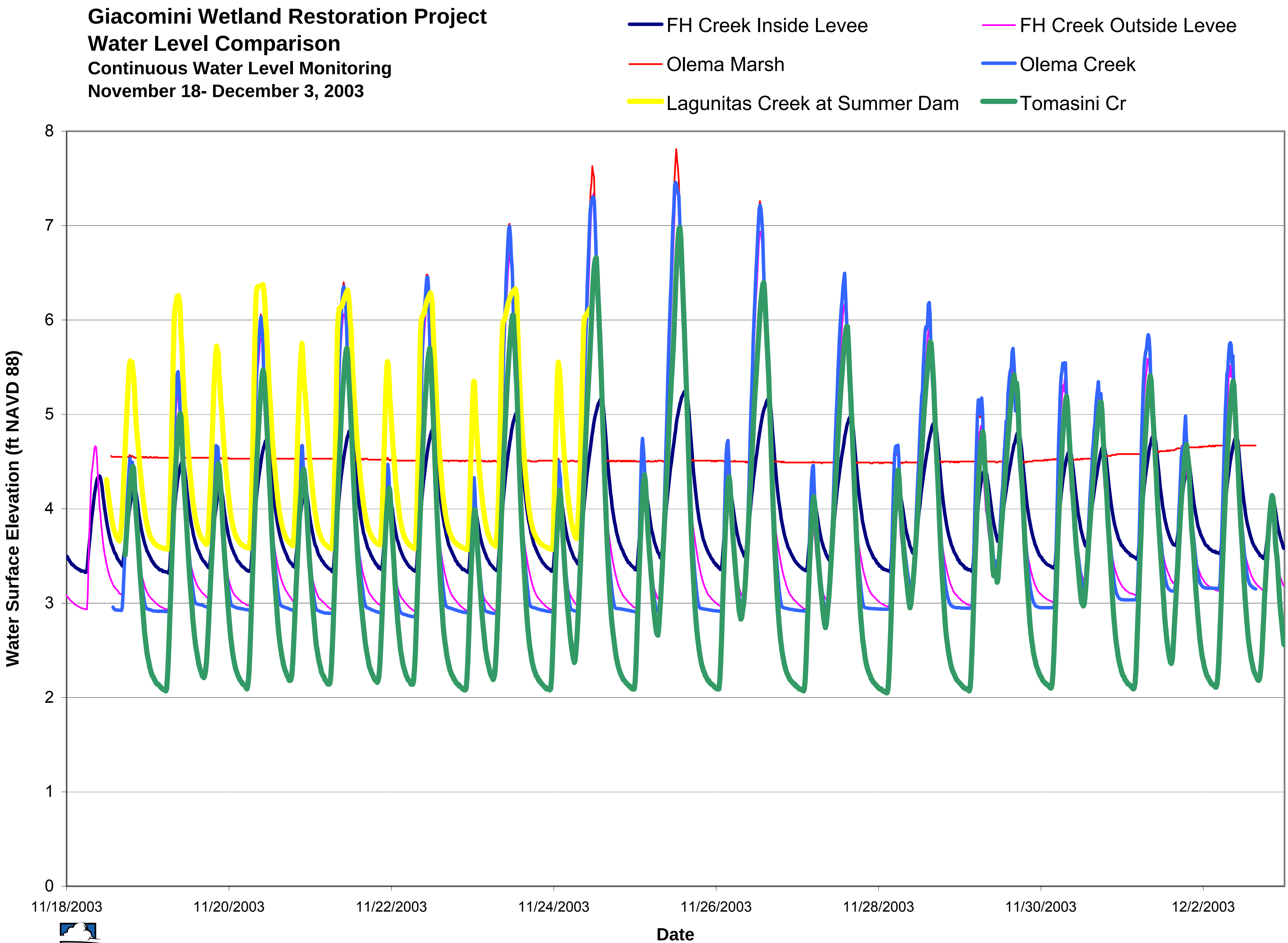
Figure B10



Kamman Hydrology & Engineering, Inc.

Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

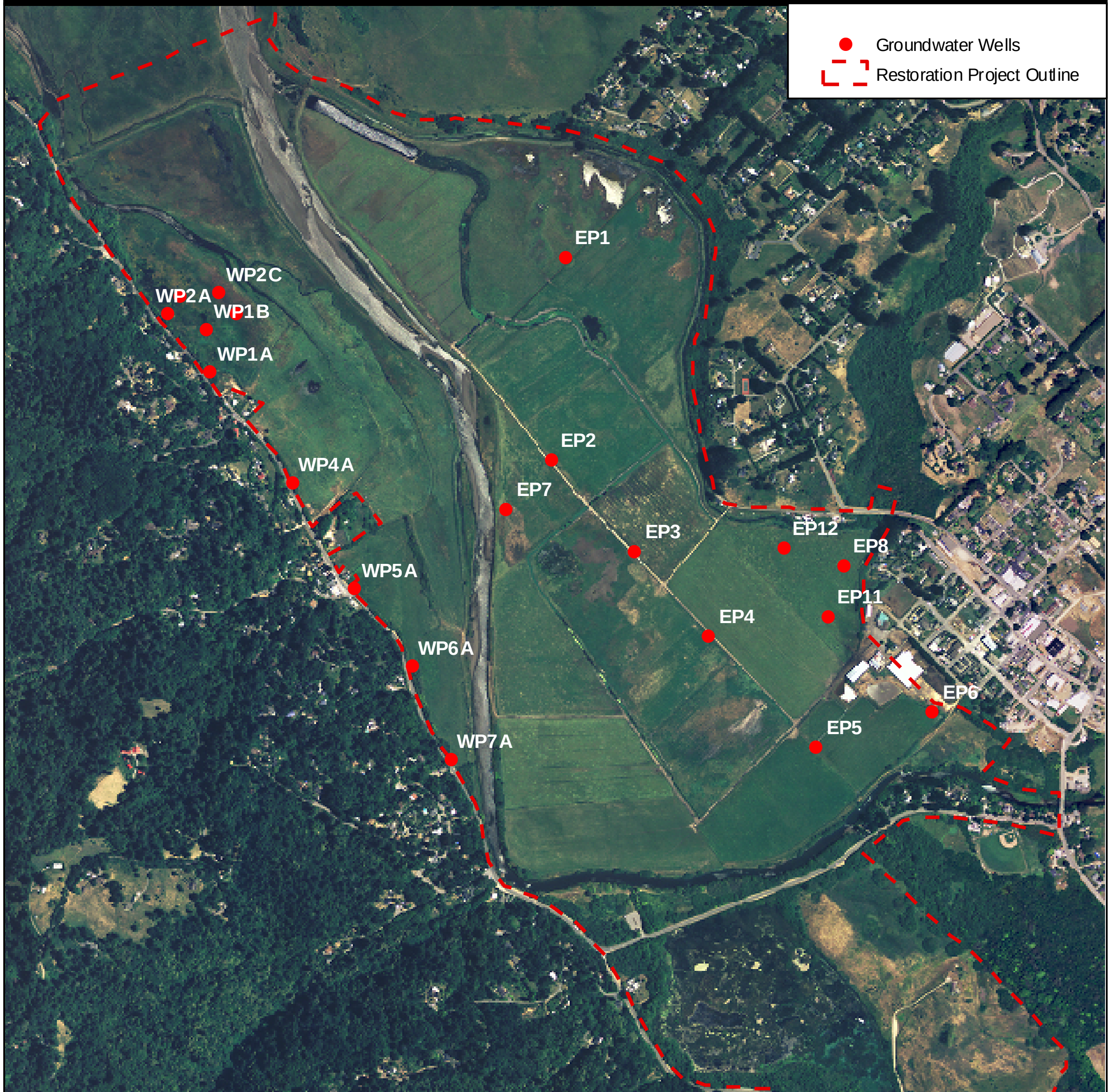
Figure B11

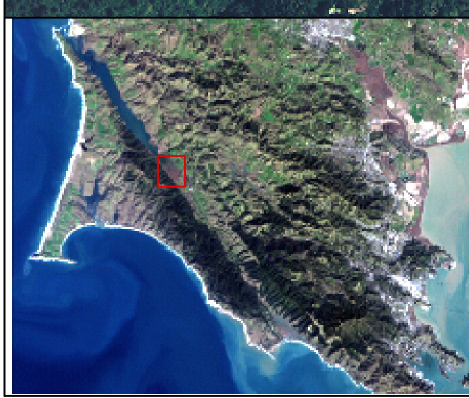
APPENDIX C

Groundwater Well Monitoring

Groundwater Well Locations

Giacomini Wetland Restoration Project



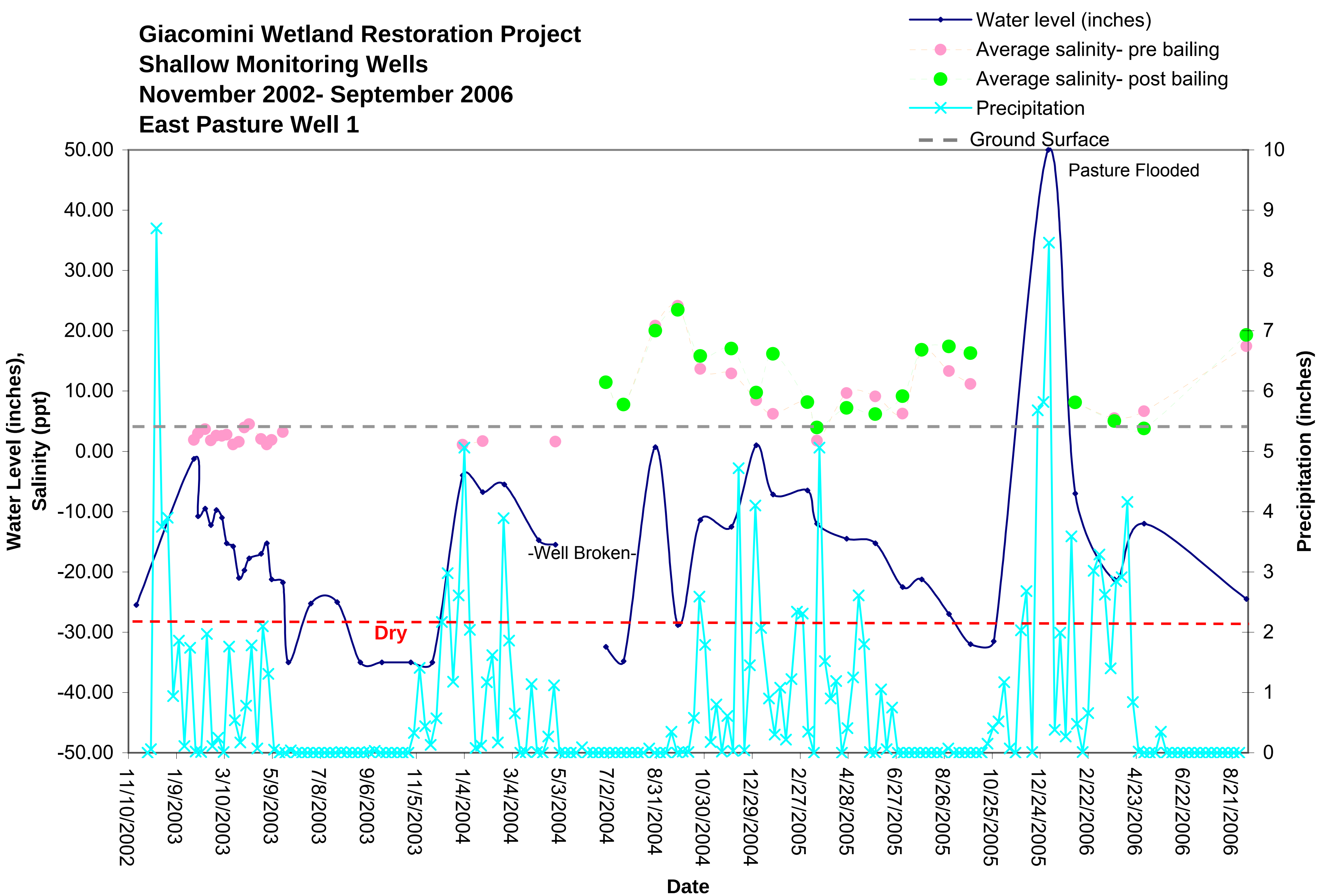


National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA

0 0.1 0.2 0.3 0.4 0.5 Miles

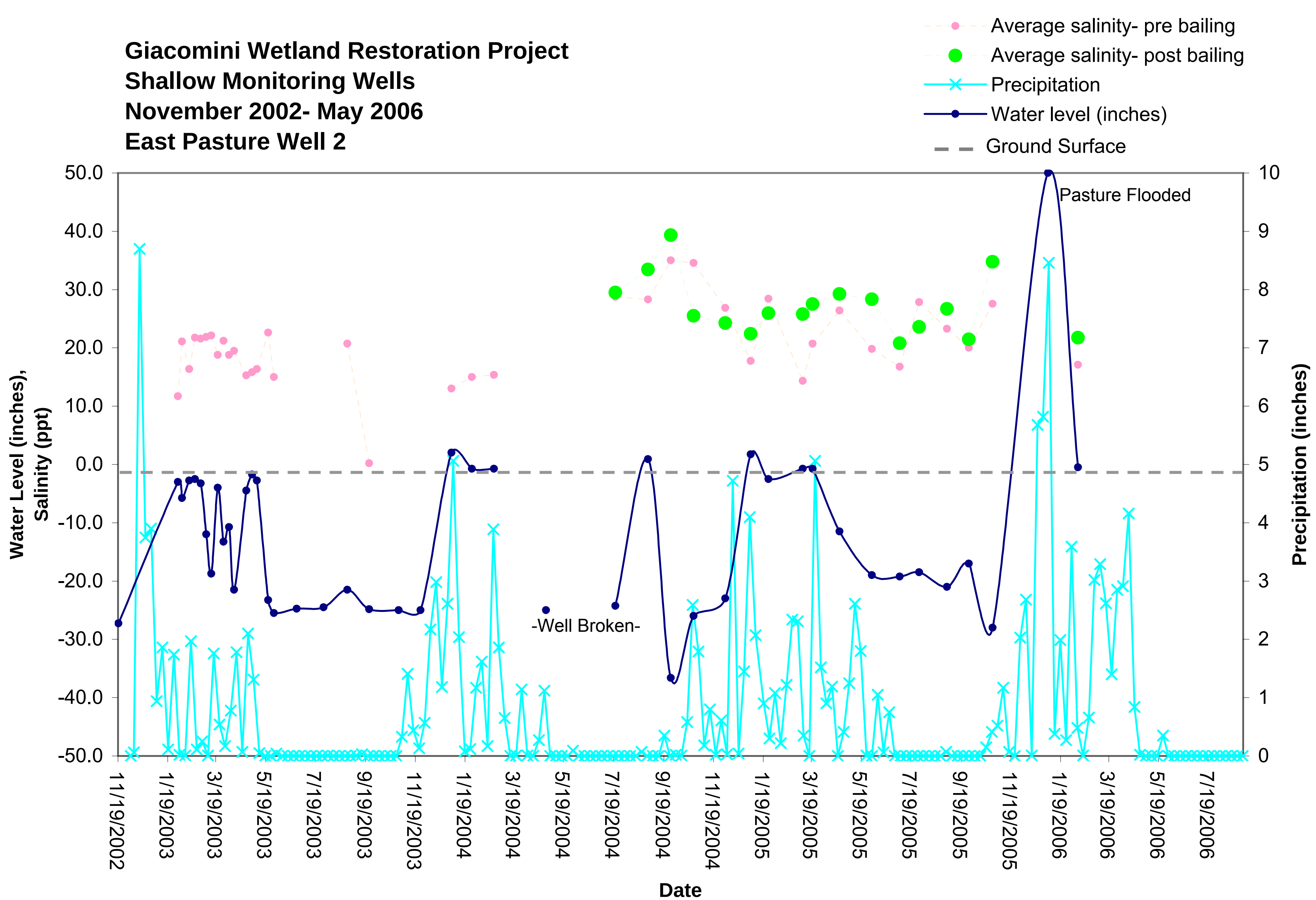
Figure C1

N



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
November 2002- September 2006
East Pasture Well 1
Water level (inches)
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Pasture Flooded
-Well Broken-
Dry
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
11/10/2002
1/9/2003
3/10/2003
5/9/2003
7/8/2003
9/6/2003
11/5/2003
1/4/2004
3/4/2004
5/3/2004
7/2/2004
8/31/2004
10/30/2004
12/29/2004
2/27/2005
4/28/2005
6/27/2005
8/26/2005
10/25/2005
12/24/2005
2/22/2006
4/23/2006
6/22/2006
8/21/2006

Figure C2.1



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
November 2002- May 2006
East Pasture Well 2
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Water level (inches)
Ground Surface
Pasture Flooded
-Well Broken-
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
10
9
8
7
6
5
4
3
2
1
0
11/19/2002
1/19/2003
3/19/2003
5/19/2003
7/19/2003
9/19/2003
11/19/2003
1/19/2004
3/19/2004
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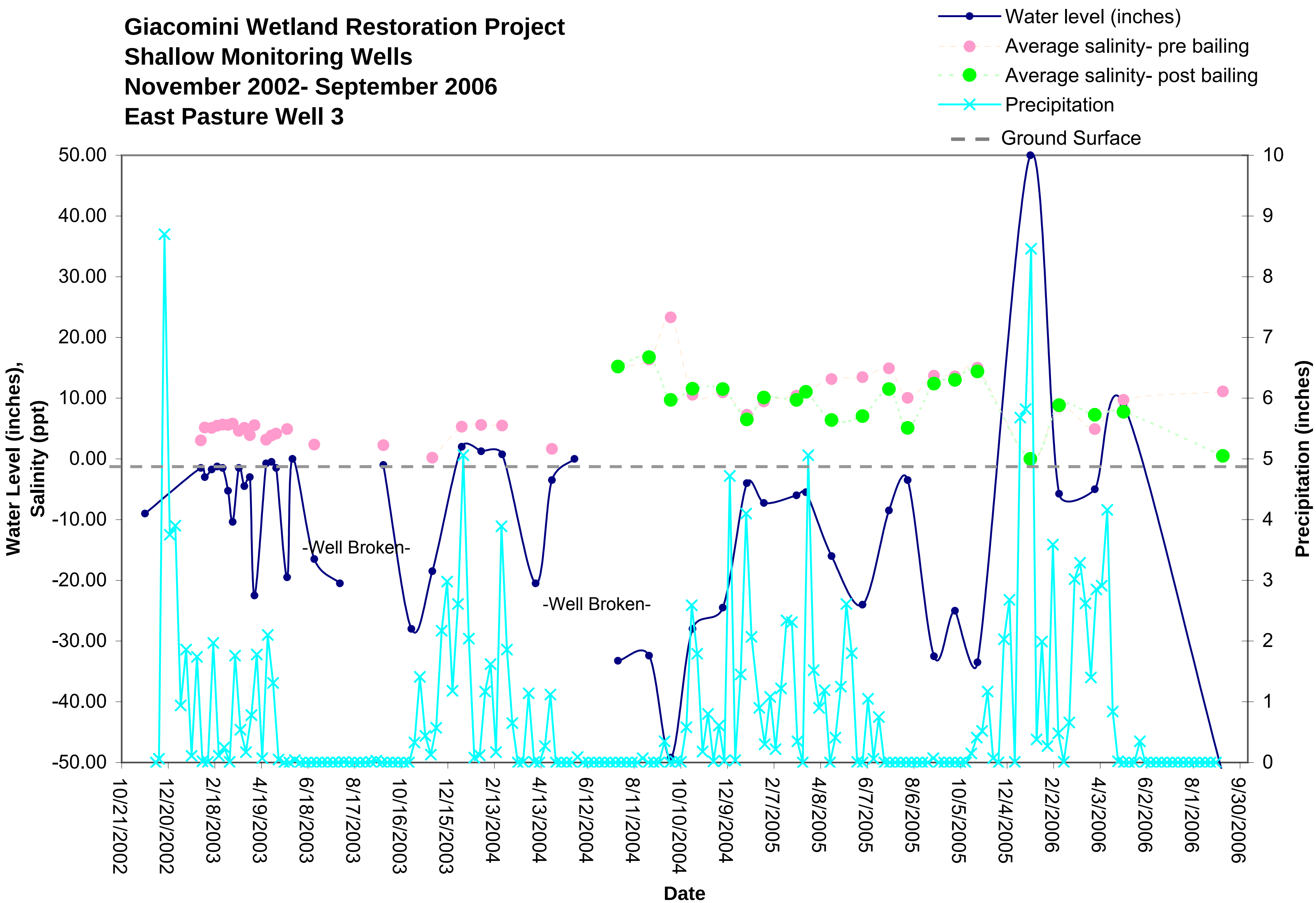
7/19/2004
9/19/2004
11/19/2004
1/19/2005
3/19/2005
5/19/2005
7/19/2005
9/19/2005
11/19/2005
1/19/2006
3/19/2006
5/19/2006
7/19/2006

Figure C2.2



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
November 2002- September 2006
East Pasture Well 3
Water level (inches)
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Water Level (inches), Salinity (ppt)
Precipitation (inches)
-Well Broken-
-Well Broken-
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
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12/20/2002
2/18/2003
4/19/2003
6/18/2003
8/17/2003
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6/7/2005
8/6/2005
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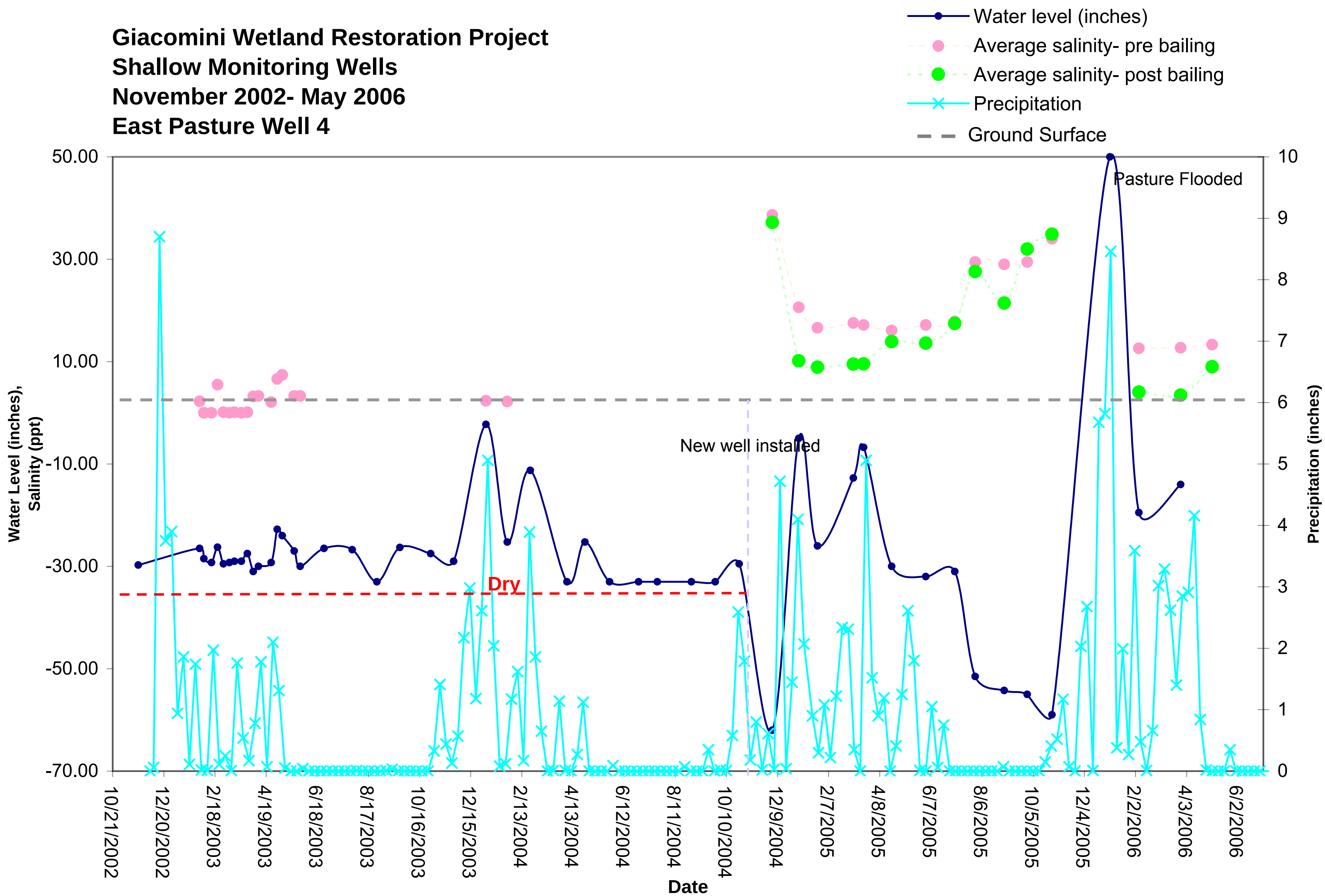
2/2/2006
4/3/2006
6/2/2006
8/1/2006
9/30/2006
Date

Figure C2.3



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
November 2002- May 2006
East Pasture Well 4
Water level (inches)
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Pasture Flooded
New well installed
Dry
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
50.00
30.00
10.00
-10.00
-30.00
-50.00
-70.00
10
9
8
7
6
5
4
3
2
1
0
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12/20/2002
2/18/2003
4/19/2003
6/18/2003
8/17/2003
10/16/2003
12/15/2003
2/13/2004
4/13/2004
6/12/2004
8/11/2004
10/10/2004
12/9/2004
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6/2/2006

Figure C2.4

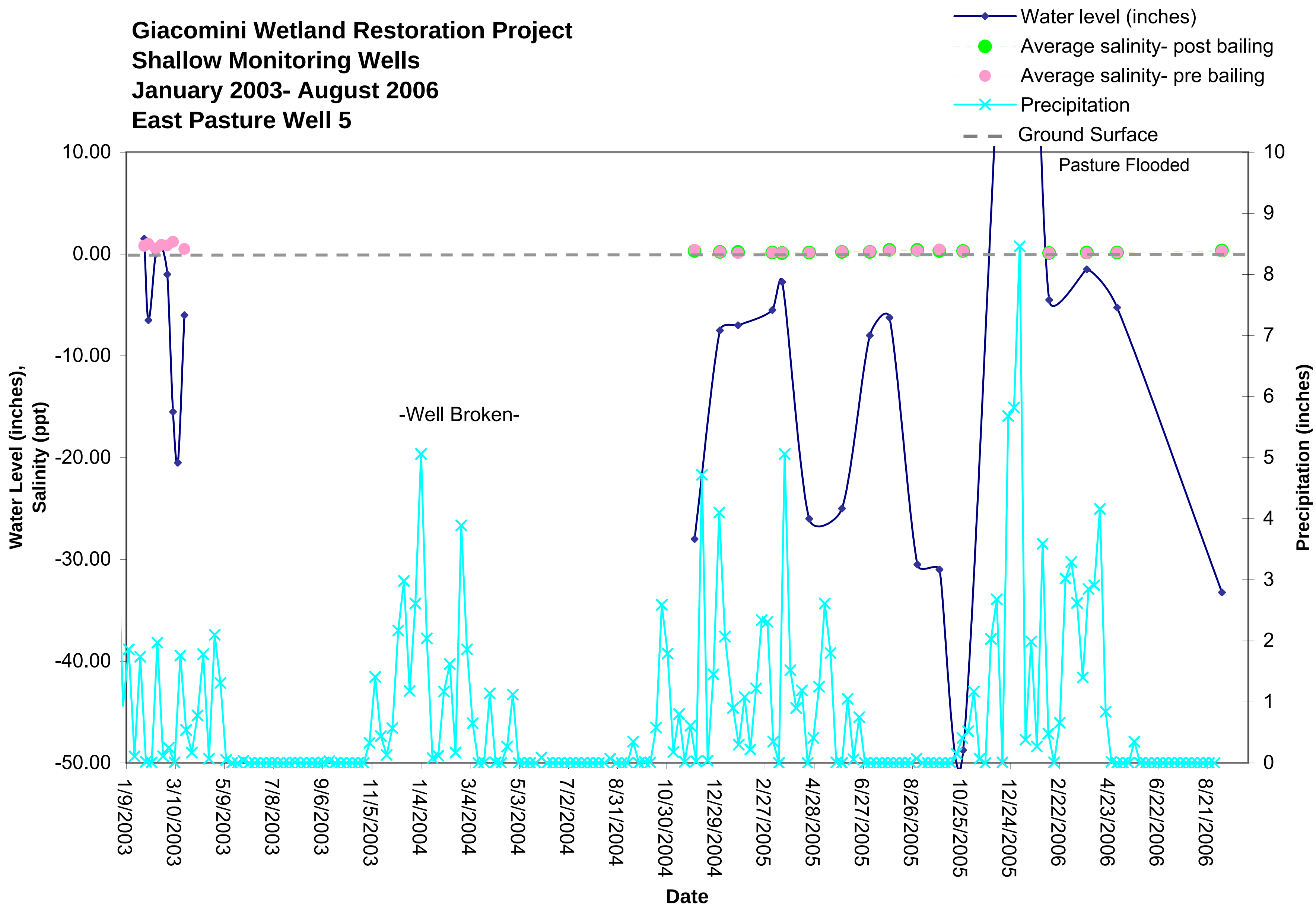
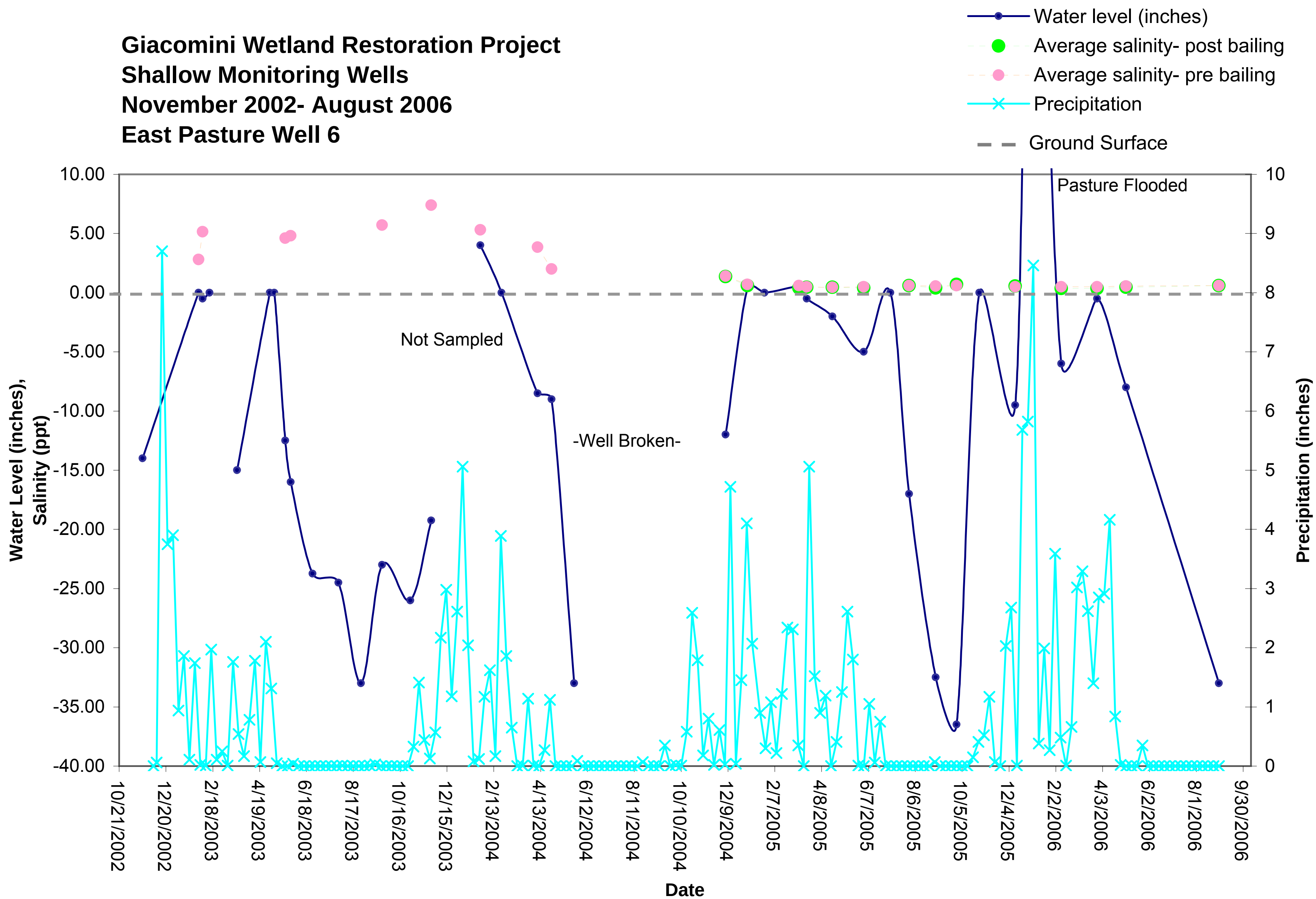

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
January 2003- August 2006
East Pasture Well 5
Water level (inches)
Average salinity- post bailing
Average salinity- pre bailing
Precipitation
Ground Surface
Pasture Flooded
-Well Broken-
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
1/9/2003
3/10/2003
5/9/2003
7/8/2003
9/6/2003
11/5/2003
1/4/2004
3/4/2004
5/3/2004
7/2/2004
8/31/2004
10/30/2004
12/29/2004
2/27/2005
4/28/2005
6/27/2005
8/26/2005
10/25/2005
12/24/2005
2/22/2006
4/23/2006
6/22/2006
8/21/2006

Figure C2.5



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
November 2002- August 2006
East Pasture Well 6
Water level (inches)
Average salinity- post bailing
Average salinity- pre bailing
Precipitation
Ground Surface
Pasture Flooded
Not Sampled
-Well Broken-
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
10
9
8
7
6
5
4
3
2
1
0
10/21/2002
12/20/2002
2/18/2003
4/19/2003
6/18/2003
8/17/2003
10/16/2003
12/15/2003
2/13/2004
4/13/2004
6/12/2004
8/11/2004
10/10/2004
12/9/2004
2/7/2005
4/8/2005
6/7/2005
8/6/2005
10/5/2005
12/4/2005
2/2/2006
4/3/2006
6/2/2006
8/1/2006
9/30/2006

Figure C2.6

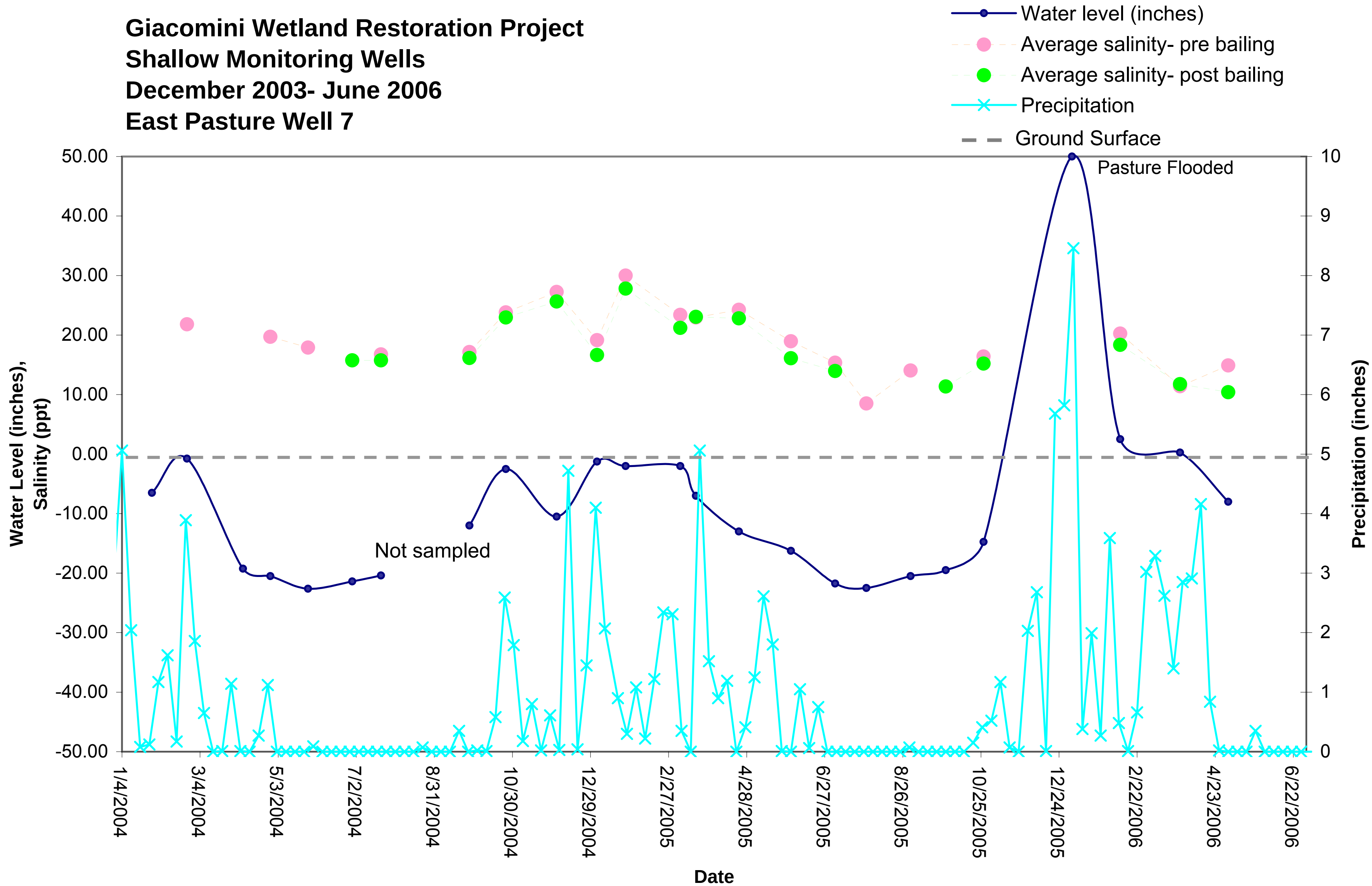
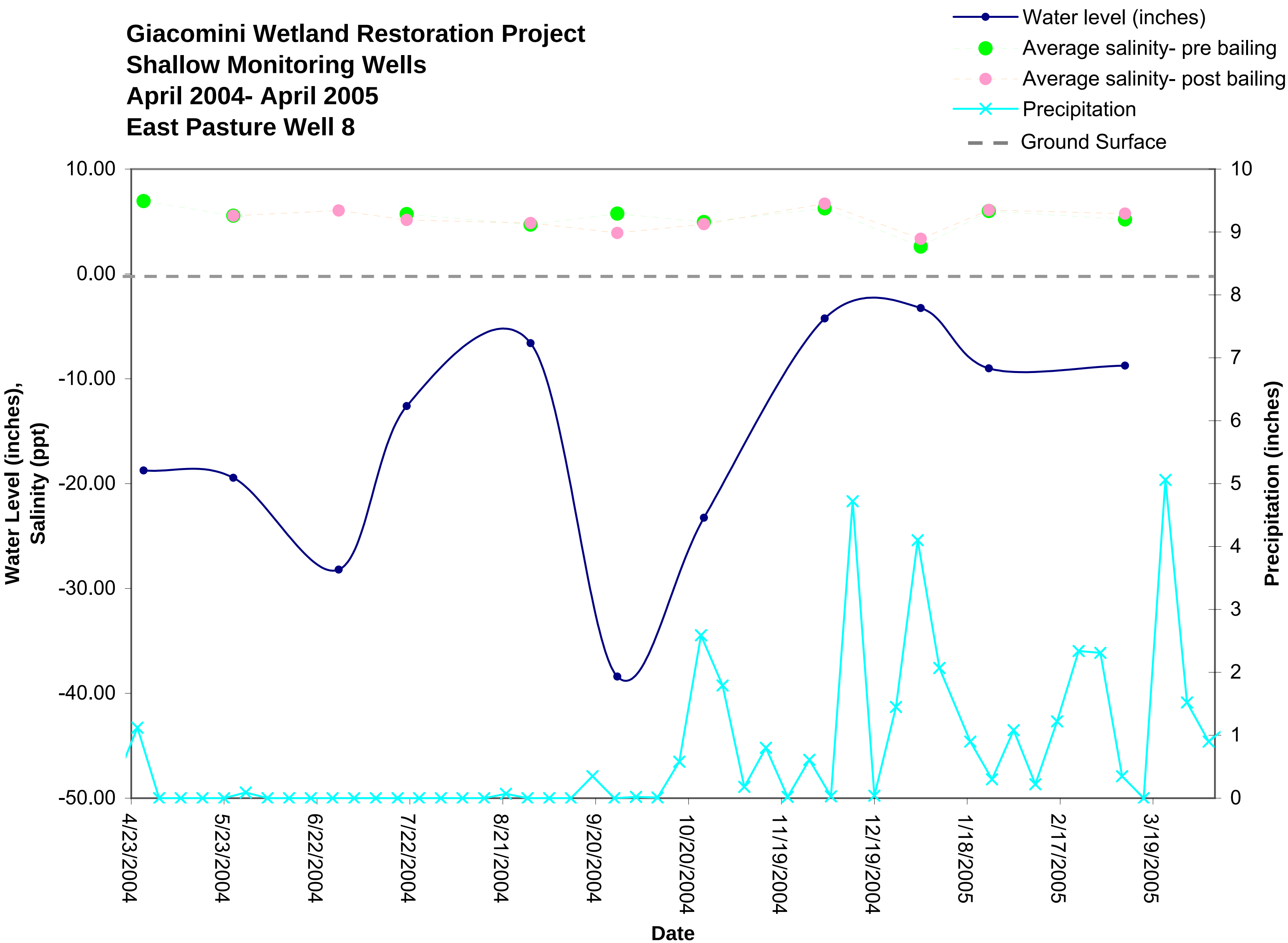

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
December 2003- June 2006
East Pasture Well 7
Water level (inches)
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Pasture Flooded
Not sampled
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
1/4/2004
3/4/2004
5/3/2004
7/2/2004
8/31/2004
10/30/2004
12/29/2004
2/27/2005
4/28/2005
6/27/2005
8/26/2005
10/25/2005
12/24/2005
2/22/2006
4/23/2006
6/22/2006

Figure C2.7



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
April 2004- April 2005
East Pasture Well 8
Water level (inches)
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Water Level (inches),
Salinity (ppt)
Precipitation (inches)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
4/23/2004
5/23/2004
6/22/2004
7/22/2004
8/21/2004
9/20/2004
10/20/2004
11/19/2004
12/19/2004
1/18/2005
2/17/2005
3/19/2005

Figure C2.8

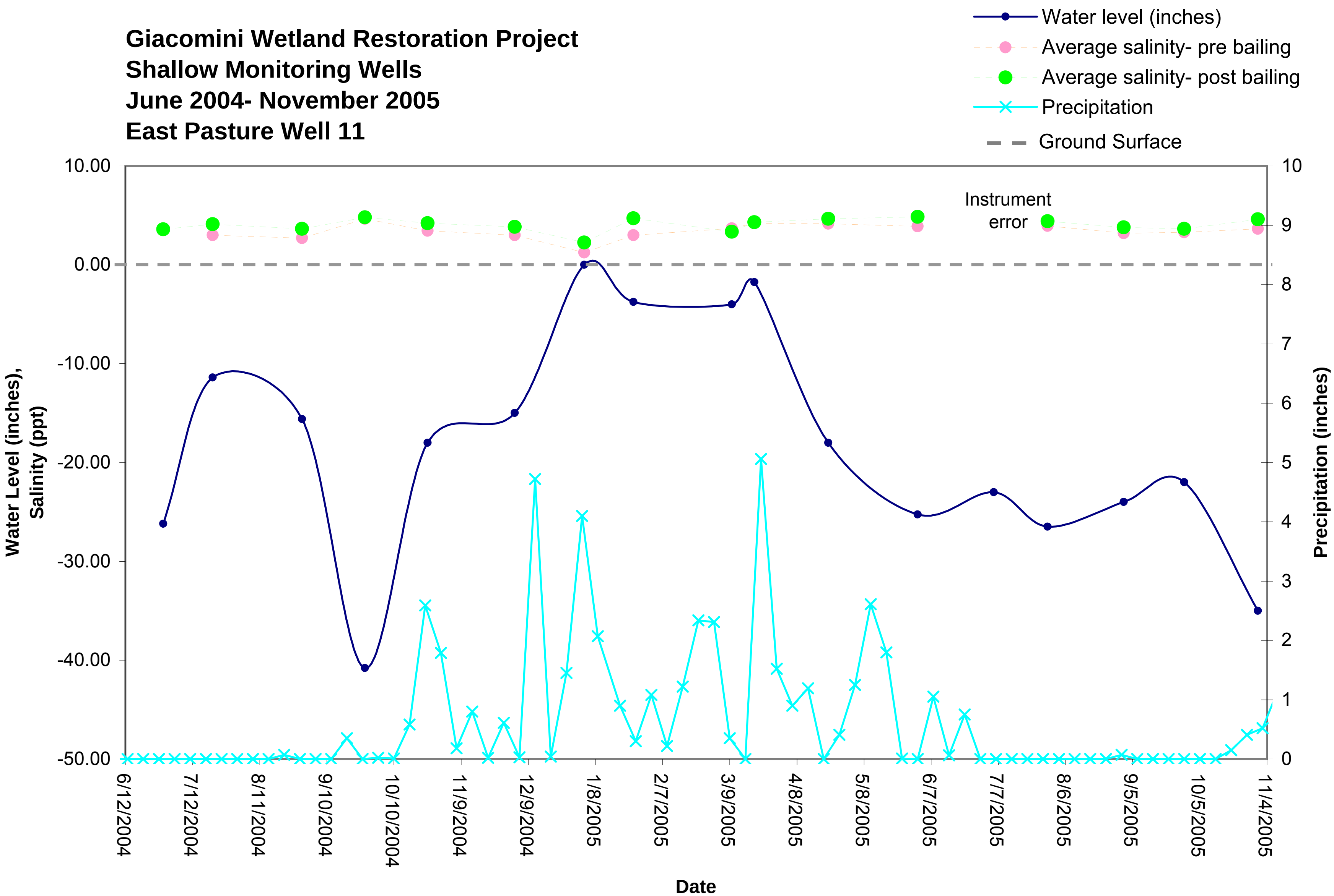
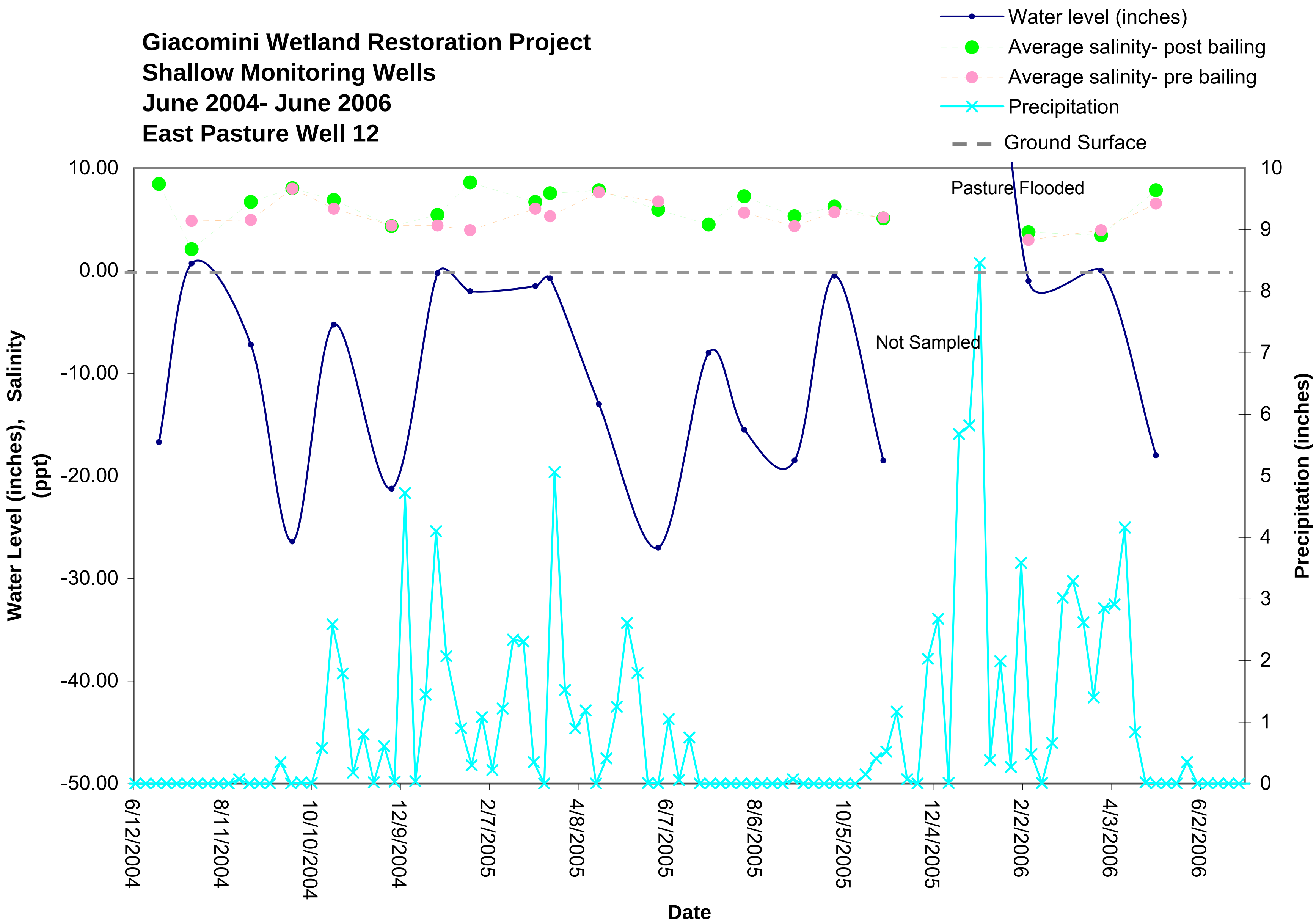

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
June 2004- November 2005
East Pasture Well 11
Water level (inches)
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Instrument error
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
6/12/2004
7/12/2004
8/11/2004
9/10/2004
10/10/2004
11/9/2004
12/9/2004
1/8/2005
2/7/2005
3/9/2005
4/8/2005
5/8/2005
6/7/2005
7/7/2005
8/6/2005
9/5/2005
10/5/2005
11/4/2005

Figure C2.9



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
June 2004- June 2006
East Pasture Well 12
Water level (inches)
Average salinity- post bailing
Average salinity- pre bailing
Precipitation
Ground Surface
Pasture Flooded
Not Sampled
Water Level (inches), Salinity (ppt)
Precipitation (inches)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
9
8
7
6
5
4
3
2
1
0
6/12/2004
8/11/2004
10/10/2004
12/9/2004
2/7/2005
4/8/2005
6/7/2005
8/6/2005
10/5/2005
12/4/2005
2/2/2006
4/3/2006
6/2/2006

Figure C2.10

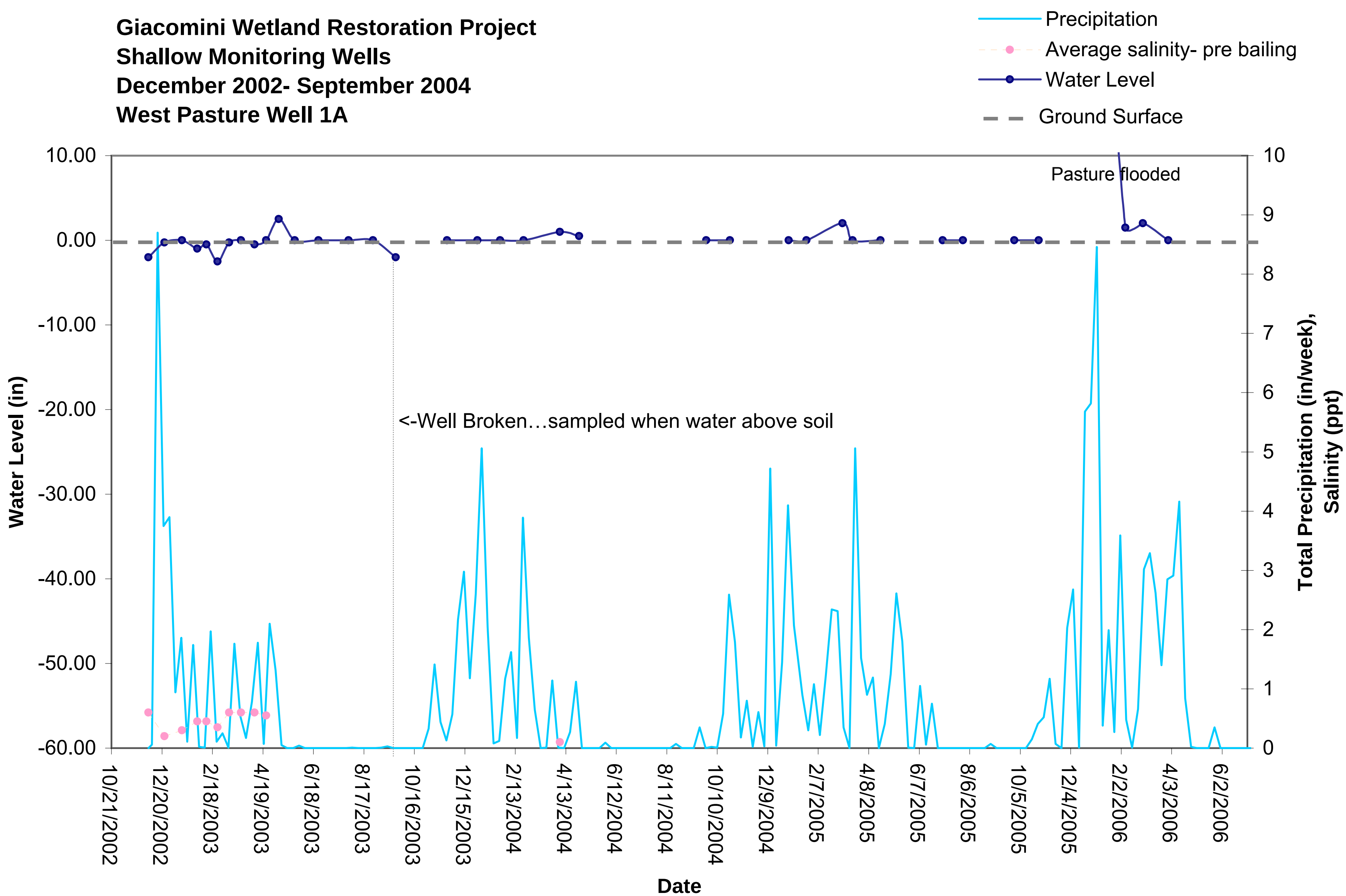
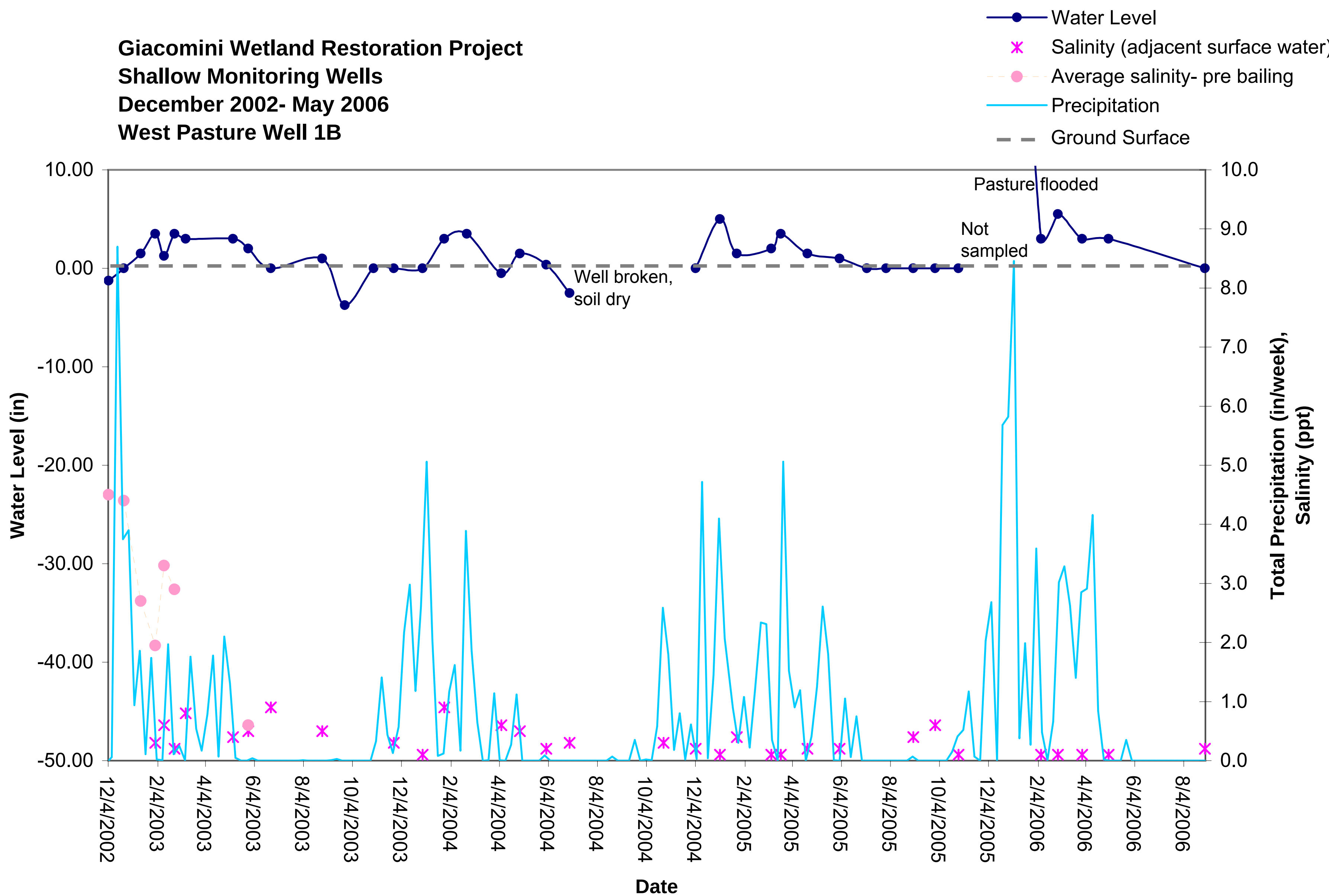
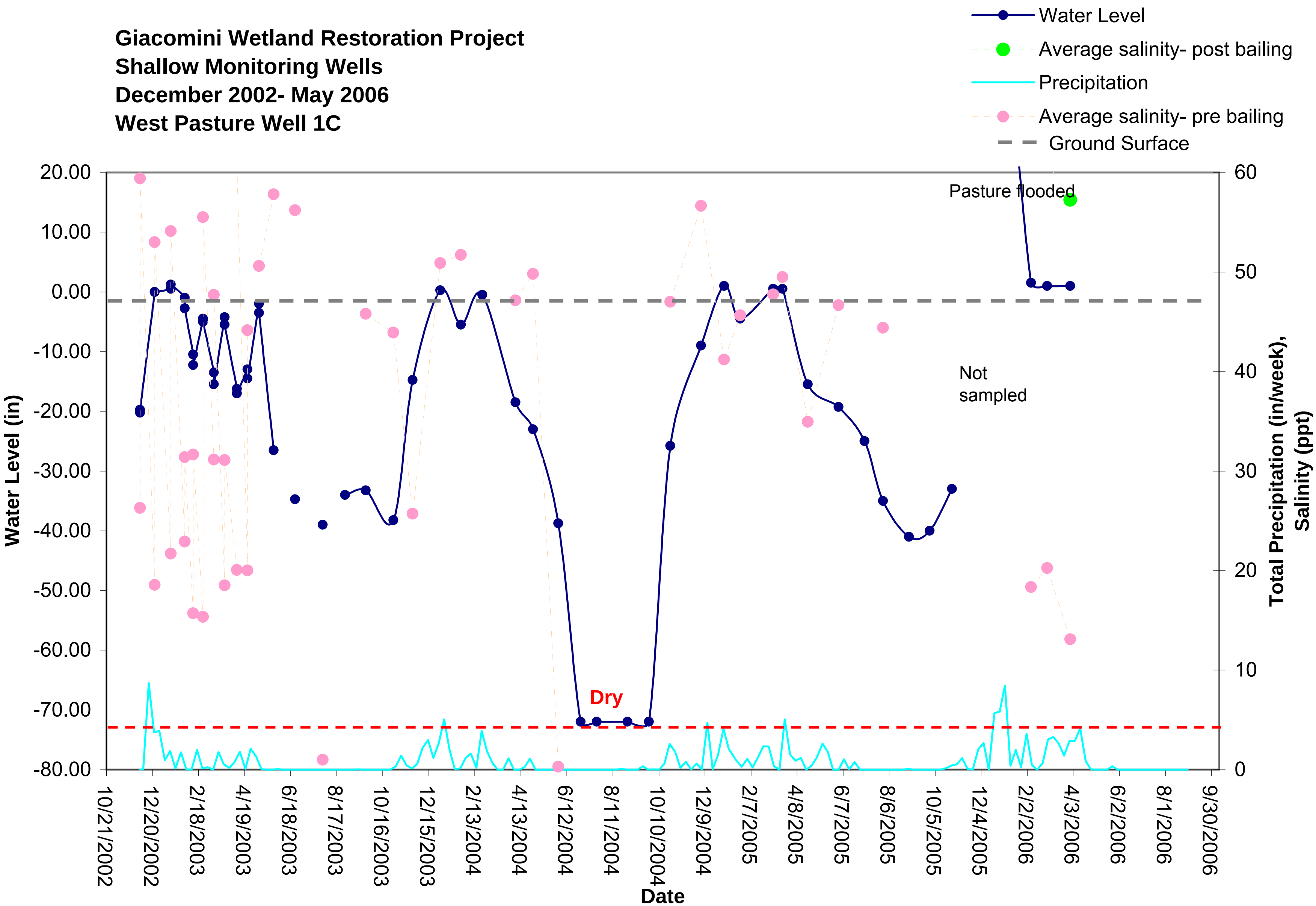

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
December 2002- September 2004
West Pasture Well 1A
Precipitation
Average salinity- pre bailing
Water Level
Ground Surface
Pasture flooded
<-Well Broken…sampled when water above soil
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10
9
8
7
6
5
4
3
2
1
0
10/21/2002
12/20/2002
2/18/2003
4/19/2003
6/18/2003
8/17/2003
10/16/2003
12/15/2003
2/13/2004
4/13/2004
6/12/2004
8/11/2004
10/10/2004
12/9/2004
2/7/2005
4/8/2005
6/7/2005
8/6/2005
10/5/2005
12/4/2005
2/2/2006
4/3/2006
6/2/2006

Figure C3.1



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
December 2002- May 2006
West Pasture Well 1B
Water Level
Salinity (adjacent surface water)
Average salinity- pre bailing
Precipitation
Ground Surface
Pasture flooded
Not sampled
Well broken, soil dry
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
12/4/2002
2/4/2003
4/4/2003
6/4/2003
8/4/2003
10/4/2003
12/4/2003
2/4/2004
4/4/2004
6/4/2004
8/4/2004
10/4/2004
12/4/2004
2/4/2005
4/4/2005
6/4/2005
8/4/2005
10/4/2005
12/4/2005
2/4/2006
4/4/2006
6/4/2006
8/4/2006

Figure C3.2



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
December 2002- May 2006
West Pasture Well 1C
Water Level
Average salinity- post bailing
Precipitation
Average salinity- pre bailing
Ground Surface
Pasture flooded
Not sampled
Dry
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
60
50
40
30
20
10
0
10/21/2002
12/20/2002
2/18/2003
4/19/2003
6/18/2003
8/17/2003
10/16/2003
12/15/2003
2/13/2004
4/13/2004
6/12/2004
8/11/2004
10/10/2004
12/9/2004
2/7/2005
4/8/2005
6/7/2005
8/6/2005
10/5/2005
12/4/2005
2/2/2006
4/3/2006
6/2/2006
8/1/2006
9/30/2006

Figure C3.3

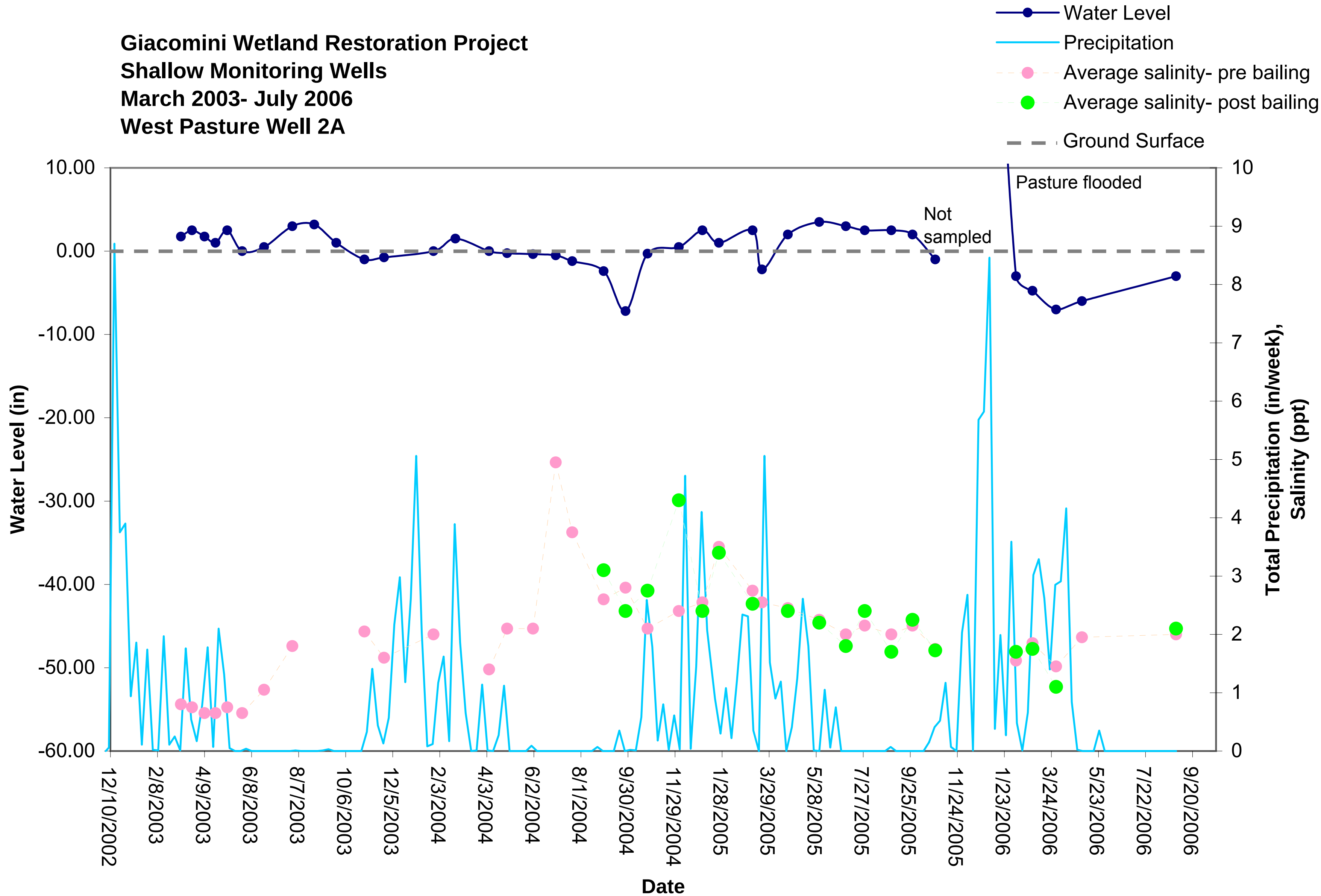

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
March 2003- July 2006
West Pasture Well 2A
Water Level
Precipitation
Average salinity- pre bailing
Average salinity- post bailing
Ground Surface
Pasture flooded
Not sampled
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10
9
8
7
6
5
4
3
2
1
0
12/10/2002
2/8/2003
4/9/2003
6/8/2003
8/7/2003
10/6/2003
12/5/2003
2/3/2004
4/3/2004
6/2/2004
8/1/2004
9/30/2004
11/29/2004
1/28/2005
3/29/2005
5/28/2005
7/27/2005
9/25/2005
11/24/2005
1/23/2006
3/24/2006
5/23/2006
7/22/2006
9/20/2006

Figure C3.4

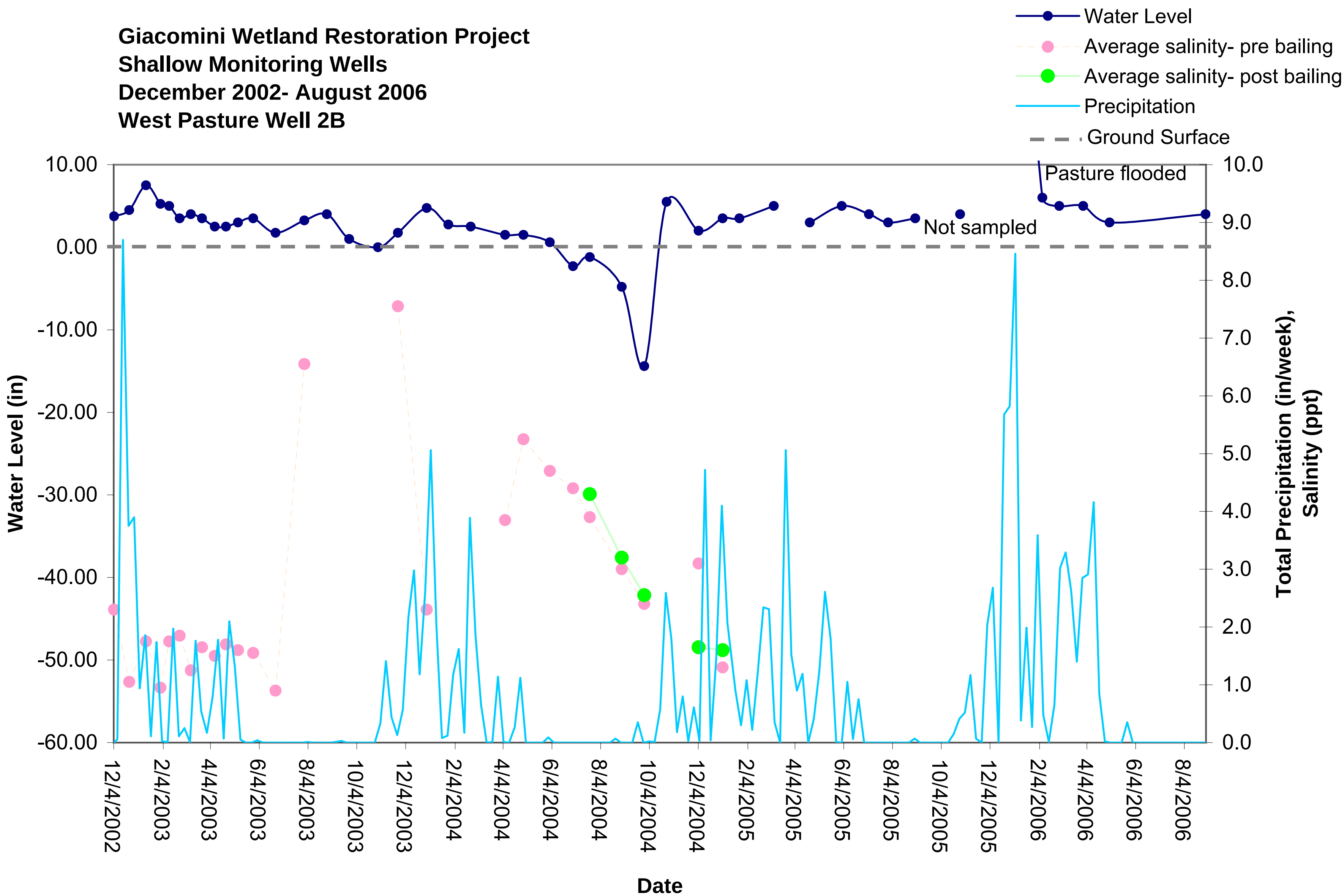

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
December 2002- August 2006
West Pasture Well 2B
Water Level
Average salinity- pre bailing
Average salinity- post bailing
Precipitation
Ground Surface
Pasture flooded
Not sampled
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
12/4/2002
2/4/2003
4/4/2003
6/4/2003
8/4/2003
10/4/2003
12/4/2003
2/4/2004
4/4/2004
6/4/2004
8/4/2004
10/4/2004
12/4/2004
2/4/2005
4/4/2005
6/4/2005
8/4/2005
10/4/2005
12/4/2005
2/4/2006
4/4/2006
6/4/2006
8/4/2006

Figure C3.5

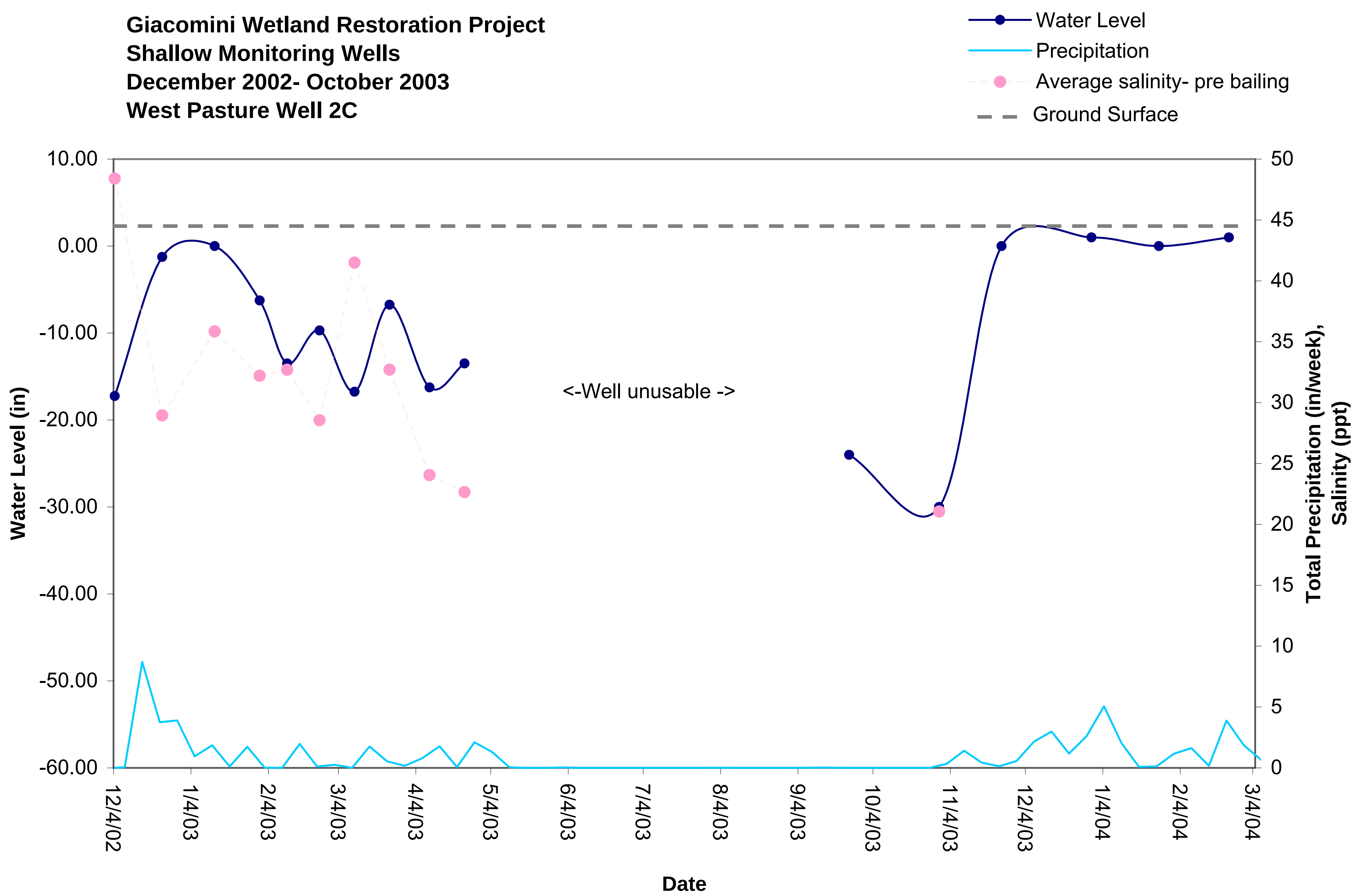
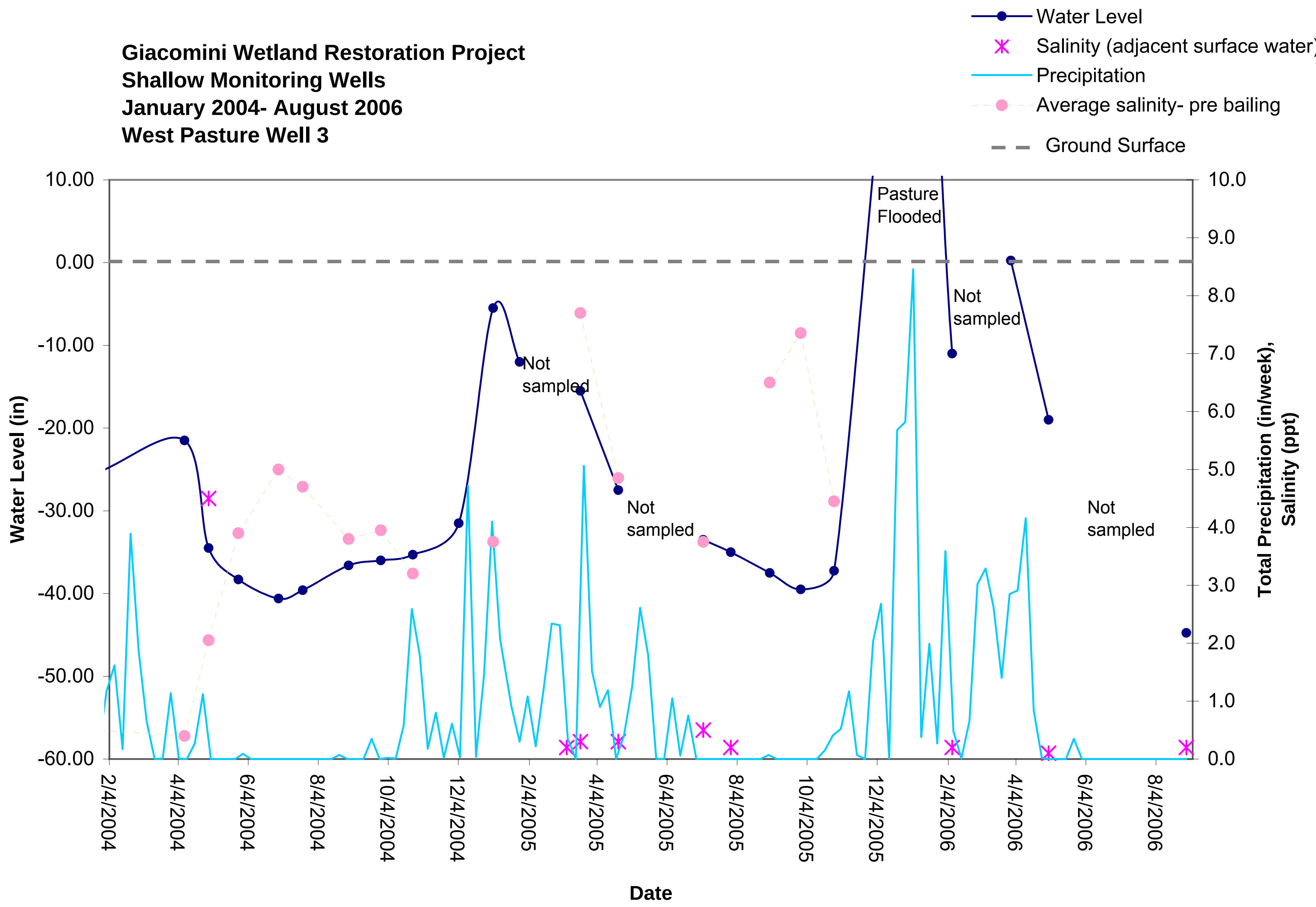

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
December 2002- October 2003
West Pasture Well 2C
Water Level
Precipitation
Average salinity- pre bailing
Ground Surface
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
<-Well unusable ->
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
50
45
40
35
30
25
20
15
10
5
0
12/4/02
1/4/03
2/4/03
3/4/03
4/4/03
5/4/03
6/4/03
7/4/03
8/4/03
9/4/03
10/4/03
11/4/03
12/4/03
1/4/04
2/4/04
3/4/04

Figure C3.6



Giacomini Wetland Restoration Project
Shallow Monitoring Wells
January 2004- August 2006
West Pasture Well 3
Water Level
Salinity (adjacent surface water)
Precipitation
Average salinity- pre bailing
Ground Surface
Water Level (in)
Total Precipitation (in/week),
Salinity (ppt)
Date
Pasture
Flooded
Not
sampled
Not
sampled
Not
sampled
Not
sampled
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2/4/2004
4/4/2004
6/4/2004
8/4/2004
10/4/2004
12/4/2004
2/4/2005
4/4/2005
6/4/2005
8/4/2005
10/4/2005
12/4/2005
2/4/2006
4/4/2006
6/4/2006
8/4/2006

Figure C3.7

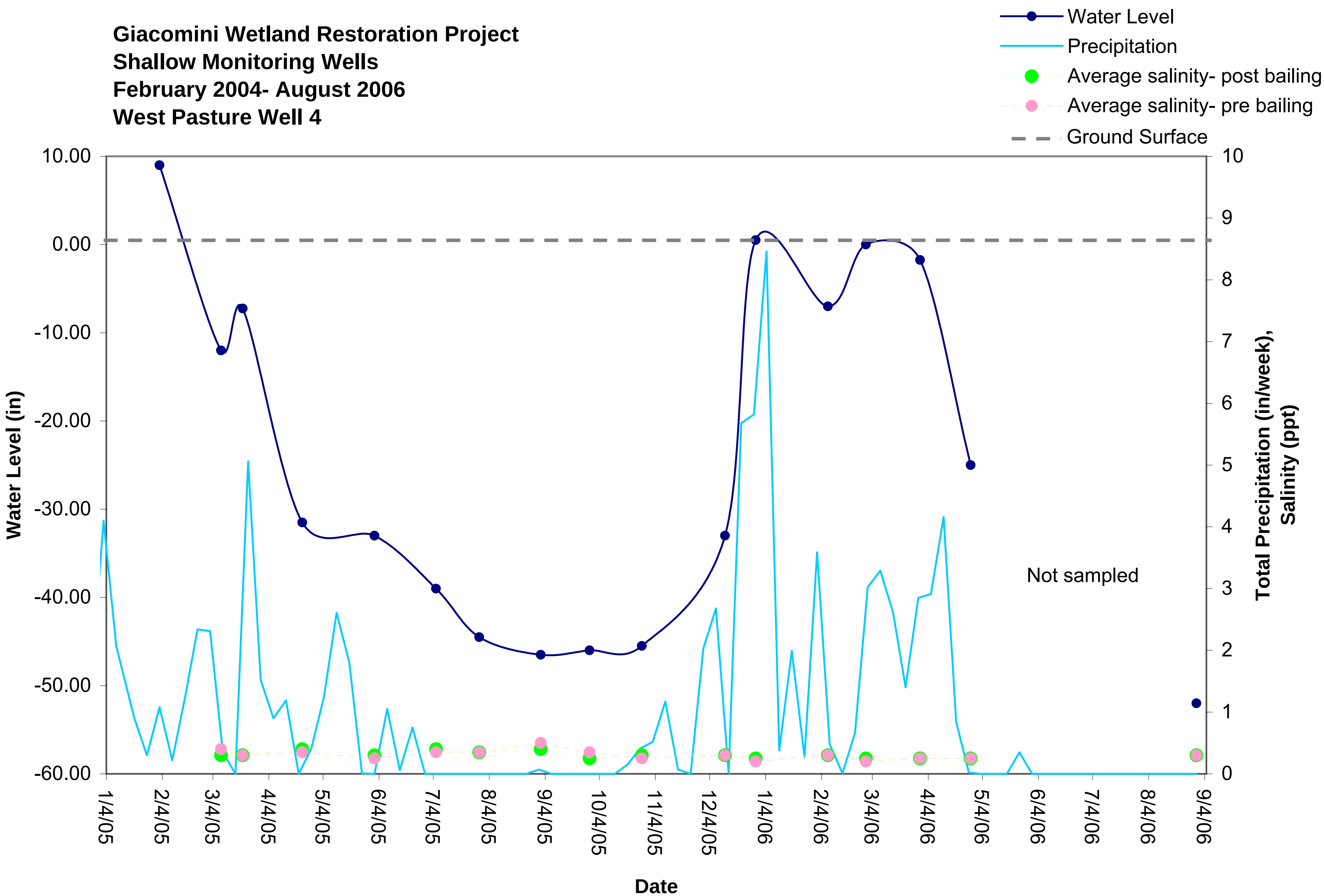

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
February 2004- August 2006
West Pasture Well 4
Water Level
Precipitation
Average salinity- post bailing
Average salinity- pre bailing
Ground Surface
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Not sampled
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10
9
8
7
6
5
4
3
2
1
0
1/4/05
2/4/05
3/4/05
4/4/05
5/4/05
6/4/05
7/4/05
8/4/05
9/4/05
10/4/05
11/4/05
12/4/05
1/4/06
2/4/06
3/4/06
4/4/06
5/4/06
6/4/06
7/4/06
8/4/06
9/4/06

Figure C3.8

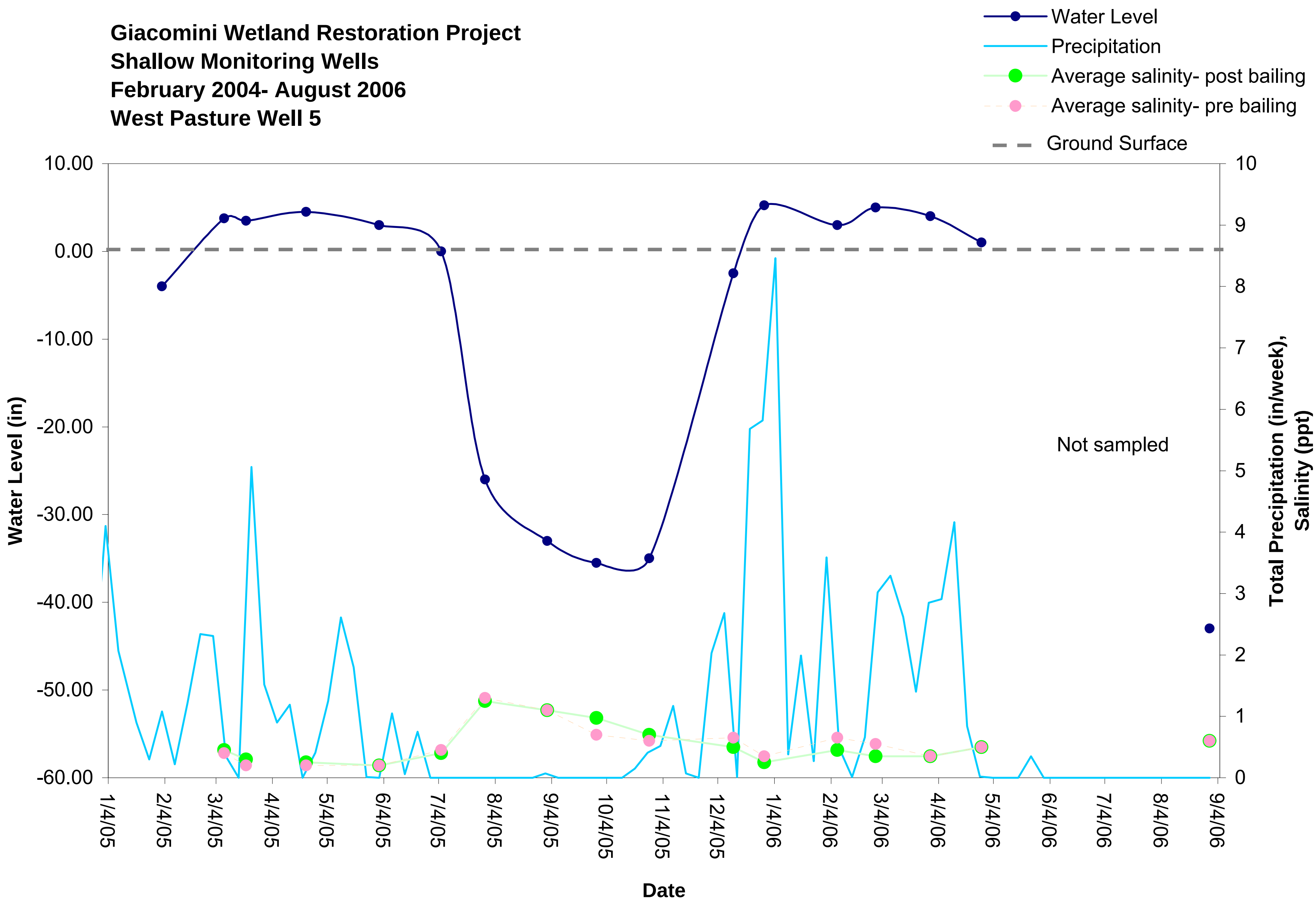

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
February 2004- August 2006
West Pasture Well 5
Water Level
Precipitation
Average salinity- post bailing
Average salinity- pre bailing
Ground Surface
Not sampled
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10
9
8
7
6
5
4
3
2
1
0
1/4/05
2/4/05
3/4/05
4/4/05
5/4/05
6/4/05
7/4/05
8/4/05
9/4/05
10/4/05
11/4/05
12/4/05
1/4/06
2/4/06
3/4/06
4/4/06
5/4/06
6/4/06
7/4/06
8/4/06
9/4/06

Figure C3.9

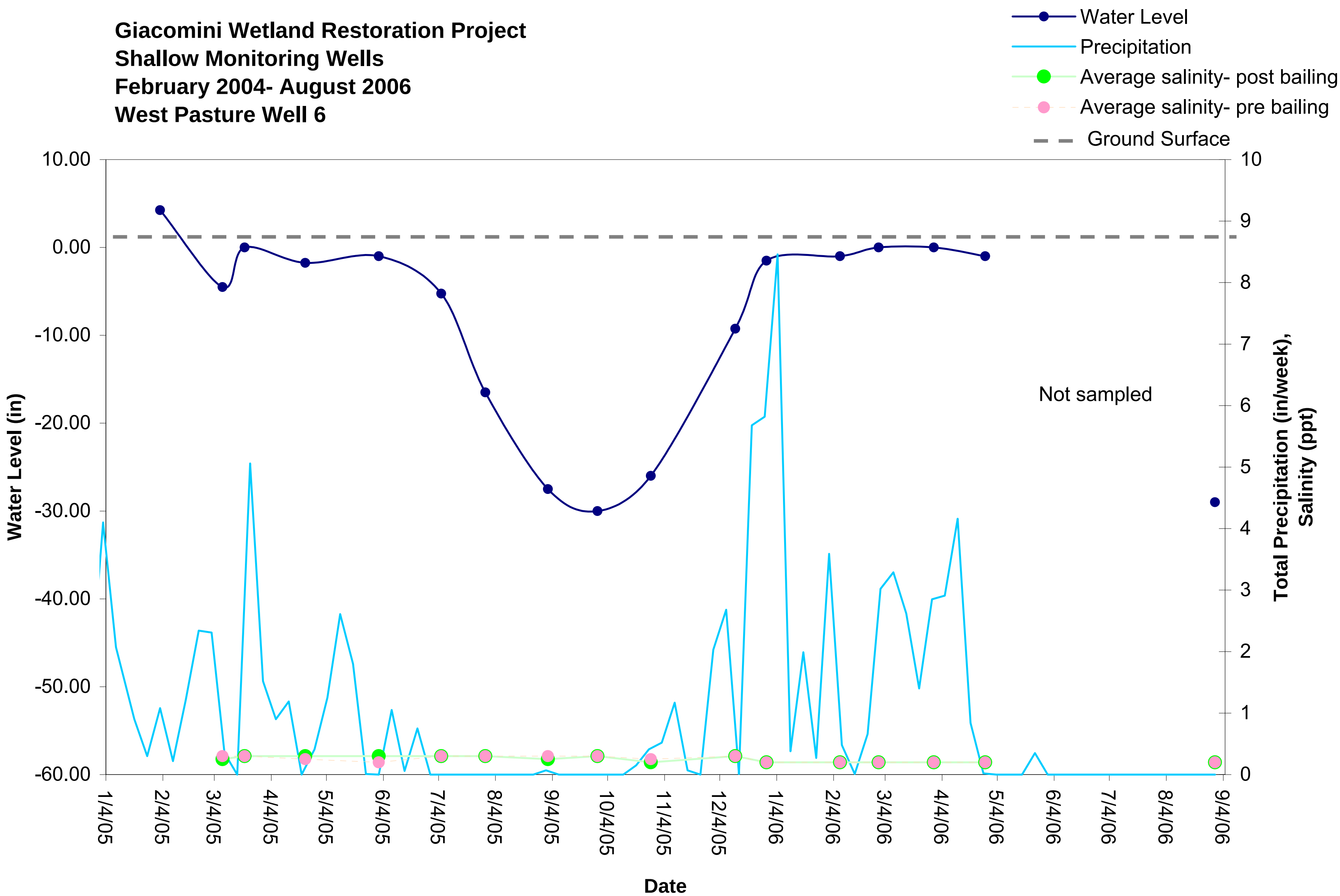

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
February 2004- August 2006
West Pasture Well 6
Water Level
Precipitation
Average salinity- post bailing
Average salinity- pre bailing
Ground Surface
Not sampled
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Date
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
10
9
8
7
6
5
4
3
2
1
0
1/4/05
2/4/05
3/4/05
4/4/05
5/4/05
6/4/05
7/4/05
8/4/05
9/4/05
10/4/05
11/4/05
12/4/05
1/4/06
2/4/06
3/4/06
4/4/06
5/4/06
6/4/06
7/4/06
8/4/06
9/4/06

Figure C3.10

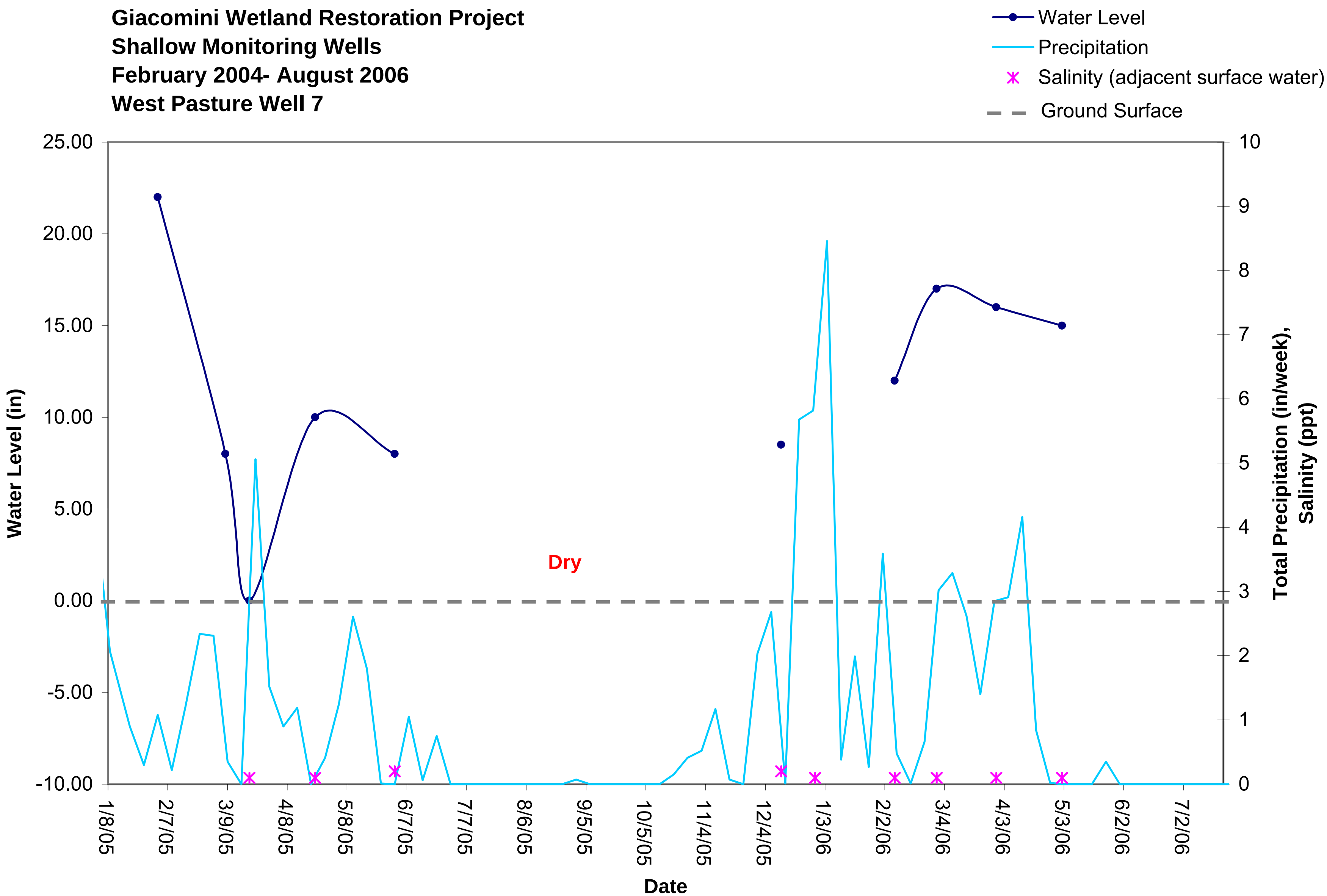

Giacomini Wetland Restoration Project
Shallow Monitoring Wells
February 2004- August 2006
West Pasture Well 7
Water Level
Precipitation
Salinity (adjacent surface water)
Ground Surface
Water Level (in)
Total Precipitation (in/week), Salinity (ppt)
Dry
Date
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
10
9
8
7
6
5
4
3
2
1
0
1/8/05
2/7/05
3/9/05
4/8/05
5/8/05
6/7/05
7/7/05
8/6/05
9/5/05
10/5/05
11/4/05
12/4/05
1/3/06
2/2/06
3/4/06
4/3/06
5/3/06
6/2/06
7/2/06

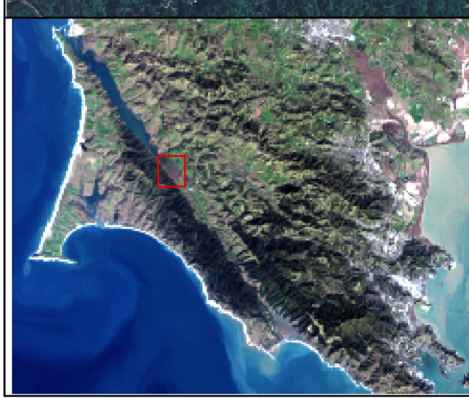
Figure C3.11

APPENDIX D

Continuous Water Quality Monitoring

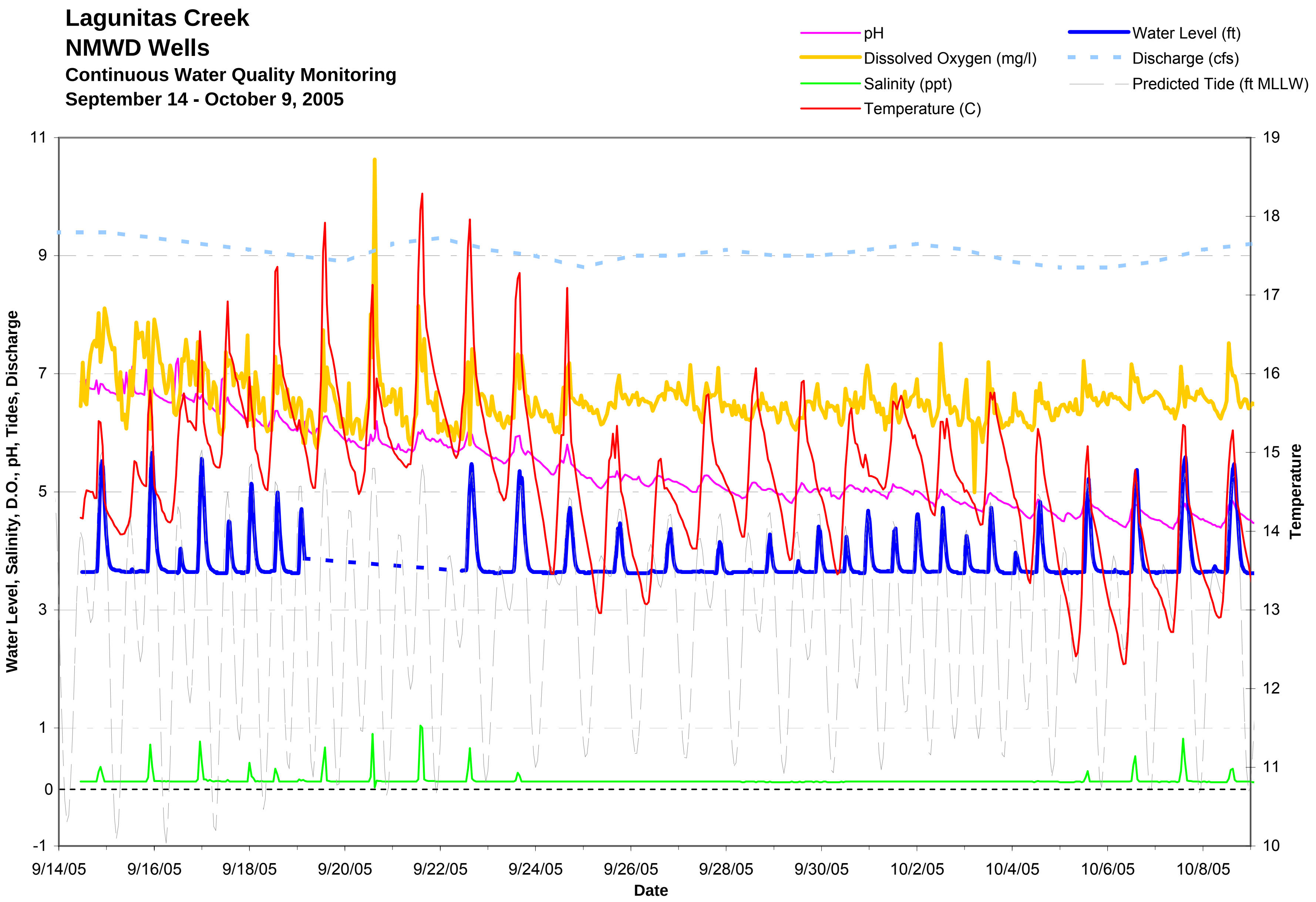
Continuous Water Quality Monitoring Locations

Giacomini Wetland Restoration Project



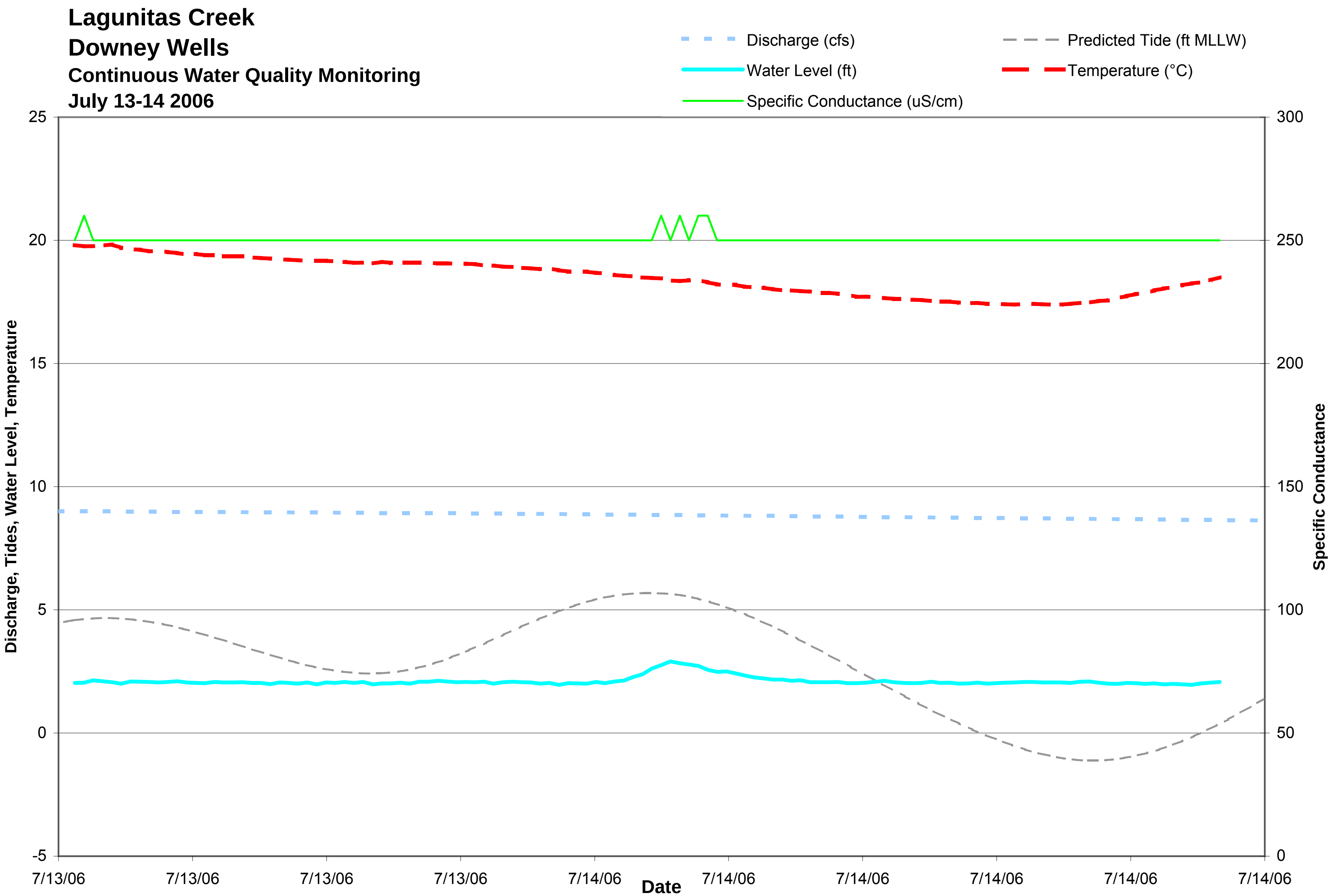
National Park Service
Point Reyes National Seashore/
Golden Gate National Recreation Area
Marin County, CA

Figure D1



Kamman Hydrology & Engineering, Inc. Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

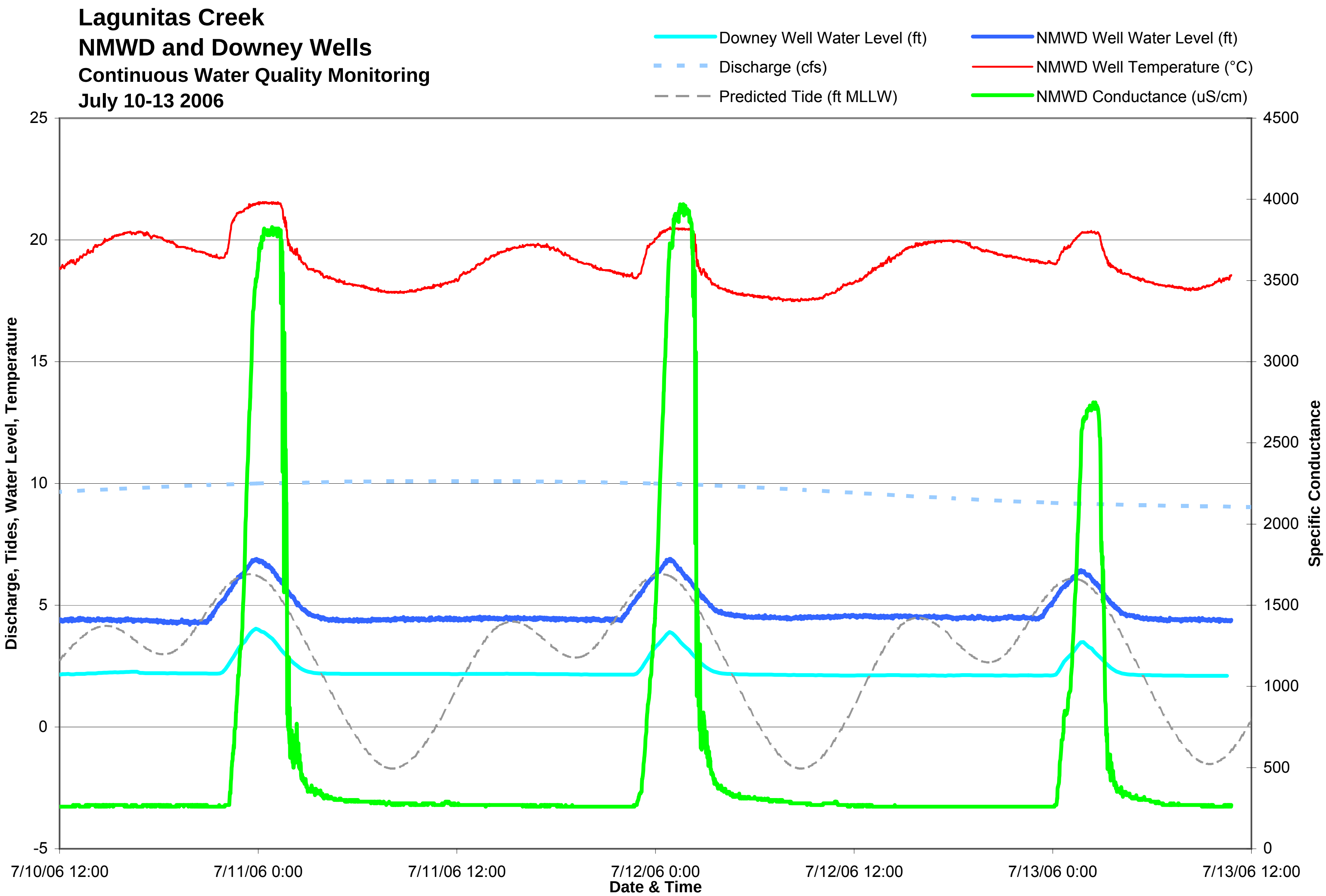
Figure D2



Kamman Hydrology & Engineering, Inc.

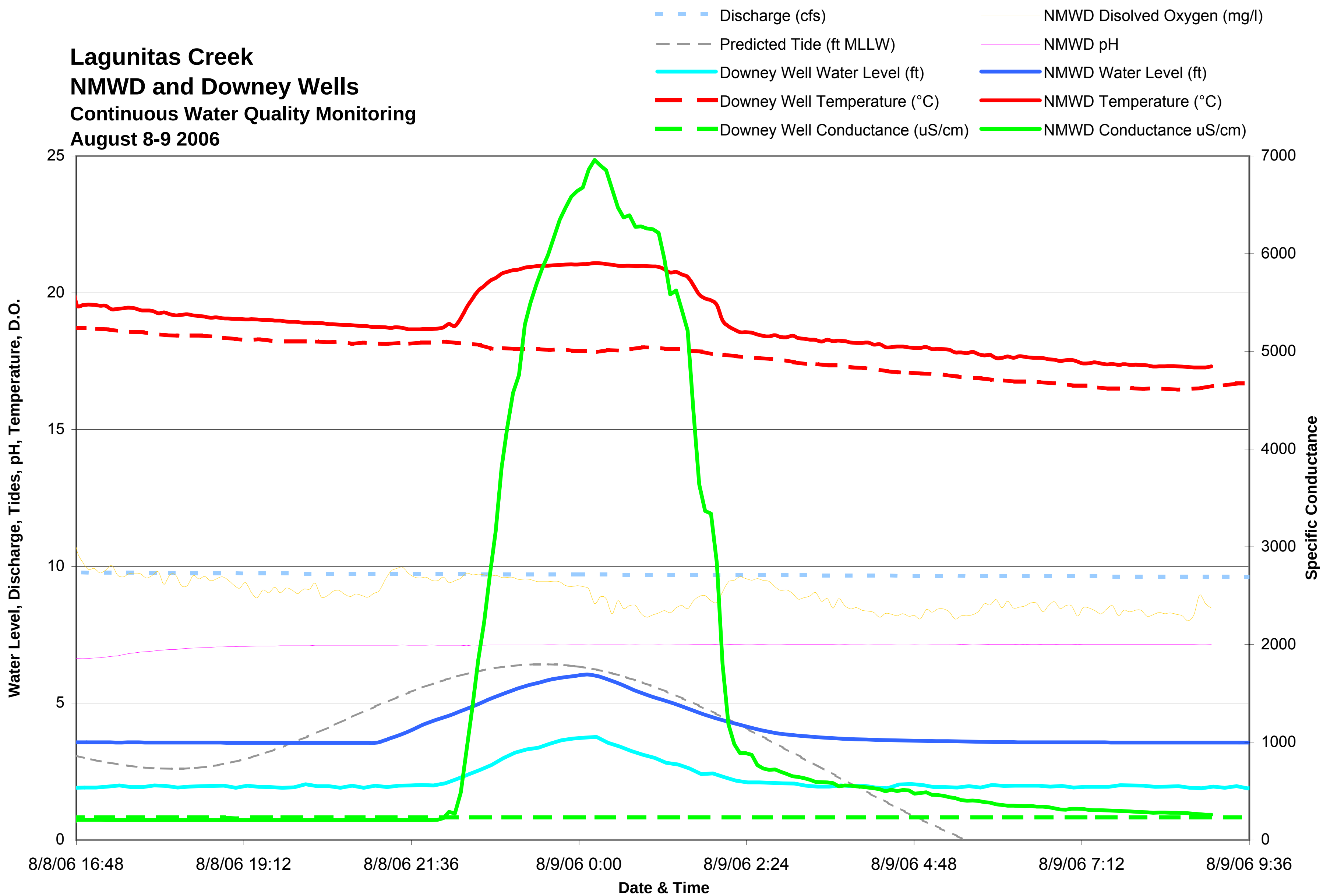
Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

Figure D3.1



Kamman Hydrology & Engineering, Inc. Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

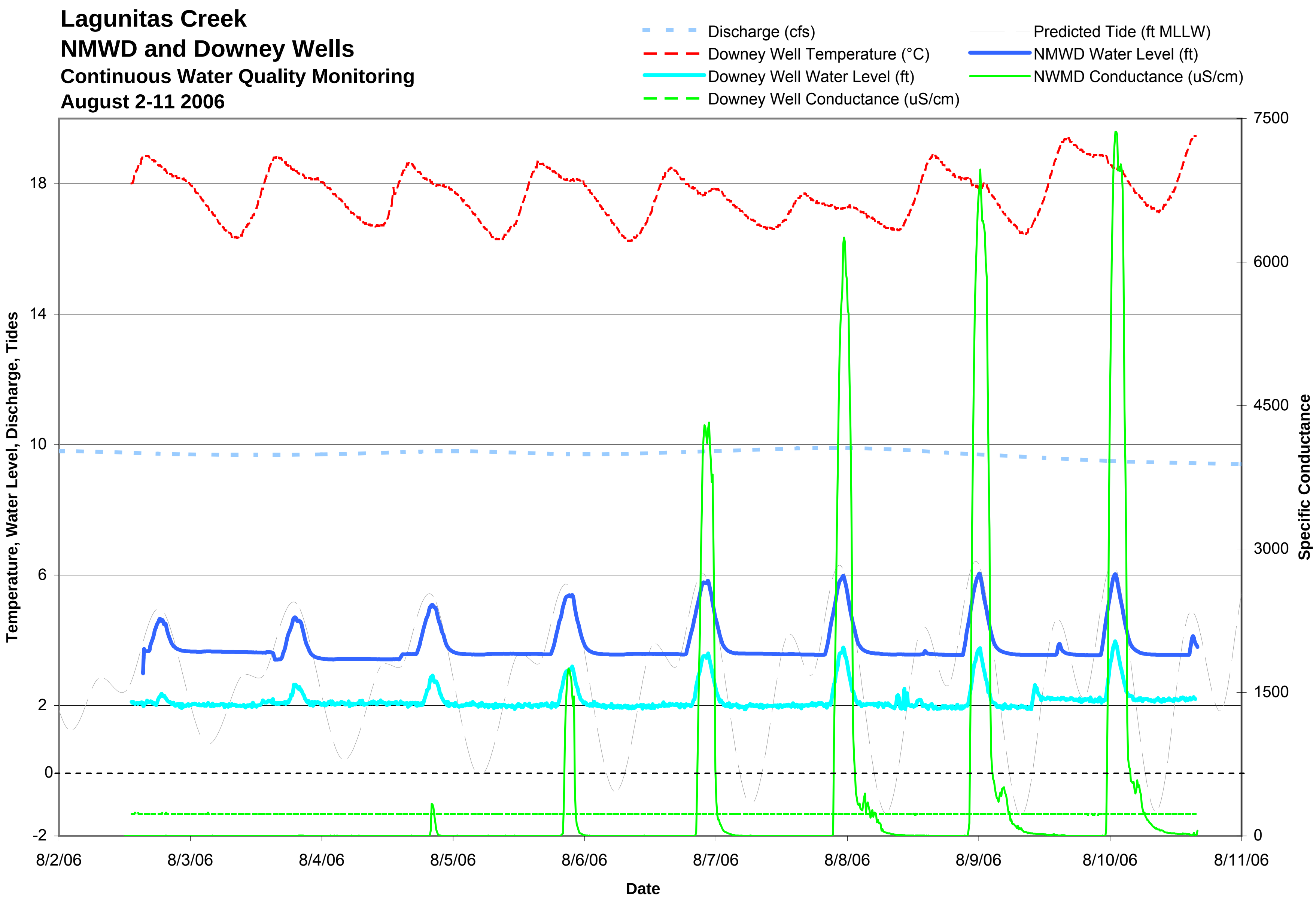
Figure D3.2



Kamman Hydrology & Engineering, Inc.

Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

Figure D3.3

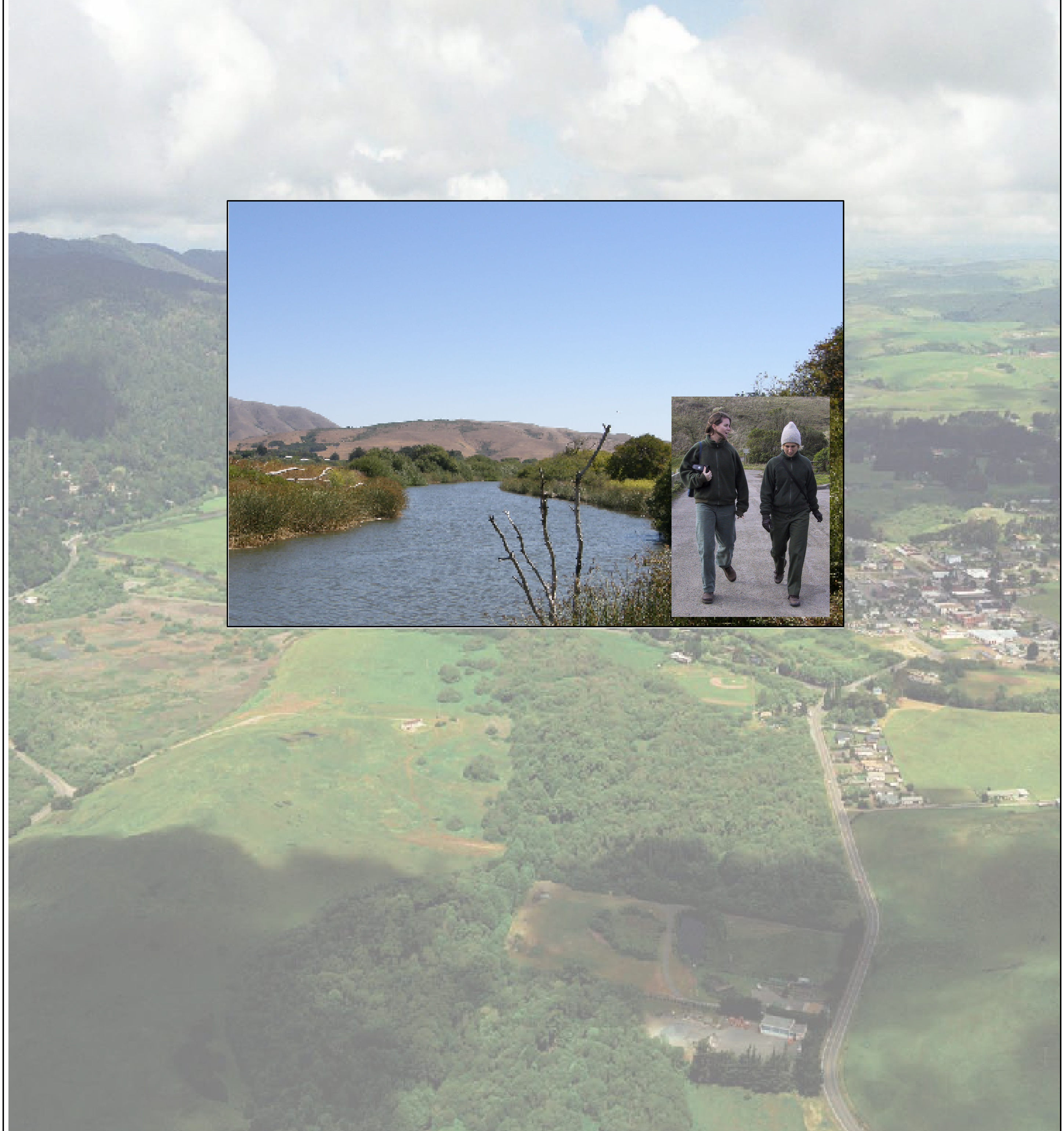


Kamman Hydrology & Engineering, Inc. Adapted from KAMMAN HYDROLOGY & ENGINEERING, INC.

Figure D3.4

APPENDIX E

Lagunitas Creek Profile



GIACOMINI WETLAND RESTORATION PROJECT

Summary of Lagunitas Creek physical profile
October 24, 2003

Prepared by Leslie Allen
In collaboration with Chelsea Donovan

Objective

To enhance hydrologic modeling of Project Alternatives, information is needed regarding the extent of saltwater intrusion from Tomales Bay at high tide into Lagunitas Creek during the season of low freshwater flow.

Methods

Leslie Allen and Chelsea Donovan measured and recorded salinity, temperature and concentration of dissolved oxygen at high tide along the main channel of Lagunitas Creek. Sampling was conducted by lowering a YSI85 probe from kayaks at half-meter increments from the water surface. Eight sampling stations were selected prior to field sampling (Figure 1). Five of the stations (LAG1-5) were the same as those used monthly for monitoring water quality in the Project Area. The station labeled "NMWD" is farthest upstream from the Project Area, near the intake system for wells operated by North Marin Water District. The station labeled "Genazzi" is located in a shallow cattle crossing where Lagunitas Creek passes through the Genazzi cattle ranch, upstream from the Project Area. The station labeled "Cow Xing" is located in the Project Area, in a relatively deep cattle crossing used by the Giacomini dairy ranch.

Weather, Precipitation and Tides

West Marin County experienced a period of record high temperatures during the week of October 20, 2003. On the day of sampling, skies were clear and air temperature was estimated to reach a maximum of approximately 82 degrees Fahrenheit. Preliminary precipitation data on the California Department of Water Resources website indicate that only .04 inches of precipitation were recorded in the Tomales Bay region between August 13 and October 24, 2003. Only one day prior to a new moon, high tide at Inverness on October 24 was predicted to be +5.4 ft at 11:56 a.m.

Results

- **Salinity** (Figure 2)

Overall, a pattern typical of tidally influenced creeks was observed in Lagunitas Creek on October 24. The lowest salinity (0.4-1.1 ppt) was observed at the uppermost station (NMWD), and the highest salinity (26.5 ppt) at the station farthest downstream (LAG5). At most stations, salinity increased with depth. Stratification was most noticeable at stations in the middle of the Project Area, which also tended to be deeper (LAG1, LAG2, LAG3, Cow Xing). Downstream stations closest to Tomales Bay appeared to be well mixed (LAG4, LAG5).

- **Temperature** (Figure 3)

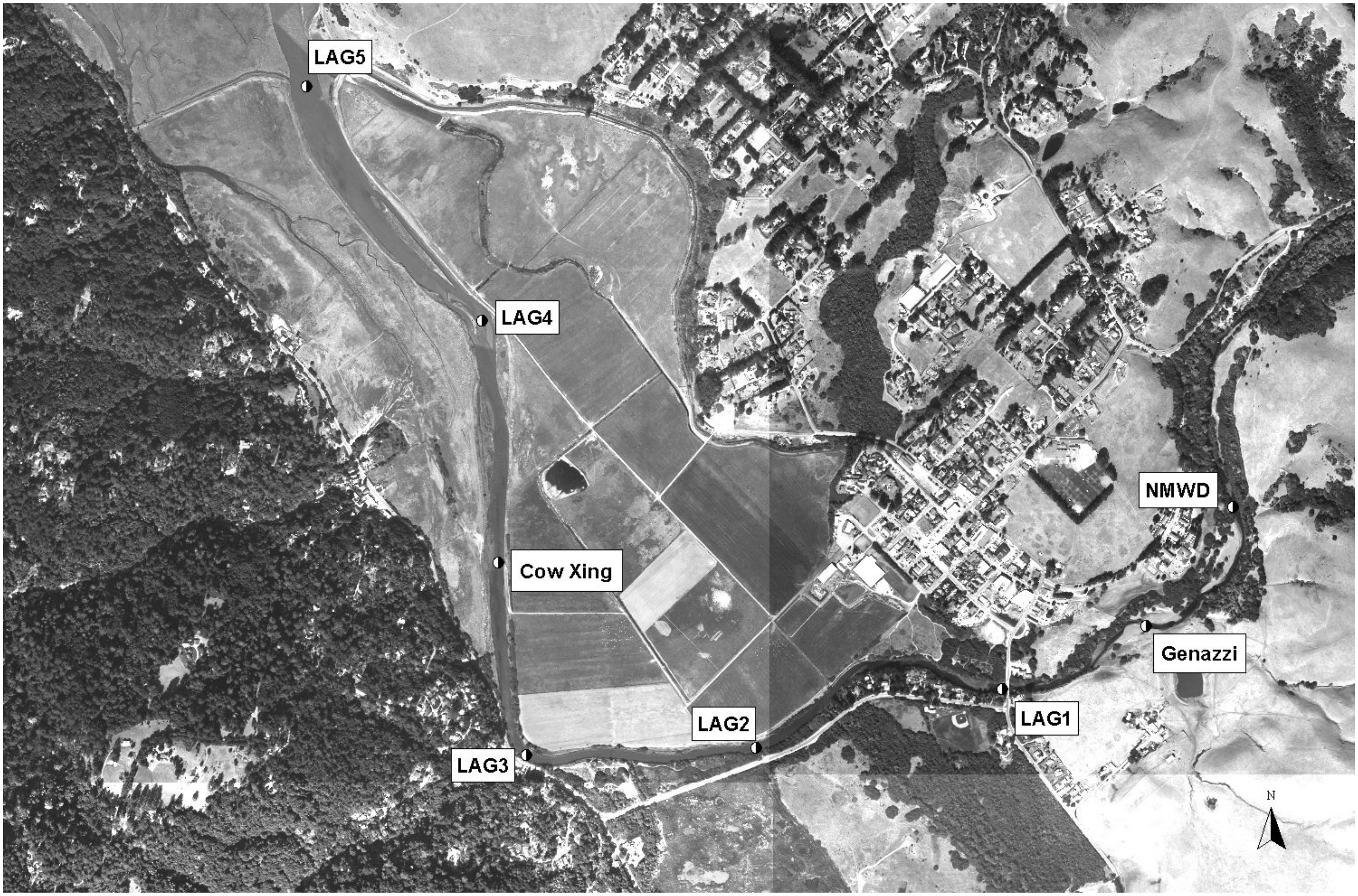
Overall, there were no unusual patterns in water temperature observed. The lowest temperatures along the creek channel were recorded at the uppermost station (NMWD). As expected, water temperature decreased with increasing depth at most stations.

- **Dissolved Oxygen** (Figure 4)

Concentrations of dissolved oxygen ranged between 7.6 and 8.4 mg/L at most stations and depths. It was slightly higher at .5 m (8.21 mg/L) below the surface. Not surprisingly, the highest concentrations of dissolved oxygen (8.74-9.2 mg/L) were measured at the station with the lowest temperature and salinity measurements (NMWD). The lowest concentration (7 mg/L) was measured at a depth of 2.5 m at station LAG3, but it is possible that the probe was resting on unconsolidated creek bottom during this measurement. LAG3 was the only station where the concentration of dissolved oxygen was not highest at the surface (8.02 mg/L).

Other observations

Cattle were seen wading across and standing stationary in the creek at the Genazzi Ranch station. Intact “patties” of cow manure were seen at station LAG1, floating downstream from the direction of Genazzi Ranch. It is possible that this form of direct discharge may be influencing nutrient and/or pathogen concentrations of water samples collected quarterly from stations LAG1 and LAG5, which are downstream from Genazzi Ranch.



Giacomini Wetland Restoration Project
Lagunitas Creek profile sampling locations
Oct 24, 2003

Figure 1.

Lagunitas Creek Profile Oct 24, 2003: salinity

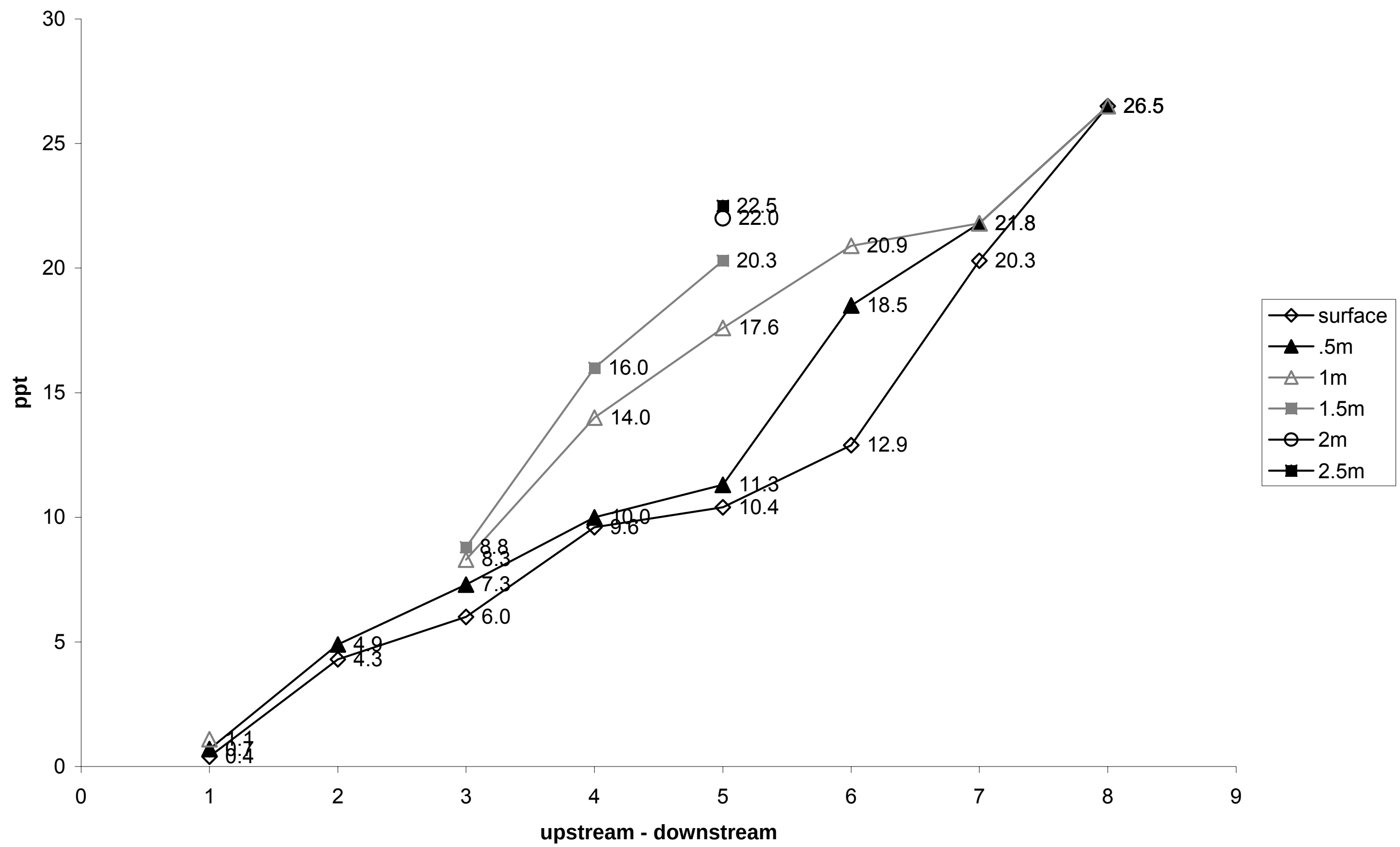


Figure 2.

High tide @ Inverness, 11:56am = +5.4 ft

1= **NMWD** (12:37pm)
2=**Genazi Ranch** (12:52pm)
3=**LAG1** (13:37pm)
4=**LAG2** (13:30pm)
5=**LAG3** (13:50pm)
6=**Giacomini Cow Xing** (14:05pm)
7=**LAG4** (14:20pm)
8=**LAG5** 14:35pm)

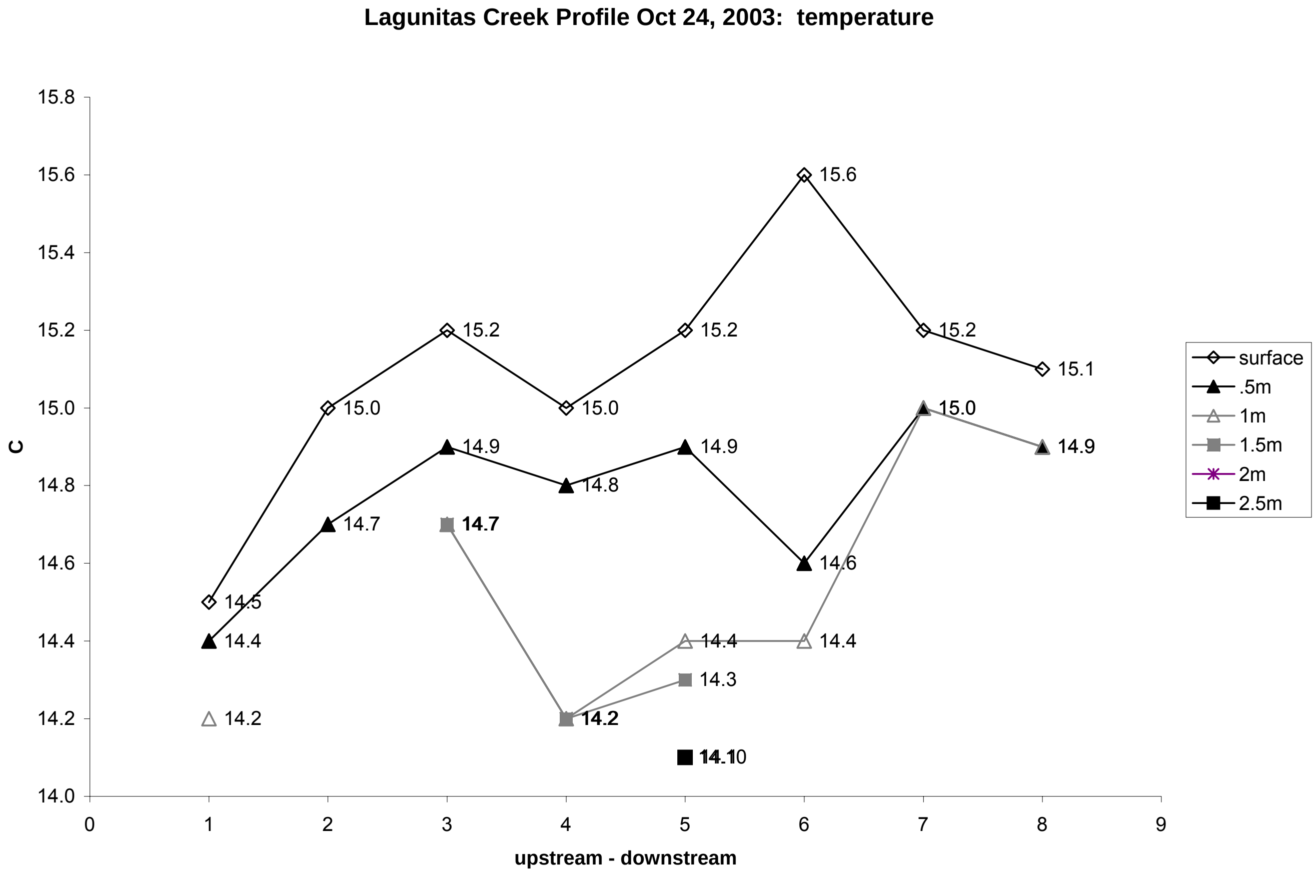


Figure 3.

1= **NMWD** (12:37pm)
2=**Genazi Ranch** (12:52pm)
3=**LAG1** (13:37pm)
4=**LAG2** (13:30pm)
5=**LAG3** (13:50pm)
6=**Giacomini Cow Xing** (14:05pm)
7=**LAG4** (14:20pm)
8=**LAG5** (14:35pm)

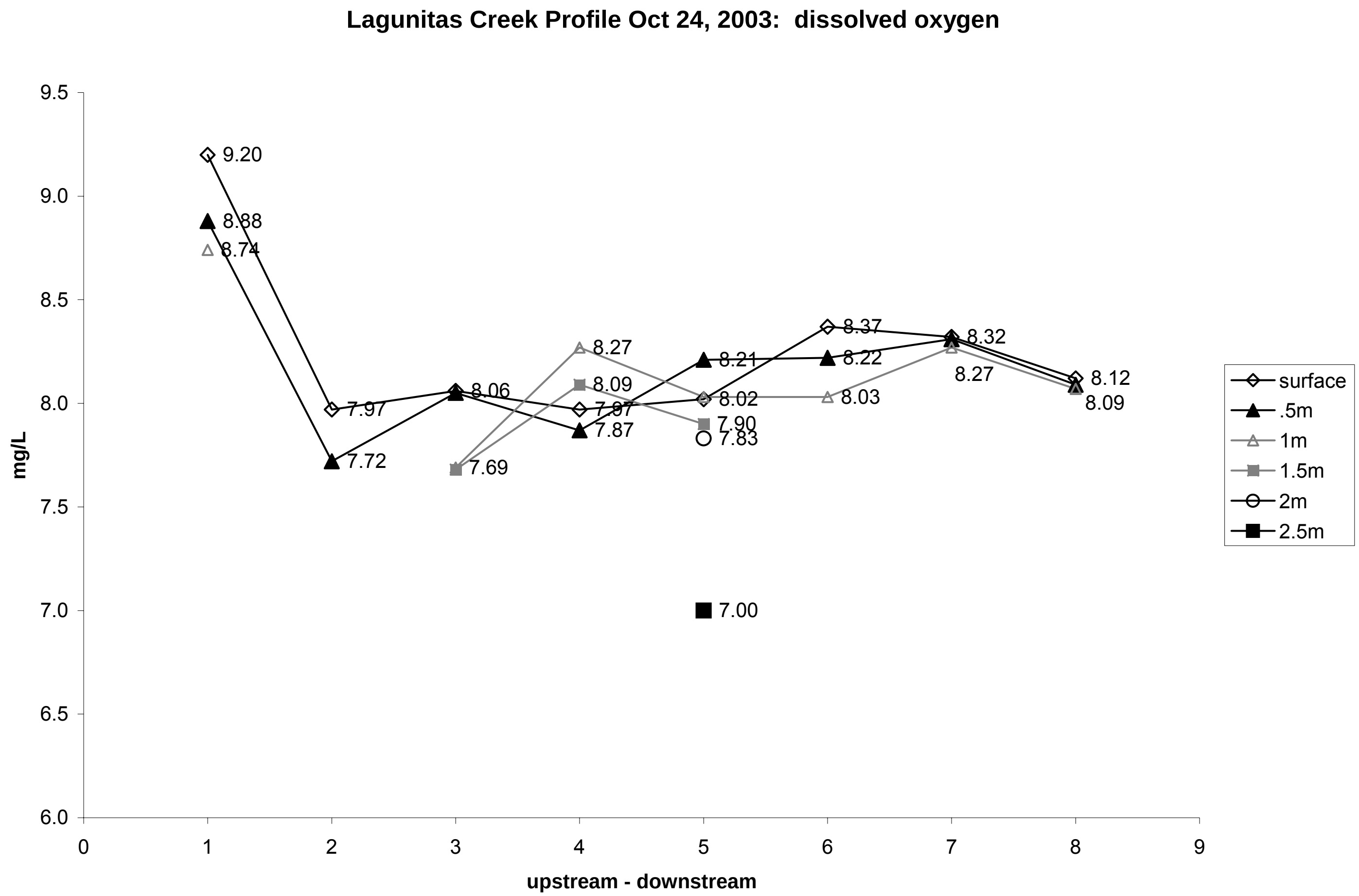


Figure 4.

1= **NMWD** (12:37pm)
2=**Genazi Ranch** (12:52pm)
3=**LAG1** (13:37pm)
4=**LAG2** (13:30pm)
5=**LAG3** (13:50pm)
6=**Giacomini Cow Xing** (14:05pm)
7=**LAG4** (14:20pm)
8=**LAG5** (14:35pm)

up_downstream	Site	depth (m)	ppt	temp (C)	%DO	mg/L_DO
1	NMWD	0.00	0.40	14.50	90.20	9.20
2	Genazi	0.00	4.30	15.00	81.20	7.97
3	LAG1	0.00	6.00	15.20	82.70	8.06
4	LAG2	0.00	9.60	15.00	84.90	7.97
5	LAG3	0.00	10.40	15.20	85.80	8.02
6	COWXing	0.00	12.90	15.60	89.40	8.37
7	LAG4	0.00	20.30	15.20	92.40	8.32
8	LAG5	0.00	26.50	15.10	93.00	8.12
1	NMWD	0.50	0.70	14.40	87.10	8.88
2	Genazi	0.50	4.90	14.70	77.00	7.72
3	LAG1	0.50	7.30	14.90	83.10	8.05
4	LAG2	0.50	10.00	14.80	83.00	7.87
5	LAG3	0.50	11.30	14.90	87.00	8.21
6	COWXing	0.50	18.50	14.60	89.60	8.22
7	LAG4	0.50	21.80	15.00	90.70	8.31
8	LAG5	0.50	26.50	14.90	94.20	8.09
1	NMWD	1.00	1.10	14.20	85.90	8.74
2	Genazi	1.00				
3	LAG1	1.00	8.30	14.70	81.90	7.69
4	LAG2	1.00	14.00	14.20	88.00	8.27
5	LAG3	1.00	17.60	14.40	80.50	8.03
6	COWXing	1.00	20.90	14.40	87.20	8.03
7	LAG4	1.00	21.80	15.00	93.20	8.27
8	LAG5	1.00	26.50	14.90	93.00	8.07
1	NMWD	1.50				
2	Genazi	1.50				
3	LAG1	1.50	8.80	14.70	80.00	7.68
4	LAG2	1.50	16.00	14.20	81.50	8.09
5	LAG3	1.50	20.30	14.30	87.50	7.90
6	COWXing	1.50				
7	LAG4	1.50				
8	LAG5	1.50				
1	NMWD	2.00				
2	Genazi	2.00				
3	LAG1	2.00				
4	LAG2	2.00				
5	LAG3	2.00	22.00	14.10	87.50	7.83
6	COWXing	2.00				
7	LAG4	2.00				
8	LAG5	2.00				
1	NMWD	2.50				
2	Genazi	2.50				
3	LAG1	2.50				
4	LAG2	2.50				
5	LAG3	2.50	22.50	14.10	80.10	7.00
6	COWXing	2.50				
7	LAG4	2.50				
8	LAG5	2.50				