Appendix A: Year One of the Giacomini Wetland Restoration Project: *Analysis of Changes in Water Quality Conditions in the Project Area and Downstream*

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Introduction and Background Summary

The Point Reyes National Seashore Association (PRNSA) and National Park Service (Park Service) have implemented an approximately 550-acre wetland restoration project in the southern end of Tomales Bay in Marin County, California (Figure A-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. 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, PRNSA in collaboration with 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. As part of this program, 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) was conducted within the Giacomini Ranch, Olema Marsh, and selected reference sites.

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). It should be noted that one of the Reference Areas (Limantour Marsh) was dropped in 2008 as a Reference Area, because upstream areas were dramatically altered through active restoration.

From 2000 (date of sale of land to Park Service) to 2006, the Giacominis continued to operate a full-scale dairy operation under a Reservation of Use Agreement. There were at least three dairy herds, and the ranch was actively maintained through manure spreading, haying, and flood and spray irrigation of certain pastures in the summer. This period is referred to in data analyses as Pre-Restoration as it pre-dates any restoration efforts.

Monitoring was continued on a more limited scale following discontinuation of the full-scale dairy operation in 2006. In 2006, the Giacominis sold the dairy string and instead grazed a much smaller herd of dairy heifers. Maintenance activities were also scaled back, with reduced haying, manure spreading, and irrigation of pastures during the summer. In 2007, the first phase of active restoration of the Giacomini Ranch was implemented. However, as most of this restoration focused on removal of dairy barns and other infrastructure and agricultural conditions and did not substantially alter hydrologic conditions, the ecological changes arising from this phase were comparatively small. The second and more intensive phase of restoration commenced in July 2008 and was completed with the final levee breach in October 2008. This phase involved full-scale levee removal, construction of new tidal channels, realignment of leveed channels, and removal of drainage ditches, although, due to the need to maintain dry working conditions, final hydrologic reconnection with Lagunitas Creek and other streams did not occur until the final levee breach in late October 2008. Because most of the restoration achieved during this period probably resulted from passive measures such as discontinuation or scaling back of active dairying and ranch management, the 2006-2008 period is referred to as Passive Restoration, because removal of agricultural management potentially could have led to some improvement or "restoration" of water quality conditions within the ranch, even without active restoration.

With final breaching of the levees and hydrologic reconnection to Lagunitas Creek and Tomales Bay in October 2008, full restoration if the Giacomini Ranch and, to a lesser extent, Olema Marsh, was initiated. Monitoring continued during the Full Restoration period, with sampling conducted in early November 2008 (only one to two weeks after the breach); late January 2009; May/June 2009; August 2009; and November 2009. Several limited-scale sampling events also occurred during storm events in February 2009, although, in general, Water Year 2009 (November 2008 to August 2009) was a relatively dry year with infrequent large storm events (Tables 1-3). While levee removal resulted in lowering of creek "bank" elevations to that sufficient to allow overflow of a 2-year-flood event, no overbank flooding from storm flows occurred during WY2008/2009. Timing and scale of monitoring efforts during this period were constrained by loss of funding due to state budget issues, with full-scale monitoring only reinitiated once funding was re-secured.

This technical memorandum summarizes changes in water quality conditions within the Project Area during the first year after restoration for Water Year 2009 (November 2008 through August 2009). Water quality conditions in the Project Area prior to restoration were summarized in a previous report (Parsons 2009). Some improvement in water quality conditions were expected immediately following restoration due to decreases in residence time for leveed waters. However, these improvements were expected to be tempered to a large degree initially by pulses in sediment and nutrients from re-working of exposed soils by tides, floods, and decomposition and mineralization of pasture vegetation, with variables such as pH and dissolved oxygen (D.O.) responding accordingly to the resulting flux in nutrients. Ultimately, restoration of more than 600 acres of historic floodplain/marshplain is expected to not only restore water quality conditions within the Project Area, but Tomales Bay itself. However, it is likely that watershed-scale benefits will not yet have been realized due to the continuing evolution occurring within the Project Area, as pasture vegetation continues to die off and convert into more natural salt- and brackish marsh vegetation communities.

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. Substitution can be employed if the number of non-detects or "censored" data is relatively low (<15 percent of the data; Helsel, 2006, *pers. comm. in* Parsons 2009.). 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 and pathogen 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. 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).

Changes Following Restoration – Year One: Results and Discussion

Improvement in General Water Quality Conditions in Project Area, Particularly Dissolved Oxygen

Salinity

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. Much of the freshwater inflow 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, prior to restoration, salinities and temperatures differed significantly between the Project Area and other Study Areas (Parsons 2009). 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 (Kruskal-Wallis, n=1261, df=2, H=472.6, $P < 0.001$; ibid). Based on statistical analyses, a significant change in average salinities occurred within the Project Area between sampling periods. Average salinities climbed from 6.9 (± 0.3; SE) ppt Pre-Restoration to 8.5 (± 0.9; SE) ppt during Passive Restoration to 16.6 (± 1.2; SE) ppt during the first year of Full Restoration, with Full Restoration differing significantly from the other two sampling periods (ANOVA, n=1,067, F=35.7, $P<0.0001$, Adj $R^2=0.06$; Figure A-1).

Some continuous water quality monitoring conducted by Kamman Hydrology & Engineering both prior to and immediately after the levees were breached confirmed that average salinity in Lagunitas Creek increased immediately after final removal of the East Pasture levees on October 25, although final removal of the West Pasture levees and completion of preliminary restoration activities in Olema Marsh two weeks earlier appeared to have no immediate effect on Lagunitas Creek salinity (KHE 2009). In general, average salinity, if not maximum salinity, increased along the entire portion of Lagunitas Creek within and upstream of the Project Area, although salinity levels and the absolute magnitude of the change decreased with distance upstream from the downstream boundary of the Project Area (KHE 2009). At this furthest downstream location (former North Levee), the maximum salinity remained the same immediately post-restoration, but average salinity increased, because there was an upward shift in the lower limit of salinity, with the range increasing from between 10 and 32 psu immediately pre-restoration to between 18 and 34 psu immediately after restoration (KHE 2009).

In addition to changes in salinity, water level patterns at the North Levee also showed some compression in maximum and minimum water levels during spring tides immediately post-restoration, suggesting that water levels are not dropping to pre-restoration "lows," because delayed outflow from the restored marsh keeps water levels – and salinities – elevated (KHE 2009). These changes in salinity and water level patterns in the northern portion of the Project Area may decrease over time to some degree as the marsh and tidal channel network in the restored wetlands evolve and equilibrate with Tomales Bay tidal forcing: only primary (or 1st-order) and a few secondary (2^{nd}-order) tidal channels were constructed as part of the restoration project to allow for more natural development of tidal channels (KHE 2009).

Similar trends in average and maximum salinity levels, if not water levels, were observed at upstream monitoring locations, with the range of salinities, for example, at the Green Bridge, the southern boundary of the Project, increasing from between approximately 1 and 6 psu before the East Pasture levee was removed to between 1 and 13 psu immediately post-restoration (KHE

2009). It should be noted that the monitoring record following restoration was extremely short (October 26, 2008 – November 2, 2008), because a storm hit on November 3, 2008, and caused salinities to drop, and average and peak salinities never totally rebounded to summer/fall levels during the remainder of that month (November 2008). Additional continuous water level/salinity data was collected by KHE in the spring and summer of 2009 in the interior of the East Pasture, but data analysis has been delayed until post-construction benchmark elevations are confirmed to ensure accuracy (KHE 2009). Ultimately, water level and salinity patterns within Lagunitas Creek will respond to morphological changes in tidal creeks driven by changes in the pattern and volume of sediment influx into and efflux out of the newly restored wetlands. Cross-sectional surveys conducted in 2009 on Lagunitas Creek showed the formation of ebb shoals in Lagunitas Creek at the mouth of newly constructed channels draining the East Pasture (KHE 2009). These shoals encroach into the mainstem of Lagunitas Creek, reducing cross-sectional area below an elevation of 2.0-ft NAVD88 and leading to further restrictions of water exchange in this area during low tide. Even prior to restoration, several prominent gravel bars or shoals along the mainstem of the creek were acting as "mini-weirs" and sequentially reducing the maximum low water level observed the downstream to upstream boundary (KHE 2006). With no sizeable storms in WY2008/2009, there was little storm energy available to counter this outflow of sediment from the newly restored marsh.

Salinities increased in the Project Area primarily in response to the reintroduction of tidal action. However, the dry weather and unusual precipitation patterns in 2008-2009 undoubtedly influenced salinity changes, as well. The influence of this dry weather can be seen in the change in salinities within Reference Areas. For the four-year period prior to restoration, the median salinity within Reference Areas was 25.5 ppt. Median salinities in Reference Areas actually decreased between Pre-Restoration and Passive Restoration (median=19.3 ppt) sampling periods, but, in 2008-2009, salinities climbed 20 percent to 30.7 ppt (Kruskal-Wallis, n=910, df=2, H=38.9, P<0.0001). Average salinities in Reference Areas during these sampling periods were 20.4 ± 1.2 (SE) ppt (Passive Restoration) and 29.3 ± 1.0 (SE) ppt (Full Restoration).

While one of the Reference Areas is adjacent to the Project Area and could have been affected by changes in tidal prism and salinity dynamics in the southern portion of the watershed, the other Reference Area sampled following Restoration is at the opposite end of the estuary near the estuary's mouth and is unlikely to have been substantially affected at this point by restoration activities. As noted earlier, one of the Reference Areas (Limantour Marsh) was dropped between Pre and Passive Restoration Periods and Full Restoration, which may have affected post-restoration summary statistics. However, salinities within this sampling site prior to restoration (average=24.0 ± 11.6 (SD) ppt) were roughly equivalent to those of Walker Creek Marsh (average=24.4 ± 11.8 (SD) ppt) and higher than those in the Undiked Marsh directly north of the Project Area (average=17.4 ± 10.0 (SD) ppt; Parsons 2009).

Temperature

The influence of freshwater was also evident in water temperatures prior to restoration (Parsons 2009). Before levees were breached, temperatures were 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; Kruskal-Wallis, n=1234, df=2, H=50.04, p<0.001). 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.

With removal of the levees and reconnection of Project Area waters to Lagunitas and Tomasini Creeks, average temperatures increased slightly (4 percent), albeit significantly, within the Project Area from 15.9 ± 0.2 (SE) degrees Centigrade Pre-Restoration to 16.6 ± 0.5 (SE) degrees Centigrade during the first year of Full Restoration (ANOVA, n=1,028, F=5.3, P=0.005, Adj

R^2=0.02; Figure A-2). Temperatures actually dropped somewhat during Passive Restoration (average=14.2 ± 0.5 (SE) degrees Centigrade) relative to Pre- and Full Restoration Year One (Figure A-2). Comparatively, mean temperatures in Reference Areas actually decreased from 17.2 ± 0.3 (SE) degrees Centigrade Pre-Restoration to 16.1 ± 0.7 (SE) degrees Centigrade during 2008/2009 (ANOVA, n=449, df=2, F=3.5, P=0.03, Adj R^2=0.02; Figure A-2). In general, average and median water temperatures in Limantour Marsh prior to restoration (average=17.5 degrees Centigrade) were slightly higher than those of the Walker Creek Marsh (average=16.9 degrees Centigrade) and closer to the Undiked Marsh (average=17.3 degrees Centigrade), although differences were not statistically significant (ANOVA, n=309, df=2, F=0.29, p=0.751): still, loss of this sampling site could be driving down average temperatures for Reference Areas.

Prior to restoration, 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, Parsons 2009). Comparatively, in the Project Area, before the levees were breached, 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. In the first year of Full Restoration, temperature exceedance levels in the Project Area climbed closer to that of Reference Areas, with temperatures exceeding 25 degrees Centigrade 4.4 and 3.3 percent of the sampling periods in Project Area and Reference Areas during the first year of restoration, respectively. Temperatures exceeded the suboptimal limit of 22 degrees Centigrade 15.0 and 14.9 percent of the sampling periods in the Project Area and Reference Areas in WY 2008/2009.

While these results would suggest that the Project Area is converging to some degree with conditions in the Reference Areas, the lower salinities in the Project Area during the first year after Full Restoration during a dry year suggest that the Project Area will probably never totally converge with that of the Reference Areas due to its geographic position within the freshwater-saltwater interface zone, although both spatial and temporal pattern of salinities and temperatures will continue to change as conditions evolve after restoration.

pH

Another variable that shows the influence of freshwater is pH. While pH prior to restoration might have been 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 – Pre-Restoration 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; Kruskal-Wallis, n= 1218, df=2, H=5.09, P=0.08; Parsons 2009). Most creeks feeding into the Project Area actually had fairly high pHs (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 (ibid). Muted tidal influence in the West Pasture and Tomasini Creek and high primary productivity during some sampling events also boosted pH (ibid). However, lower pH waters (~5.9 – 6.6) occurred only in areas where more extensive influence from groundwater occurs or, less frequently, where there was organic matter decomposition actively occurring (ibid).

Based on statistical analyses, the geometric mean or median pH actually decreased slightly from 7.60 Pre-Restoration to 7.30 during Passive Restoration and to 7.25 during the first year of Full Restoration despite the increase in tidal influence and the expected decrease in groundwater inflow during the dry winter (Kruskal-Wallis, n=1,017, df=2, H=55.7, p<0.0001; Figure A-3). The increase in exchange and decrease in residence time may have led to decreases in pH associated with phytoplankton blooms. However, breakdown of organic matter from die-off of pasture vegetation can also increase release of humic acids into overlying Project Area waters, resulting in a decrease in pH. In addition, flushing of sulfuric and iron-associated acids from oxidation of reduced sulfur and iron complexes in soils into overlying waters can also decrease pH: sulfuric and iron-associated acids are generated when pyrites or other reduced or anoxic forms of sulfate and iron in the soil are oxidized and broken down or converted during drawdown periods, with soluble acids from oxidation then released into overlying waters when tidal exchange is reintroduced. The Project Area was deliberately dried out before and during construction to improve constructability conditions, resulting in even drier conditions than when the Project Area was ranched.

Interestingly, a similar seemingly slight, but significant, decrease was observed in Reference Areas, with pH dropping from a geometric mean of 7.62 during the Pre-Restoration sampling period to 7.44 during the first year of Full Restoration (ANOVA, n=444, df=2, F=3.2, P=0.04, Adj R^2=0.10; Figure A-3). While not necessarily statistically significant, there did also appear to be the potential for a treatment X site interaction effect such that average pH appeared to drop more in the Undiked Marsh, which is furthest from the mouth of Tomales Bay, than in Walker Creek Marsh, which is located close to the mouth (ANOVA, n=444, df=4, F=2.1, P=0.08). Low sample size in the Full Restoration Sampling Period may have decreased statistical power in this analysis and reduced the ability to detect differences. While overall decreases in pH during WY2008/2009 might lead to questions about the effect of ocean acidification on pH of tidal waters flowing into estuaries, the fact that change appeared greatest furthest from the mouth of the estuary suggests that other forces may account for the changes observed this year. However, it does not rule out that we may begin to see changes in future years, although pH in estuaries is normally more highly variable than that in oceans even without the influence of climate change.

Dissolved Oxygen

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While diking did not appear to negatively impact salinities, temperature, or pH of waters within the unrestored Project Area, diking and other agricultural land management practices did appear to affect oxygen concentrations within drainage ditch and creek waters, often causing hypoxic or even anoxic conditions (Parsons 2009). 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 loose vegetation material that was consumed by oxygen-dependent bacteria (ibid). 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.

Prior to restoration, oxygen levels in the East Pasture averaged 4.98 ± 3.86 (SD) mg/L, with median levels actually slightly lower (4.56 mg/L; Parsons 2009). 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 ± 1.21 (SD) mg/L; ibid). Median oxygen concentrations in other Project Area subsampling areas or sub-groups – excluding upstream sampling sites -- ranged from 8.64 mg/L in Lagunitas Creek to 7.91 mg/L for Tomasini Creek, with the less heavily managed West Pasture having slightly higher levels (8.50 mg/L; ibid).

Following restoration, average oxygen levels in the Project Area increased 20 percent from 7.30 ± 0.13 (SE) mg/L during Pre-Restoration to 8.55 ± 0.35 (SE) mg/L during Passive Restoration and to 8.75 ± 0.38 (SE) mg/L in the first year after Full Restoration (ANOVA, n=1044, df=2, F=11.5, P<0.0001, Adj R^2=0.02). Oxygen concentrations in the East Pasture jumped from an average of 4.98 ± 3.86 (SD) mg/L pre-restoration to 9.85 ± 2.83 (SD) mg/L post restoration, an increase of 98 percent (Kruskal-Wallis, n=353, df=2, H=60.6, P<0.0001; Figure A-4). While D.O. also appeared to increase 26 percent in Olema Marsh between pre- and post-restoration conditions (Figure A-4), increasing from 5.83 ± 1.21 (SD) mg/L to 7.34 ± 2.04 (SD) mg/L, this change was not statistically significant, perhaps because of the relatively low power in the first year of post-restoration analysis (ANOVA, n=24, df=2, F=2.01, P=0.139).

In the Project Area, oxygen concentrations prior to restoration fell below the Basin Plan standard during 25 percent of the sampling periods, with most of these exceedances occurring in the East Pasture (Parsons 2009). In contrast, only approximately 8 percent of the oxygen concentrations recorded in reference marshes fell below 5 mg/L, the Basin Plan standard, a difference of 68 percent (ibid). In the first year of Full Restoration, the number of Basin Plan standard exceedances in the Project Area dropped 43 percent from 25 percent to 14.2 percent and compared reasonably well with the number of incidences recorded in Reference Areas during the same period (12.8 percent). Incidences of hypoxia (< 2 mg/L) and anoxia (<0.5 mg/L) in the Project Area totaled 2.7 and 0 percent, respectively, in the Project Area in the first year after Full Restoration, compared to 12.2 percent and 5.4 percent, respectively, prior to restoration. This is a 78 percent decrease in hypoxia incidences within the Project Area.

Oxygen concentrations might have been expected to decrease – or only increase somewhat overall – due to the abundant organic matter that die-off of pasture vegetation has been releasing into Project Area waters during the first year of restoration. With high levels of organic matter, bacteria become extremely active and rapidly deplete oxygen levels in overlying waters, particularly during the night, when oxygen stores are not replenished through primary production. While pasture vegetation appeared to go through multiple stages of die-off between October 2008 and August 2009, the effect of this die-off is not evident in Project Area oxygen concentrations.

Turbidity

Prior to restoration, 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; Parsons 2009). 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 (ibid). Based on this, it would appear that turbidity levels were similar between the Project Area and Reference Areas, but much lower in the fluvially dominated Upstream Area portions of the system. Before levee removal, differences also existed within the Project Area itself. Turbidity levels were higher in the heavily managed 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; ibid). The disparity between sub-sampling areas was even more apparent with means, with turbidity averaging 36.6 ± 97.0 (SD) NTU in the East Pasture and 13.3 ± 18.25 (SD) NTU in the more lightly managed West Pasture (ibid). Again, these numbers will not necessarily correspond with those discussed earlier in this section, because they exclude upstream sampling sites.

The highest measured turbidity Pre-Restoration occurred at the downstream sampling station near the Giacomini Ranch North Levee in June 2003 with a value of 266 NTU (Parsons 2009). In general, before the levees were removed, turbidity fell below 50 NTU in Lagunitas and Fish Hatchery Creeks and 40 NTU in Tomasini Creek (ibid). Turbidity did show a somewhat unexpected temporal trend, with the highest values in spring, summer, or early fall: turbidity is typically expected to be highest during the winter when sediment is being actively moved by creeks (ibid). The production of suspended particles during these periods may have been due to events such as upstream dam releases, biological activity, cattle activity, tidal action, and other activities within streams, ditches, and other water bodies.

Turbidity would be expected to increase, at least temporarily, following restoration due to the resuspension of sediment disturbed by excavation and other construction activities, die-off of pasture vegetation, and evolution of the marsh surface in response to tides and stormwater flows. In addition, release of decomposing organic matter into overlying waters would decrease clarity. As noted above under Salinity, sediment efflux does appear to be occurring, based on the formation of ebb shoals at the confluence of newly constructed primary tidal channels in Lagunitas Creek (KHE 2009). Interestingly, however, turbidity levels in the Project Area showed no significant differences between pre- and post-restoration (ANOVA, n=849, df=2, F=1.2, P=0.30; Figure A-5). Median turbidity levels were estimated at 10.8 NTU in the first year of Full Restoration, compared to 10.7 NTU during Pre-Restoration and 10.5 NTU during Passive

Restoration. The means displayed more disparity, with levels appearing to drop from 22.7 ± 2.3 (SE) NTU during Pre-Restoration to 15.8 ± 1.6 (SE) NTU Post-Restoration. High variability within the Passive Restoration data – turbidity averaged 40.0 ± 13.7 (SE) NTU – may have reduced power of the analysis and the ability to discern the apparent decline in turbidity levels after restoration.

The surprising trend in turbidity levels following restoration may at least partly due to the fact that conditions were relatively dry during WY 2008/2009 due to low rainfall and low-energy storm events, with no overbank flooding occurring that year. With higher rainfall, more overbank flooding would have been expected to occur that would have continued to shape this evolving wetland system and potentially at least temporarily increase resuspension of sediment into overlying waters. Because rainfall was so low, most of the "re-working" of the constructed site came solely from tides, although they, in conjunction with vegetation die-off, would have been expected to increase turbidity within Project Area waters. As noted earlier, shoaling at creek mouths show that re-working of the landscape was taking place, even without the influence of storm events. Turbidity levels may increase, at least temporarily, in future years should wetter years – and much larger storms – occur.

Nitrates Predominant Nutrient Source Particularly in Ranch Prior to Restoration, but Levels Already Decreasing After Restoration

Nitrates

The relatively well oxygenated conditions present in most of the Study Areas -- except the East Pasture prior to restoration – may contribute to the dominance of nitrates as the primary source of nutrients (Parsons 2009). In contrast to ammonia and phosphates, nitrates have only very infrequently fallen below detection limits, even at relatively high limits used by commercial laboratories. Results from the LMER/BRIE study conducted a decade earlier – which were, at least for Bay samples, generally much lower in magnitude than our pre-restoration results – also showed nitrates to represent the predominant source of nutrients (ibid). In our study, average nitrate concentrations did differ prior to restoration 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 (0.70 mg/L; ibid).

Prior to restoration, 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 ± 1.83 (SE) mg/L (NO_3^-) for the East Pasture and then dropped to below 1.10 mg/L for the other sub-groups (Parsons 2009). 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 into groundwater that flows along the perimeter of the Giacomini Ranch and Olema Marsh (ibid).

The similarity in nitrate concentrations between the Project Area and Reference Areas and even among the different Reference Area units – 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 (Parsons 2009). Indeed, these factors at times appear to override the differences in concentrations and loading that would be expected from the three Reference Area units 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 (ibid). 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; ibid).

Following restoration, estimated mean nitrate concentrations appeared to climbed slightly (7 percent) from 3.22 ± 0.83 (SE) mg/L pre-restoration to 3.45 ± 1.50 (SE) mg/L during the first year of Full Restoration, although that actually was a small drop from levels during Passive Restoration (4.52 ± 2.35 (SE) mg/L; Figure A-6). Estimated medians showed statistically significant differences, with median nitrate values dropping 55 percent from 0.83 mg/L Pre-Restoration to 0.37 mg/L during Passive Restoration to 0.13 mg/L in the first year after Full Restoration (Wilcoxon, n=222, df=3, Chi-Square=15.6, p=0.001; Figure A-6). There appeared to be no change in either mean or median nitrate concentrations in Reference Areas between Pre-Restoration and the first year of Full Restoration, with levels estimated at 0.35 mg/L (average) and 0.07 (median), even without inclusion of Limantour Marsh (MLE, n=234, df=2, Chi-Square=26.3, P<0.0001; Figure A-6).

Higher estimated average relative to median nitrate concentrations following restoration appeared to have been driven by some large values recorded in the first sampling one week after levee breaching and during two storm events in February 2009 after a relatively dry December 2008. Estimated nitrate concentrations showed a statistically significant relationship with sampling date in WY2008/2009, with January, May, and August 2009 sampling results differing significantly from November 2008, and the two February 2009 storm sampling events (MLE, n=43, df=5, Chi-Square=20.0, p<0.0001). In November 2008, estimated nitrate concentrations averaged 3.44 ± 1.59 (SE) mg/L, with median concentrations of 1.60 mg/L, but, by January 2009, estimated concentrations had dropped to an average of 0.18 ± 0.08 (SE) mg/L and median of 0.13 mg/L, which were seemingly higher, but not significantly so from August 2009 (est. average=0.06 ± 0.04 (SE) mg/L) and May 2009 (est. average=0.02 ± 0.01 (SE) mg/L) events. So, following the early transitional period after levee breaching, the only recorded surge in nitrates occurred during the two February 2009 storm sampling events, where estimated nitrates climbed to average levels between 1.63 and 1.93 mg/L and median levels between 1.6 and 2.0 mg/L during both events due to strong pulses at certain Project Area sampling sites. It should be noted that average levels recorded during non-storm events between January 2009 and August 2009 in the Project Area were roughly half that of Reference Areas.

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, even prior to restoration (Parsons 2009). However, in the East Pasture, approximately 7 percent of the nitrate samples collected exceeded 10 mg/L prior to restoration, with all of the exceedances coming from a ditch at the base of the Dairy Mesa that receives non-point source run-off from Point Reyes Station, as well as potentially septic-influenced groundwater (ibid). This same sampling site continues to show elevated nitrates even after restoration. Interestingly, nitrites were generally not detected (<0.05 mg/L), in the Project Area prior to restoration, 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 (ibid). Because nitrates were only rarely recorded prior to restoration, nitrites were not specifically sampled during the Passive Restoration and Full Restoration sampling periods.

Ammonia

Prior to restoration, 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 (Parsons 2009). 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 rather than as nitrates.

Within the Project Area (excluding upstream sites), estimated ammonia concentrations Pre-Restoration 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; ibid). However, because of the high number of non-detects during Pre-Restoration due to use of a commercial laboratory, a more valid parameter might be the distribution of "detections" among sampling sites. Of the 64 detections of ammonia during the Pre-Restoration period, 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 (Contingency Table, Chi Square, n=99, df=4, Chi-Square=13.4, p=0.009; ibid).

Overall, there was apparently no statistically significant differences in the number of detections between Study Areas Pre-Restoration (Contingency Table, Chi Square, n=320, df=2, Chi-Square=2.70, p=0.26; Parsons 2009). However, before levees were breached, 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) or 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, ibid). Ammonia pulses in Reference Areas prior to restoration most 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 from oint-source loading. Conversely, 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 to the presence of a low oxygen environment.

Following restoration, the number of ammonia detections decreased in the Project Area during the first year of Full Restoration, dropping 43 percent from 22.8 percent of the samples Pre-Restoration to 13.0 percent of the samples after restoration (Contingency, n=226, df=2, Chi-Square=10.0, P=0.007; Figure A-7). Interestingly, the number of detections decreased even more dramatically during Passive Restoration, falling to 4.6 percent before climbing up to 13.0 percent after restoration (Figure A-7). Based on statistical analysis, there did not appear to be a difference in estimated concentrations between treatments, although estimated concentrations within the Project Area did appear to drop 73 percent from 1.26 ± 0.58 (SE) mg/L Pre-Restoration to 0.34 ± 0.10 (SE) mg/L during the first year of Full Restoration (Wilcoxon, n=226, df=2, Chi-Square=2.8, P=0.249). Estimated East Pasture concentrations dropped even more dramatically from 2.61 ± 1.51 (SE) mg/L to 0.44 ± 1.51 (SE) mg/L, a decrease of 83 percent. The resurgence in ammonia detections between Passive and Full Restoration periods could be entirely attributable to restoration-related changes: increase in ammonia following mineralization of decomposing organic matter and flushing of ammonia from soils into overlying waters with reintroduction of tidal and creek flows after the deliberate drawdown during construction. Oxygen and pH conditions within Project Area waters would appear sufficient to promote rapid conversion of ammonia into nitrates, so these detections suggest local, continued production of ammonia at sampling sites from plants and, to some degree, wildlife.

One interesting caveat to this hypothesis is that ammonia detections increased in all of the Study Areas following restoration, even those distant from the Project Area. The number of detections in Reference Areas jumped from 3.9 percent of the samples Pre-Restoration to 10.3 percent in WY2008/2009, while detection frequencies during Passive Restoration were roughly equivalent to Pre-Restoration (4.0 percent; Figure A-7). Not surprisingly, differences among Study Areas (PA, US, REF) between treatments (Pre-, Passive, Full) showed strong statistical significance (Contingency, n=562, df=8, Chi-Square=40.3, P<0.0001). However, changes in estimated concentrations between treatments within Study Areas did not seem to be significant (Wilcoxon, n=619, df=2, P=0.157), although average ammonia concentrations seemingly dropped 55 percent from 0.60 ± 0.20 (SE) mg/L Pre-Restoration to 0.27 ± 0.04 (SE) mg/L. Estimated average ammonia concentrations for Reference Areas appeared roughly equivalent between Pre-Restoration (0.23 ± 0.01 (SE) mg/L) and post-restoration (0.24 ± 0.04 (SE) mg/L).

The overall increase in the frequency of ammonia detection, if not average concentrations, within both the Project Area and Reference Areas – some of which are distant from the Project Area – suggests that the increases in ammonia detections documented in WY2008/2009 do not all result from the effects of restoration. One possible explanation for the increase in ammonia detections may be the dry winter, which allowed tidal influence or the "salt wedge" to extend further upstream due to the lack of a strong countering force from freshwater flows. Recent research on salinity intrusion associated with sea level rise on the East Coast found that intrusion of even weakly saline waters into formerly freshwater tidal areas – tides affect rise and fall of water level, but do not affect salinity – mobilized ammonia into overlying waters, causing a net efflux or transport from the system. In these areas, ammonium, phosphate, and silicate fluxes increased by 20 to 38 percent, reduced iron fluxes increased by ~150 percent, methane fluxes decreased by 77 percent, and in situ organic carbon mineralization rates increased by ~110 percent (Joye et al. undated). Most of this increase probably results from cation exchange of the strongly ionic sodium chloride for ammonium (Craft et al. 2009), but ammonia may also be produced through increased mineralization of organic matter under tidal versus freshwater regimes. Salinity data collected in WY2008/2009 showed increases in salinity not only understandably in the Project Area, but in Reference Areas, so this supports the potential for increased upstream tidal influence to have caused biogeochemical changes that resulted in more frequent ammonia detections.

Interestingly, despite occasional spikes in ammonia concentrations, only a few sampling locations prior to restoration exceeded the maximum concentration limit for unionized ammonia in estuarine waters of 0.16 mg/L (Parsons 2009). Some of these included East Pasture drainage ditches, where ammonia reached as 76 mg/L prior to restoration, and even one sampling location on Lagunitas Creek in April 2003, when total ammonia levels climbed as high as 13 mg/L. While ammonia was obviously detected in lower, but still relatively high, concentrations elsewhere in the dairy ranch, particularly in the East Pasture, temperature and/or pH did not climb high enough to encourage dissociation of ammonia into its unionized ion.

Phosphates

Phosphates appeared to be driven more by biogeochemical processes than upstream loading, at least in most of the Project Area (Parsons 2009). While concentrations of phosphates prior to restoration were sometimes high during storm events – as was observed in Walker Creek and Lagunitas Creek -- they also showed peaks during spring and fall (ibid). 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.

Prior to restoration, 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 to agricultural management regimes that caused oxygen levels within ditch waters to frequently be low (Parsons 2009). Before the levees were breached, 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 (ibid). Phosphates averaged an estimated 0.99 ± 0.16 (SE) mg/L in the Project Area Pre-Restoration compared to 0.23 ± 0.03 (SE) mg/L for Reference Areas and 0.12 ± 0.01 (SE) mg/L for Upstream Areas (Wilcoxon Score, n=346, df=2, p<0.001; ibid).

The East Pasture largely accounted for the disproportionate number of samples in which phosphates were detected Pre-Restoration (26 percent; Chi-Square Test, n=51, df=4, Chi-Square=25.47, p<0.001; ibid). 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 (ibid). In the East Pasture, concentrations averaged an estimated 2.40 ± 0.33 (SE) mg/L Pre-Restoration, 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; ibid).

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 most of these systems to the ocean, where phosphorous is naturally high (Mitsch and Gosselink 2000, Day et al. 1989).

Following restoration, estimated phosphate concentrations in the Project Area appeared to drop significantly, decreasing 88 percent from 0.99 ± 0.16 (SE) mg/L Pre-Restoration to 0.12 ± 0.01 (SE) mg/L in the first year of Full Restoration (Wilcoxon, n=203, df=2, Chi-Square=22.7, $P<0.0001$). Estimated levels after levee removal were even lower than those during Passive Restoration (average=0.68 ± 0.37 (SE) mg/L). Estimated concentrations in the East Pasture dropped 95 percent from 2.40 ± 0.33 (SE) mg/L Pre-Restoration to 0.11 ± 0.02 (SE) mg/L during the first year of Full Restoration, with the other sites having estimated mean concentrations ranging from 0.05 mg/L (TOM) to 0.20 mg/L (OM; Wilcoxon, n=203, df=8, Chi-Square=178.8, $P<0.0001$). Phosphate concentrations – and perhaps the frequency of phosphate detection – have probably dropped to the discontinuation of active agricultural management and, with the removal of the levees, the improvement in oxygen levels within pasture waters.

Some caveats must be noted for these results. Analytical chemistry methods were changed between Pre-Restoration and subsequent sampling periods or treatments, with measurement of Total Dissolved Phosphates being changed to measurement of Orthophosphates. Also, the method detection limit decreased greatly, which negates our ability to use Contingency Tables to evaluate changes in the number of detections between treatments. Total Dissolved Phosphates typically incorporates both Orthophosphates, as well as Polyphosphates, so Orthophosphates would be considered to represent a smaller fraction of the dissolved phosphorous component, although Polyphosphates are unstable and will eventually convert over time to Orthophosphate, particularly in low oxygen waters (Murphy 2007). A comparison of Orthophosphate and Total Dissolved Phosphates for several sampling periods during Passive Restoration when both were measured showed typically 94 to 99 percent correlation, although, during one sampling event, correlation was as low as 48 percent: as samples were collected in different jars and sent to different laboratories, the dynamic and extremely variable nature of natural waters, which can change rapidly from moment to moment, does not make the latter result extremely surprising.

Pathogens A Major Issue in Project -- and Reference – Areas, but Levels in Project Area Dropped Dramatically After Restoration

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.

Prior to restoration, the Project Area had substantially higher estimated median concentrations of fecal coliforms (1,600.9 mpn/100ml) than the Reference Areas (72.0 mpn/100 ml), although seeming differences with Upstream Areas (705.6 mpn/100 ml) might have been obscured to some degree by high variance in the data (MLE Regression, n=379, df=2, Chi-Square=98.5, p<<0.0001; Parsons 2009). Not surprisingly, the heavily managed East Pasture had significantly higher estimated geometric means or medians (6,298.8 mpn/100 ml) Pre-Restoration 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; ibid). 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 (ibid).

In terms of compliance with Basin Plan or TMDL standards, prior to restoration, more than 95 percent of all samples collected from the Project Area and Upstream Areas exceeded objectives for shellfish harvesting and municipal water supply of 14 and 20 mpn/100 ml respectively (Parsons 2009). 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 (ibid). 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 (ibid). 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 (ibid).

Following restoration, the estimated geometric mean or median fecal coliform concentrations decreased significantly in the Project Area, dropping 93 percent from 1,600.9 mpn/100 ml to 113.2 mpn/100 ml (MLE, n=229, df=7, Chi-Square=56.2, P<0.0001; Figure A-8). Estimated median concentrations during Passive Restoration fell in-between those of Pre- and Full Restoration (919.9 mpn/100 ml; Figure A-8). Not surprisingly, large decreases were recorded in the East Pasture, with estimated median levels dropping more than 6,000 percent from 6,298.8 mpn/100 ml to 114.0 mpn/100 ml (Figure A-9). Estimated mean concentrations in the West Pasture also dropped by more than 95 percent from 1,137.5 mpn/100 ml Pre-Restoration to 48.7 mpn/100 ml post-restoration (Figure A-9). Decreases in Olema Marsh were also substantial (125 percent), with concentrations slipping from 1,821.4 mpn/100 ml to 394.8 mpn/100ml in the first year of Full Restoration, even though restoration was not quite as extensive in this area during this phase of the project (Figure A-9). Concentrations in downstream Lagunitas Creek after restoration (median=141.5 mpn/100 ml) appeared to be lower than those recorded before restoration (median=356.9 mpn/100 ml; Figure A-9).

Estimated median levels in Reference Areas were lower in WY2008/2009 (median=21.0 mpn/100 ml) than in the years prior to restoration (72.0 mpn/100 ml; Figure A-8). This might suggest that lower concentrations in WY 2008/2009 have been affected to some degree by the dry winter, decreased precipitation, and reduced pollutant inflow. For Reference Areas, it is also possible that it reflects the absence of Limantour Marsh from post-restoration years, although concentrations in this marsh were typically low as reflected by the estimated mean of 23.1 mpn/100 ml for the Pre-Restoration sampling period.

The dramatic declines in fecal coliform concentrations following restoration are also evident in changes in the frequency of exceedance of Basin Plan or TMDL standards. Exceedance of municipal water supply thresholds of 20 mpn/100 ml dropped from 95 percent of all samples collected in the Project Area Pre-Restoration to 80 percent of all samples collected in the first year of Full Restoration. Approximately 39 percent of all samples collected after restoration exceeded the contact water recreation standards of 200 mpn/100 ml, compared to approximately 78 percent Pre-Restoration, a 50 percent decrease. Only 4 to 7 percent of samples collected after levees were breached exceeded 2,000 to 4,000 mpn/100 ml, the standards for non-contact water recreation, whereas 36 to 47 percent exceeded before levee removal, an 85- to 89 percent decrease in exceedances, respectively.

Similar decreases were observed for Lagunitas Creek, with the TMDL standard of 200 mpn/100 ml being exceeded approximately 40 percent of the time, a 44 percent decrease from 72 percent of the sampling events prior to restoration. The 90th percentile standard was exceeded approximately 27 percent of the sampling periods post-restoration as opposed to 58 percent of the time Pre-Restoration. Exceedances of the 95 mpn/100 ml TMDL load-based allocation for the Green Bridge sampling site dropped from 100 percent to 52 percent during WY 2008/2009, a 48 percent decrease. The overall geometric mean and 90th percentile were estimated at 211.2 mpn/100 ml and 871.6 mpn/100 ml, respectively, both of which are substantially lower than that estimated for Pre-Restoration. Interestingly, while median concentrations for Reference Areas dropped last year, the frequency of exceedance of contact water recreation standards increased from 34 percent to 50 percent of the sampling events, although there were no recorded exceedances of non-contact water recreation standards.

Again, given the similar patterns in fecal coliform levels observed between Project and Reference Areas in the first year following Full Restoration, changes in Project Area concentrations before and after levee removal cannot be completely ascribed to restoration, as reduced precipitation and pollutant inflow must be taken into account. While two storm events were sampled in 2009, reduced rainfall may have caused an overall drop in pollutant mobilization or loading for the 2008/2009 Water Year. More sampling post-restoration is necessary to determine whether results from the past year are reflective of climatic conditions or real declines associated with restoration or changes in watershed use or loading patterns.

Loading Rates in Project Area Increase Slightly as Expected After Restoration Due to Hydrologic Reconnection of Diked Former Pasture Lands

Despite high concentrations in the Project Area prior to restoration, loading rates for the Giacomini Ranch and Olema Marsh Pre-Restoration were usually lower or only slightly higher than Reference Areas (Parsons 2009). 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 (ibid). The only potential for loading from the East Pasture came during moderate to large storm events when waters in the pasture overtopped the levees or when the Giacominis occasionally pumped ditch waters into Lagunitas Creek (ibid). 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 both Lagunitas and Tomasini Creeks, the East Pasture had no other source watersheds to increase flow and loading volumes (ibid).

Prior to restoration, then, 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 (Parsons 2009). 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; ibid). 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) considerably lower, which, as discussed earlier, may relate to the more substantial marine influence in these areas (ibid).

As with concentrations, estimated median loading rates Pre-Restoration were considerably smaller than mean loading rates, showing the influence of pulses during the winter or wet season sampling events (Parsons 2009). 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 (ibid). 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 have been the least sampled due to inherent planning and logistical difficulties, however, we are increasing efforts to capture storm events in the future monitoring record.

Because levees essentially precluded or minimized export of pollutant loads from the ranch pastures, with full levee removal, the contribution of the Project Area to downstream loading would be expected to increase, even if concentrations within the Project Area dropped dramatically. For example, for fecal coliform, estimated geometric mean or median loading rates appeared to increase from 56.0 mpn/s to 118.0 mpn/s, a 111 percent increase, although differences between these two treatments or sampling periods were technically not considered statistically significant based on the strong variance(MLE, Z-test, $p<0.076$; Figure A-10). Conversely, estimated arithmetic mean loading rates seemingly decreased from 249,389 ± 369,023 (SE) mpn/s to 64,150.9 ± 89,216.4 (SE) mpn/s. Similar trends of higher medians and lower arithmetic means were also observed for fecal coliform loading when all Study Areas (e.g., PA, REF, US) were incorporated into the pre- and post-restoration comparative analysis, although, again, differences were not statistically significant (MLE, Z-test, all $P>0.694$). The lower arithmetic means again may reflected the dry conditions during WY2008/2009, as discussed above, although at least two storm events were sampled: there were few outliers or spikes in coliform loading in any of the Study Areas during WY2008/2009 (Figure A-10).

For nitrates, loading appeared to increase between Pre-Restoration and Full Restoration, with estimated means climbing from 0.54 ± 0.35 (SE) mg/s to 0.96 ± 0.01 (SE) mg/s, even though differences between treatments or sampling periods were not statistically significant (Wilcoxon, $n=163$, $df=2$, $P=0.349$). A similar trend was observed when all Study Areas (e.g., PA, REF, US) were incorporated into the pre- and post-restoration comparative analysis, with the estimated average nitrate loading climbing from 1.54 ± 0.81 (SE) mg/s Pre-Restoration to 2.15 ± 0.90 (SE) mg/s during the first year of Full Restoration, even though differences, again, were not seemingly statistically significant (Wilcoxon, $n=460$, $df=2$, Chi-Square=4.98, $P=0.083$). Conversely, nitrate loading within Reference Areas alone appeared to decrease from 0.51 ± 0.11 (SE) mg/s Pre-Restoration to 0.11 ± 0.06 (SE) mg/s in WY2008/2009. Again, dry weather conditions may have reduced average nitrate loading within reference marshes, but these reductions were seemingly offset in the Project Area and for the Study Areas as a whole by the reconnection of the formerly diked pastures to Lagunitas and Tomasini Creeks and the increased connectivity of Bear Valley Creek and Olema Marsh with Lagunitas Creek. It should be noted that nitrate loading did not include August 2009 data.

Restored Wetlands' Potential to Trap Downstream Pollutant Loads Still Evolving

Because of being extensively leveed prior to restoration, the Project Area was not expected to provide much in the way of downstream reduction in either concentrations or loading of nutrients or pathogens (Parsons 2009). 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 marshplain 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 prior to restoration were evaluated for two parameters – nitrates and fecal coliform (Parsons 2009). 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. Before the levees were breached, 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 (ibid). 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 (ibid). Median pathogen concentrations and/or loading rates actually increased downstream in some areas, including Fish Hatchery Creek and Bear Valley Creek (ibid). For the latter, 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 wildlife use or septic-influenced surface water and groundwater flowing from the adjacent developed portion of Inverness Ridge into the west end of the marsh (ibid).

Despite the fact that soluble nutrients such as nitrates are the least effectively trapped pollutants by floodplain systems, nitrates did show some downstream reductions Pre-Restoration for many of the creeks, including Fish Hatchery Creek, Tomasini Creek, and Bear Valley Creek, all of which were leveed or impounded to some degree (Parsons 2009). 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; ibid).

Nitrate reductions 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 (Parsons 2009). Fish Hatchery Creek was not leveed directly adjacent to the creek, but contained within the Lagunitas Creek levees, with exchange with Lagunitas Creek and other undiked areas limited to a tidegate at its downstream end (ibid). Trapping also appeared to occur on Bear Valley Creek and Tomasini Creek (ibid). 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, which were limited to narrow strips of marshplain within the tightly confining levee system (ibid). (Tomasini Creek was leveed separately by the Giacominis in the 1960s to exclude it from the East Pasture). 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 (ibid).

Post-restoration pollutant trapping has not been fully analyzed as yet, and the Giacomini Wetlands will take time to reach their full nutrient trapping potential due to the loss of vegetation and larger expanse of bareground during the conversion of pastureland to marsh. Some preliminary evaluations of data collected in the first year of Full Restoration showed no statistically significant differences in estimated nitrate concentrations between upstream and downstream sampling sites, with the exception of Tomasini Creek/Slough (MLE, n=11, df=1, Chi-Square=5.1, 0.05>p>0.02). Following breaching of the levee, estimated average nitrate levels dropped 97 percent on Tomasini Creek/Slough from 8.84 ± 4.26 (SE) mg/L upstream of the site to 0.24 ± 0.68 (SE) mg/L at the downstream end at the confluence with Lagunitas Creek. Both Fish Hatchery and Bear Valley Creek in Olema Marsh also appeared to show downstream reductions in estimated average nitrates post-restoration, but differences were not statistically significant, perhaps because power was not strong enough due to low sample size (MLE, 0.20>p>0.10).

Post-restoration fecal coliform concentrations and loading also showed a similar analytical pattern: there were no statistically significant differences between upstream and downstream sampling sites in the first year of Full Restoration, although most creeks did appear to show lower estimated geometric means or medians for pathogen levels and loading downstream than upstream. One exception to this was Bear Valley Creek in Olema Marsh, where estimated median loading, if not estimated median concentrations, actually appeared to be higher downstream than upstream, although differences were not statistically significant (MLE, n=12, df=1, Chi-Square=2,83, 0.10>p>0.05).

Ultimately, all of these analyses suffer from low power due to the few sampling events that have occurred since restoration. Continued sampling in future years will boost power and perhaps the ability to detect the apparent reduction downstream in nitrates and fecal coliform, at least for most creeks. Over time, the restored Giacomini Wetlands will evolve into a more functional floodplain/marshplain system that will be more effective at trapping pollutants. The ability of this wetland to trap pollutants will be enhanced in years with overbank flood flow: in WY2008/2009, there were no overbank flood events due to reduced rainfall and small magnitude of storms that did occur. We also intend to improve our analytical approach to comparison of upstream and downstream sampling sites in the future by potentially incorporating paired techniques for censored data to increase the power of our analyses.

Conclusions

In the environmental assessment document (NPS 2007), the impact analysis section predicted short-term negative impacts resulting from the conversion of pastureland to marsh, with long-term benefits for water quality conditions within the former Giacomini Dairy Ranch, as well as for downstream water quality and the health of Tomales Bay. In general, the speed with which conditions improved within the Project Area for variables such as dissolved oxygen and nitrate and fecal coliform concentrations far exceeded our expectations, and expected issues with temporary increases in turbidity and temporary decreases in dissolved oxygen and pH did not materialize. Some of this may have resulted from the fact that WY2008/2009 was a dry year, and few large storms occurred that would have contributed to reworking of this evolving landscape, even though we captured some of the few larger storm events that did occur. None, however, overtopped the southern creek banks and flowed northward across the newly reconnected floodplains. Despite the lack of storms, reworking of the landscape did occur, largely due to reintroduction of tidal action, with shoals evident at the mouth of newly created tidal channels due to sediment efflux from the marsh (KHE 2009).

As would be expected, loading rates of pathogens and presumably nitrates increased relative to pre-restoration conditions, because, prior to levee removal, the pastures had either no direct connection to Lagunitas or other creeks (East Pasture) or only muted tidal connection (West Pasture). One of the most important indicators, however, of the success of this project in improving downstream water quality conditions in Tomales Bay will be changes in concentrations and, even more importantly, loading between upstream and downstream sampling locations. While estimated average nitrate concentrations and median coliform concentrations and loading appeared to show downstream reductions in the first year of Full Restoration, few of these differences were strong enough to be statistically significant, probably due to the large variance in this type of data. One of the exceptions proved to be Tomasini Creek/Slough, which flows through the newly restored East Pasture. Estimated average nitrate levels dropped 97 percent from 8.84 ± 4.26 (SE) mg/L upstream of the site to 0.24 ± 0.68 (SE) mg/L at the downstream end at the confluence with Lagunitas Creek. Another exception was Bear Valley Creek in Olema Marsh, where where estimated median loading, if not concentrations, actually appeared to be higher downstream than upstream, although differences were not statistically significant. Continued sampling in future years will boost power and, hopefully, the ability to detect trends for downstream loading of nitrates and fecal coliform. In addition to statistical analysis improvements, over time, the restored Giacomini Wetlands will evolve into a more functional floodplain/marshplain system that will be more effective at trapping pollutants.

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 fullness of restoration efforts. Based on evaluation of preliminary data, predicted restoration changes, and results from some of the progress criteria analyses proposed in the Long-Term Monitoring Program Framework: Part I (Parsons 2005), 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. 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.

Photograph of restored marsh by Louis Jaffe

For the second year of Full Restoration, we will continue quarterly synoptic sampling of field parameters, nutrients, pathogens, and productivity indicators. We will also attempt to improve our understanding of hydrodynamics within the restored wetlands through potential installation of continuous water level and conductivity instruments. In keeping with the goals outlined in our analysis of Pre-Restoration data (Parsons 2009), we are continuing to improve our monitoring approach by 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. 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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