Castle & Cooke

LĀNA'I

April 30, 2012

LAND USE COMMISSION
STATE OF HAWAII
2012 MAY -2 A 8: 11

Maui County Council
County of Maui
200 South High Street, 8th Floor
Wailuku, Hawaii 96793

Dear Council Member Hokama,

RE: Hulopo'e Bay 2011 Fourth Quarter Environmental Monitoring: Part A Water Chemistry Monitoring Program Report and Part B Biological Monitoring Program Report

Attached is one (1) copy each of the subject reports, prepared by Richard E. Brock, Ph. D. of the Environment Assessment Company. The reports comprehensively addresses Condition 16 of the approval granted by the Lāna`i Planning Commission on November 7, 2007 for the Special Management Area (SMA) Use Permit & Project District Phase II 5-year Time Extension, request for residential and multi-family development at Manele, Island of Lāna`i, we herewith submit the Hulopo'e Bay 2011 fourth quarter, Part A Water Chemistry Monitoring Program and Part B Biological Monitoring Program Reports. Condition 16 states:

"16. That the applicant continue to submit quarterly monitoring reports of Hulopo'e Bay to the Department of Health, Department of Land & Natural Resources, Hulopo'e Beach Park Council and the County, and shall mitigate and restore any impacts to Class AA Waters."

Should there be any questions or the need for further information, please call me at (808) 244-5432.

Very truly yours,

Ralph Masuda

Ralph Masuda
Vice President of Planning & Zoning

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Wailuku, Hawaii 96793
Telephone: (808) 244-5432
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encl: CD w/ Part A Water Chemistry Monitoring Program Report
Part B Biological Monitoring Program Report

cc: Hulopo'e Beach Park Council – Lettie Castillo
Department of Health Clean Water Branch
Department of Land & Natural Resources
County of Maui, Dept. of Public Works – David Goode
Lanai Public Library
County of Maui, Dept. of Planning – William Spence
Lanaians for Sensible Growth – Ron McOmber
Lanai Planning Commission – c/o William Spence

A QUANTITATIVE ASSESSMENT OF THE MARINE COMMUNITIES AND WATER QUALITY IN AN AREA FRONTING THE HULOPOE - MANELE BAY GOLF COURSE DEVELOPMENT - FOURTH QUARTER 2011

PART A: WATER CHEMISTRY MONITORING PROGRAM REPORT

Prepared For:

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By:

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April 2012

EAC Report No. 2012-09A

EXECUTIVE SUMMARY

This study represents the 78th report monitoring the status of the water chemistry characteristics along a 2.7 km section of coastline fronting the golf course development of approximately 185 ha (458 acres) in and adjacent to Hulopoe Bay, Lana'i. The first five reports (December 1989 through January 1993) collectively detail baseline conditions; the following two reports (June and October 1993) present the "during construction" analysis and the last 71 (December 1993 through December 2011) cover the period since completion of the golf course. The Hulopoe-Manele development is taking the land from a natural state and developing a golf course, housing units and infrastructure. Identified environmental concerns include the potential impact of changes in (1) runoff and sedimentation during construction and (2) water quality due to the subsequent operation of the facilities on the adjacent marine communities and waters fronting the project site.

The studies have been focused on three areas: in Hulopoe Bay which is a Marine Life Conservation District adjacent to the development, in a control area about 4 km to the east (Makole), and at two sites (Huawai Bay and Kaluakoi Point) fronting the golf course just west of Hulopoe Bay. Besides these sites, sampling has been carried out at a number of other locations along the coastline between them. The water quality monitoring encompasses an area from the shoreline to a point more than 700 m offshore. This study monitors 18 sites routinely and an additional three sites at Awehi gulch about 12 km east of Hulopoe Bay. In total, 11 stations sample near shore marine waters fronting the development (the "experimental" sites), 5 stations sample "control" locations removed from the development and 5 stations (including Awehi gulch) are sampled to provide additional information on the spatial variability in the chemistry of near shore waters along the south shore of Lana'i.

This report is presented in two sections. The water quality monitoring results are presented in this section (Part A) and Part B presents the status of the marine life monitoring program. Because this environmental monitoring program is carried out in a Marine Life Conservation District (MLCD), the work requires an annual permit issued by the Department of Land and Natural Resources. Our 2010 permit was not received until 28 April 2010, thus we could not complete the first quarter 2010 field work. Thus the second, third and fourth quarter 2010 field work were carried out in May, October and November. The first quarter 2011 field survey was completed in March 2011. We requested and received our 2011 permit on 8 April 2011 and carried out the second quarter field work in June 2011. Because of the vessel Captain's absence through much of the third quarter, field work was completed on 1-2 November and the fourth quarter fieldwork was done on 13-14 December 2011. This document presents the findings from this most recent field effort. The companion document (Part B) covers the monitoring of marine communities for the December 2011 survey.

Because storm water runoff may strongly influence coastal water quality, three high rainfall events in 2002 are noted herein. These events caused considerable runoff to occur to the ocean along Lanai's south and eastern shores. High turbidity resulted and persisted up to August 2003 (an 18-month period) along the southern shoreline and continued up to June 2005 survey (a 41-month period) on the undeveloped eastern side of the island.

In the December 2011 survey, the geometric means for the monitored parameters (nitrate nitrogen, ammonia nitrogen, total nitrogen, turbidity and chlorophyll-*a*) were out of compliance with state "dry" water quality standards when considering all stations together. Further examination found that the geometric means for nitrate nitrogen, ammonia nitrogen and total nitrogen were out of compliance with dry state standards at the stations fronting the development (i.e., the experimental sites), at control stations and the control stations plus the Awehi stations. Turbidity was out of compliance at stations fronting the development as well as with the control plus Awehi stations and chlorophyll-*a* did not meet state standards at the two control station groups. Otherwise other parameters were in compliance with state water quality standards for dry coastlines for all station groups in the December 2011 survey. There have been only four occasions (the December 1994, June 1996, April 1999 and August 2009 surveys) when the geometric means of all parameters at experimental and control stations were in compliance with state dry coastline standards while only one survey (January 2002) where the geometric means of all parameters were out of compliance at control and experimental stations due to extreme high rainfall and runoff from land. Therefore in all other surveys of the 78 completed thus far, were the geometric means of at least one parameter out of compliance with state standards at one or more station groups.

In general, when a parameter is out of compliance at stations fronting the development, it is usually out of compliance at the control stations which suggests coast-wide trends rather than something happening differentially at stations fronting the development at Hulopoe Bay. However, this generality must be tempered by the finding in the April 2009 survey where the means for both orthophosphorous and total phosphorus were the highest measured to date at stations fronting the development only. Despite not finding the source for this elevation of phosphorus in April 2009, the concentration of phosphorus measured in subsequent surveys found the concentrations of this material had returned to normal and has remained this way at all stations where values were previously elevated demonstrating that the source was transitory. However with the October 2010 survey total phosphorus was elevated at all sampling stations (i.e., at controls and fronting the development) and the greatest means were found at control stations suggesting a coast-wide trend and not something differentially occurring at stations fronting the development. In all subsequent surveys (November 2010, March, June, November and December 2011), total phosphorus had decreased to mean concentrations in the middle to lower part of the range encountered over the 78 surveys to date.

Other than the above elevation of phosphorus in the April 2009 survey at sites fronting the development, examination of the parameter means by survey date measured at stations fronting the development to those at control stations well-removed from development has found that the greatest mean concentrations for all parameters except orthophosphorous, total phosphorus, salinity, temperature and pH were at control stations suggesting that the runoff and subsequent persistence in near shore waters is more severe at control stations. These findings suggest that the best management practices put into place to control runoff as well as the better vegetative cover afforded by the Manele Bay Golf Course probably serve to reduce the inputs to the ocean during high rainfall periods relative to those from the surrounding natural poorly-vegetated terrain. Despite these safeguards, these high rainfall events (like the 7-inch, 24-hour rainfall event as measured at Hulopoe Bay on 29 January 2002) did result in considerable runoff to the sea.

The question "Has there been any significant change in water quality parameters due to the construction and operation of the golf course and continuing residential development at Hulopoe Bay?" has been addressed by conducting statistical analyses from a number of different perspectives. Data considered in these analyses are from the routinely monitored 5 control and 11 experimental stations. The first analysis considers all stations in aggregate (i.e., experimental plus controls) and makes the comparison between sample dates prior to any golf course construction (i.e., the baseline period, December 1989 through January 1993 - five sample periods) to the sample periods during and following completion of the golf course (since January 1993 to present - 73 sample periods). This analysis found statistically significant differences in the mean concentrations of ammonia nitrogen, total nitrogen, silica, salinity, turbidity, percent dissolved oxygen, chlorophyll-*a* and pH. The during- and post-construction means which are significantly greater than the pre-construction means include those for ammonia nitrogen (pre-construction mean = 3.08 ug/l, post-construction mean = 3.20 ug/l), total nitrogen (pre-construction mean = 75.61 ug/l, post-construction mean = 108.39 ug/l), turbidity (pre-construction mean = 0.26 NTU, post-construction mean = 0.47 NTU), silica (pre-construction mean = 84.90 ug/l, post-construction mean = 118.49 ug/l), and salinity (pre-construction mean = 34.497 ppt, all later sample dates mean = 34.746 ppt). Other than turbidity, these differences are well within the normal ranges encountered in Hawaiian waters and have no relationship to the development. In marine settings, both ammonia nitrogen and total nitrogen are derived from a number of sources which are primarily related to community metabolism. The significantly greater post-construction turbidity is not related to the development, but rather to the high rainfall events of 2002-2003. Through the duration of this 264-month study, greatest measured mean turbidity has been found at control stations, well-removed from the development at Hulopoe. These elevated turbidities are probably related to the poor vegetative cover along the natural (undeveloped) sections of the coastline as well as to ineffectual circulation which would normally dilute and transport fine terrigeneous materials out to sea.

The next analysis examined the question, "are there differences in the means of parameters by date that show a chronology related to development?". Other than phosphorus measured in the April 2009 survey, there is no evident statistical separation among the sample period means by date (i.e., prior to and following the start of construction). Furthermore, the highest grand means of most parameters from the control sites are greater relative to the grand means from sites fronting the Hulopoe development consistently through all of the nutrient data to date except for the above-mentioned April 2009 means for orthophosphorous and total phosphorus only at stations fronting the development. Thus the highest grand means for nitrate nitrogen, ammonia nitrogen, total nitrogen, silica, turbidity and chlorophyll-*a* are at control stations. Only the grand means for orthophosphorous, total phosphorus, salinity, temperature and pH have their greatest means at stations fronting the development. The differences in salinity, temperature and pH means between station groups are small and have no biological impact. The greater grand means of other parameters measured at control sites suggest that the runoff has been greater and the subsequent advection/dilution and uptake of materials has been probably less along the undeveloped portions of Lanai's south coast. Greater runoff along the undeveloped sections of the coastline is related to the intensity and amount of local rainfall as well as the amount of vegetative cover and erosion control occurring in the area. The best management practices in place on the project site are probably serving to contain more of the runoff on site than occurs on the natural terrain under similar rainfall regimes.

The next analysis examined the changes in mean concentration of parameters at the 11 stations fronting the development to the 5 control stations over the entire period of this study (December 1989 - December 2011, 78 sample periods). The results of this analysis noted a statistically significant greater mean concentration of chlorophyll-*a* at control stations, a significantly greater mean turbidity at control stations (0.36 NTU versus 0.69 NTU), a significantly greater mean dissolved oxygen concentration at experimental stations (0.3% greater) and temperature at experimental stations (0.4°C greater). Finally, mean nitrate nitrogen at stations fronting the development is significantly greater (2.75 ug/l) relative to the mean at control stations (2.32 ug/l). Despite the statistical separation of nitrate between experimental and control stations, the greatest survey means for nitrate nitrogen occur at the control stations (January 2002 mean = 16.26 ug/l) relative to stations fronting the development (May 2002 mean = 9.88 ug/l). Thus there is a statistical separation, but it is not related to the development.

The next step in the analysis was to make the same examination as directly above, i.e., comparing changes in mean parameter concentrations at experimental stations relative to control stations in the period preceding any golf course construction (i.e., from December 1989 through January 1993). This analysis found that salinity was significantly greater at the experimental stations (i.e., those adjacent to the development, mean = 34.568°/oo) relative to the control stations (mean = 34.432°/oo). Also, the mean percent saturation of dissolved oxygen was significantly greater at the control stations (mean = 102.8%) relative to the experimental stations (mean = 102.1%) in the period preceding golf course construction. These differences are very small relative to the ranges usually encountered in near shore waters and the analysis suggests that there were no changes of any significance in water chemistry parameters that would impact marine biota.

The final statistical analysis carried out in this study compared changes in mean parameter concentrations at control stations relative to the experimental stations in the period subsequent to the commencement of golf course construction (from January 1993 to present, n=73). This analysis found that mean chlorophyll-*a* concentration was significantly greater at control stations (mean = 0.149 ug/l) than at experimental stations adjacent to the golf course (mean = 0.144 ug/l) in the period since construction and operation of the golf course had commenced. Again, mean turbidity measured at control stations (0.71 NTU) was significantly greater than at stations fronting Hulopoe (0.37 NTU); these relatively high turbidities are probably related to the lingering impacts of the 2002 high rainfall/runoff events that occurred around the entire island. In addition, mean temperatures were significantly greater at post-construction experimental stations over the control stations with the difference being 0.4°C and mean dissolved oxygen concentrations were significantly greater at experimental stations (mean = 100.6%) over control stations (mean = 100.4%). Finally, mean nitrate nitrogen is significantly greater at stations fronting the development in the during/post-construction period (2.72 ug/l) relative to the control stations (2.29 ug/l). Despite the statistical separation with nitrate, the greatest survey means for nitrate nitrogen are found at control stations. Again, most of these differences are small, are in the range of natural variability encountered in Hawaiian coastal waters and have no biological impact.

Examination of the means of water quality parameters collected at permanent sample sites by quarterly survey date show considerable variability from quarter to quarter irrespective of proximity to the development at Hulopoe Bay. In most instances, the measured concentrations track between sites fronting the development to those measured at control sites for a given date but variability is high between dates. Water quality samples were collected on two separate occasions spaced one day apart in June 2006 and again in January 2008 to address the question of short-term variability. In the June 2006 survey, the means of four of the twelve parameters were significantly different between the two days and in the January 2008 back-to-back surveys, the means of five parameters were significantly greater on the first day relative to the second day collection. Despite these statistical separations, the numeric differences were not large in the June 2006 dataset while in the January 2008 surveys, these differences were greater. The most important fact to emerge from these closely spaced surveys is that variability in these water quality parameters on short temporal scales appears to be the norm. This being the case underscores the fact that despite statistical separation in parameter means from one survey to the next, this separation is not anything caused by development but is due to the natural variability in the chemistry of coastal waters.

Total nitrogen has shown increases in the 1999-2004 period, a decrease subsequent followed by an increase in December 2006 and January 2007 surveys. Total nitrogen then dipped in the February 2007 survey only to increase in August 2007 and remained elevated until February 2009 when it again dipped, increased in March, dipped in August 2009 but then increased in October 2009 through November 2010 after which it again decreased but in November 2011 through December 2001 it has remained elevated. These oscillations occur at both control and experimental stations. Examination of the measured concentrations at individual stations during some sample dates shows evidence of concentration gradients which greatest concentrations close to land and declining with distance from shore but this gradient is not usually well-defined nor is it always the case in the Lana'i data (there are instances where the gradient is reversed, i.e., being greater offshore). These data could suggest that the elevation of total nitrogen may be from episodic land inputs. Total nitrogen is a measure of all forms of dissolved organic and inorganic nitrogen present in a sample. Approximately 94% of all of the total nitrogen measured in samples from this study is from organic sources. The nitrogen applied to golf courses is usually in the nitrate and ammonium forms both of which are inorganic. Thus a probable source of the past fluctuation and increases in total nitrogen is from plant detritus carried to the sea via storm water runoff due to recent rainfall events. Despite these increases in total nitrogen in this study, the maximum measured concentrations are about half of those measured in oceanic waters below the photic (lighted) zone in offshore Hawaiian waters and changes in local oceanography could bring these waters close to shore which could also be a source for some of the increases seen here thus reversing the gradients as noted above.

Thus, despite the imposition of three high rainfall events causing severe runoff along Lanai's east and southern shores in January, May and October 2002 leading to persisting high turbidity up to the August 2003 survey (an 18-month period), water quality impacted by these runoff events has largely returned to normal. The comparative analysis of the data from this 264-month period of this study support the contention that there has been no significant change to measured water quality parameters that may be attributed to the development and operation of the Manele Bay Golf Course or to the recent residential construction up through the December 2011sample period. However as noted above, the April 2009 survey found the means for both orthophosphorous and total phosphorus to be the highest to date only at stations fronting the development. The distribution of these high measured concentrations of phosphorus suggested that the source may have been from activities on land, but the lack of change in concurrent salinity measurements and the high known sorption of phosphorus to soils does not support this hypothesis. The results of subsequent surveys found that the concentrations of both orthophosphorous and total phosphorus had decreased dramatically at all stations to the low levels measured previously thus the spike in phosphorus may never be known. However in the October 2010 survey, total phosphorus means were elevated at all stations suggesting coast-wide trends but there is no concurrent upward trend with orthophosphorous. Despite the October 2010 increase, the total phosphorus geometric means were within state standards at sample sites fronting the development at Hulopoe. Furthermore in the November 2010 and subsequent surveys (March, June, November and December 2011), mean total phosphorus had declined to the middle and lower part of the range of concentrations measured over the 78 surveys completed to date. In summary, the December 2011 survey has continued to find the quality of the waters fronting the project site as well as the controls as being typical of well-flushed, open Hawaiian coasts.

INTRODUCTION

Purpose

Hulopoe Bay on the south shore of Lana'i has been designated a Marine Life Conservation District (MLCD) because of the exceptional marine communities in the area. With the development of the Manele Bay Hotel fronting the MLCD, concern has surfaced that the construction and subsequent operation of the hotel, infrastructure, adjacent golf course and ongoing residential development would have a negative impact to nearby marine communities and the quality of the surrounding waters. This concern has lead to steps being taken to develop a comprehensive monitoring plan to protect the resources of Hulopoe Bay and environs. As a first step to this monitoring plan, we suggested that a quantitative survey of the biota and extant water quality conditions be conducted to establish baseline conditions against which anthropogenic impacts could be assessed. This first survey was completed in December 1989 (Brock 1990c). The first five surveys (December 1989, October 1991, June 1992, August 1992, and January 1993) comprised the baseline period which spanned a 37-month period and encompassed the impact of a major hurricane in September 1992. Golf course construction commenced in January 1993 and the June 1993 as well as October 1993 surveys covered the period of its construction. Post-golf course construction surveys have been undertaken on a quarterly schedule commencing in December 1993 and continuing up to the present time (December 2011) and will continue during the operation of the golf course as well as during the continuing development of the adjacent residential units.

Scheduling problems in the first quarter of 2006 as well as in the third and fourth quarters of 2007 precluded the collection of samples at those times. Therefore, sampling for both the first and second quarter 2006 as well as the third and fourth quarters of 2007 were each carried out "back-to-back" over a three day period (28-30 June 2006 and on 25-27 January 2008) which afforded the opportunity to examine the variability in data collected in two closely spaced points in time as well as meet the needs of the monitoring program.

The Lana'i environmental monitoring program must have a valid permit issued by the Department of Land and Natural Resources to enter the Hulopoe-Manele MLCD. This permit is issued to specific individuals and an identified vessel is assigned to the permit. Hence the option of switching vessels and captains requires written permission from DLNR which may take considerable time. Furthermore, the presence of surf has a negative impact on the field operation, making in-water surveys difficult if not impossible at some sample locations when the surf is occurring. Thus these problems have resulted in three field surveys being completed in

2007, two surveys finished in 2008 and two back-to-back surveys in March 2009 (to complete the 2008 year) as well as the four surveys finished in 2009. In the afternoon of 3 February while carrying out biological survey work, the author was attacked by an aggressive Hawaiian monk seal (#RO-42) in the western part of Hulopoe Bay. Since the behavior was extremely aggressive, we decided to stop further in-water work until the seal had either moved to another island or was translocated by the National Marine Fisheries Service (NMFS). The seal was subsequently captured by NMFS personnel on 24 February 2009 and later transferred to Nihoa Island. We returned to Lanai to complete two back-to-back surveys in March 2009. Following the October 2009 fourth quarter survey, we returned our 2009 DLNR permit and requested one for 2010. The 2010 permit was finally received on 24 April 2010 thus missing the first quarter of 2010. Field work for the second, third and fourth quarters was carried out in May, October and November 2010 and the first quarter 2011 field work was completed on 9-10 March 2011. The 2010 permit was set to expire at the end of March 2011 so it was returned to DLNR with a request for a 2011 permit which was received on 8 April 2011. The second quarter 2011 survey was completed on 29-30 June 2011 and the absence of the vessel captain precluded carrying out the third quarter field work until late October. The third quarter field work was completed on 1-2 November and the fourth quarterly survey was carried out on 13-14 December 2011; this document presents the water quality findings from this most recent field effort. The companion document (Part B) covers the biological monitoring results for this fourth quarter 2011 survey.

High rainfall in January 2002 created high turbidity; this high turbidity continued to persist along the south and eastern shores of Lanai through the May 2003 survey. At the time of the August 2003 survey, this turbidity had dissipated in the area around the south shore sampling stations but continued to be present (in patches) along the eastern shores of the island until the June 2005 survey. Thus marine communities along the southern shoreline of the island were exposed to highly turbid waters for an 18-month period and on the eastern side for a period between 37 to 41 months.

Strategy

Marine environmental surveys are usually performed to evaluate feasibility of and ecosystem response to specific proposed activities. Appropriate survey methodologies reflect the nature of the proposed action(s). An acute potential impact (as channel dredging) demands a survey designed to determine the route of least harm and the projected rate and degree of ecosystem recovery. Impacts that are more chronic or progressive require different strategies for measurement. Management of chronic stress to a marine ecosystem demands identification of system perturbations which exceed boundaries of natural fluctuations. Thus a thorough understanding of normal ecosystem variability is required in order to separate the impact signal from background "noise".

The potential impacts confronting the Hulopoe Bay marine ecosystem are most probably those associated with chronic or progressive stresses. Other than changes in runoff characteristics caused by the introduction of cattle to Lana'i in the last century, terrigenous input to the bay and environs has probably remained fairly constant due to the dry climate in the watershed. (These inputs are most obvious following heavy rainfall). Direct human impacts on the bay ecosystem, such as fishing pressure and physical damage from vessel anchors, have diminished since the bay was declared a Marine Life Conservation District in 1976. However, there is concern that the modifications to land use in the watershed with resort and golf course construction as well as the nearby residential development may bring alterations to the quantity and quality of the runoff. Recreational activities in the bay could result in additional nutritional subsidies and other impacts to the ecosystem.

Monitoring strategies for assessing chronic stresses rely on comparative spatial and temporal evaluations in relation to ambient conditions. Usually in order to reliably detect system perturbations, detailed quantitative descriptions of the pre-development environment are necessary as a "benchmark" against which later studies may be comparatively analyzed. However, since development (of the hotel) commenced at Hulopoe Bay so that a preconstruction benchmark was not available, an alternative strategy employing comparative analysis of quantitative data taken from a series of temporal (times) and spatial (localities) scales was used to follow the delineation of change as it occurs. Hence the strategy of this study is to conduct comparative analyses of water quality directly fronting the project site and at selected areas well removed to serve as controls. These sites are sampled at a number of points in time. The sampling schedule was established to develop a preliminary baseline (completed in December 1989) with subsequent sampling through wet and dry periods to determine the variability in measured parameters. In total, the first five surveys comprise the baseline against which change may be measured. With the commencement of the construction of the golf course, sampling was undertaken on a quarterly schedule. Over the last several years, residential development has also commenced in the area around the Manele Bay Golf Course. This residential construction is continuing up to the present time thus the 71 water quality surveys that have been completed since construction of the golf course not only monitor the potential impact that the operation of the golf course may be having on the adjacent marine communities but also those that may occur with the ongoing residential construction as well.

Such a sampling strategy should allow the quantitative delineation of changes in Hulopoe Bay and environs if they occur. Relating changes in marine water quality to human activities elsewhere (as on land) may not always be a simple matter when the disturbance is of a chronic nature. However, quarterly monitoring of water chemistry parameters at permanent stations should assist in early detection of problems if the arise. If statistically significant changes are noted in the measured parameters that may require corrective action, management and permit agencies, to the extent required, will be notified so that they may take corrective measures.

MATERIALS AND METHODS

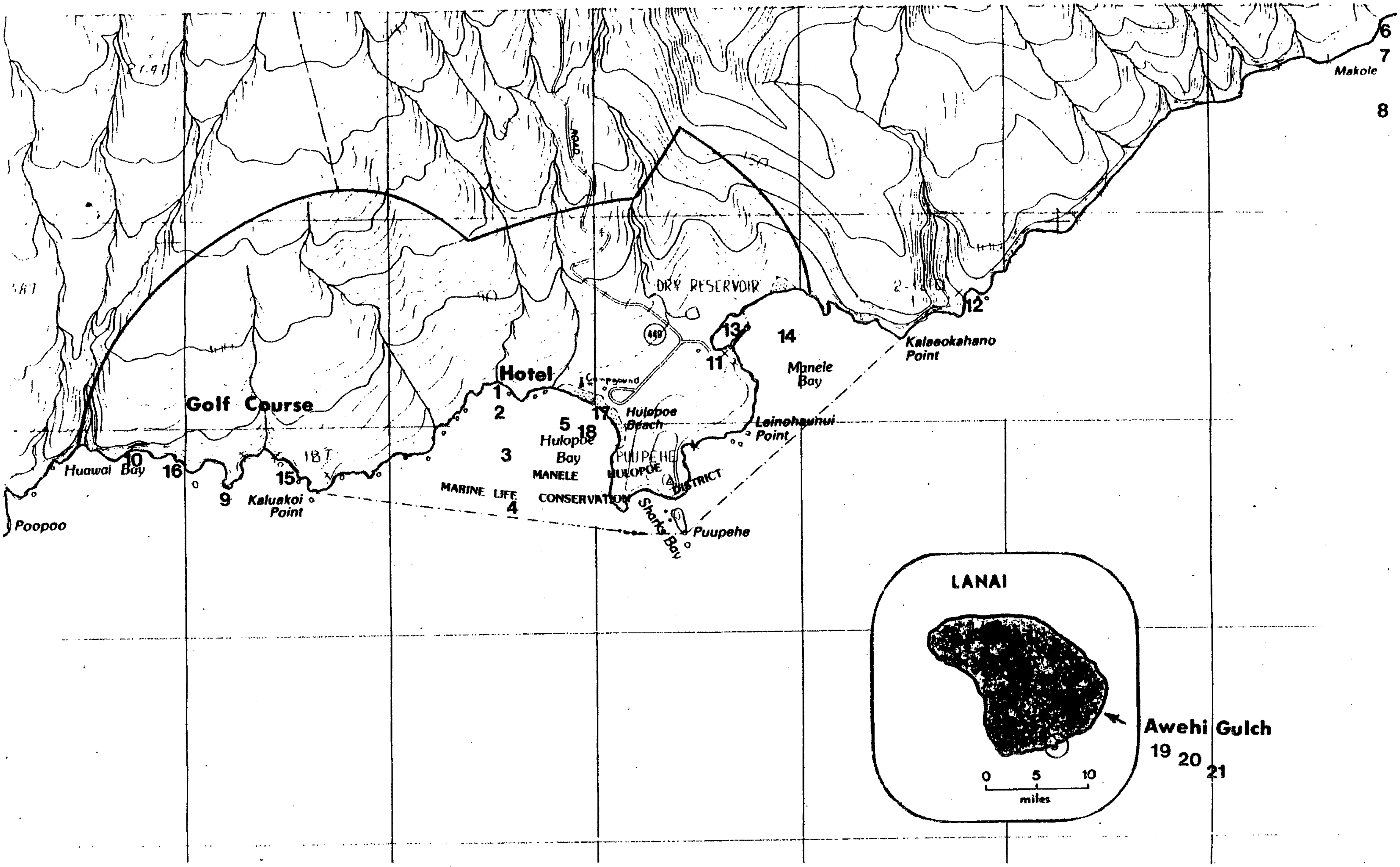
Sample Station Selection

Initially ten water quality sampling stations were established; four of these in Hulopoe Bay were established to sample from shore in a seaward direction through any gradient that might exist fronting the intermittent stream bed at Hulopoe (the Hulopoe gulch just west of the Manele Bay Hotel). These are sites 1 through 4 in Figure 1. Station 1 is in the shore break fronting the gulch, station 2 about 60 m offshore, station 3 at 300 m offshore and station 4 located at the MLCD boundary (about 700 m offshore). Additional locations include a site about 200 m offshore of Hulopoe's sand beach (station 5), and two sites to the west of the bay: at Kaluakoi (station 9) and at Huawai Bay (station 10). Stations 9 and 10 were selected because the (then) proposed golf course was to be constructed on the bluff overlooking these two locations. Both of these stations are near the base of the sea cliff so as to sample any material that may come from the golf course. The control sites (stations 6, 7, and 8) were established again in a shore to seaward direction fronting an unnamed intermittent stream bed near Makole. Station 6 is in the shore break fronting the intermittent stream terminus, station 7 about 100 m offshore and station 8 is approximately 500 m offshore. These sites were selected as controls because of their (1) location on the south coast of Lana'i which is a similar exposure as Hulopoe Bay, (2) distance from any development (Manele Harbor being the closest -- about 6 km to the west), and (3) most importantly, the proximity to an obvious intermittent stream bed.

If the concern is nutrient pollution from human activities, these sources are almost always from land. The usual transport mechanism for these nutrients is water, either from water and nutrients traveling vertically through the soil horizons (via irrigation water) down to seaward flowing groundwater which often enters the ocean at or near the shoreline, or from surface sheet flow which occurs as runoff following heavy rainfall. In this study heavy rainfall is defined as a rainfall event of sufficient magnitude to cause surface runoff to the ocean in sufficient quantity to allow its detection. The majority of this surface runoff will enter the ocean via intermittent streams. Because there is little, if any, groundwater entering the ocean along the south coast of Lana'i (see MacDonald 1940), our sampling focused in areas where runoff might carry materials to the ocean, i.e., near intermittent stream mouths.

The idea of sampling water quality characteristics from shore in a seaward direction (i.e., through any existing gradient) follows the sampling protocol as laid out in the West Hawai'i Monitoring Protocol (1992). In West Hawai'i there is considerable groundwater entering the sea

FIGURE 1. Map of the project site and environs showing the marine life conservation district boundaries for Hulopoe and Manele Bays and the approximate locations of the 21 water quality monitoring stations. Stations 6, 7, 8, 12 and 14 serve as the primary control sites and stations 19-21 offshore of Awehi Gulch are secondary control stations. Station 11 is a freshwater (high level aquifer) source and station 13 monitors the water of Manele Harbor. All other sites monitor the water quality fronting the development at Hulopoe Bay. The inset map of Lana'i Island shows the location of the Hulopoe-Manele district (circled) and the arrow shows the approximate location of Awehi Gulch. Scale: 1 cm = 250 m.



6
7
Makole
8
DRY RESERVOIR
12
Kalaeokahano Point
13
14
Manele Bay
11
Hotel
Golf Course
1
2
5
17
18
Hulopoe Beach
Hulopoe Bay
Leinohaunui Point
3
MANELE
PUUPEHE
HULOPOE
DISTRICT
MARINE LIFE
CONSERVATION
4
Sharks Bay
Puupehe
10
Huawai Bay
16
15
9
Kaluakoi Point
Poopoo
LANAI
Awehi Gulch
19
20
21
0
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10
miles

so there is often a well-developed gradient of low salinity groundwater emanating from land (with possible pollutants) moving seaward and mixing with near shore marine waters. On Lana'i this is not the case. Since materials would, in most instances, be carried to the sea following heavy rainfall (as runoff), the surface layers of the ocean would best show this effect, especially close to shore at the point of entry. Freshwater is less dense than seawater and will overlie the denser more saline marine water thus most of the water quality sampling in this study has focused on the surface layer and many of the stations have been established in an onshore-offshore direction to sample through any potential gradients of materials emanating from land.

Table 1 provides a summary of the chronology of sampling that has occurred at the water quality monitoring stations. Eight water quality sampling stations were added to the original ten in the June 1992 survey (the third of five baseline period sample efforts). In general, these stations were added to provide better spatial coverage of monitoring sites in the experimental and control areas. Increasing the number of sample sites in the third survey (of 78 thus far) has the effect of obtaining a more accurate picture of parameter concentrations. Stations 15, 16, 17, and 18 were placed to give better coverage of sampling in the experimental area (close to development) and two stations (numbers 12 and 14) were away from the development. Station 12 is located at Kalaeokahano Point and station 14 is in Manele Bay. Two other stations were sampled for other reasons; these were numbers 11 and 13. Station 11 represents a sample from a faucet supplying low salinity water to Manele Harbor grounds as well as irrigation for the plantings around the Manele Bay Hotel. The source of this water is from the high level aquifer and it is sampled because it could serve as a carrier for pollutants entering the ocean at the Hulopoe gulch. Data from station 11 is not included in any statistical analysis below. Station 13 is located in Manele Bay Harbor and was established to provide data on the harbor as a potential source of materials entering the more offshore waters of Manele Bay. Again, data from this station (no. 13) is not included in any statistical analysis or geometric mean calculations below.

In February 1994 three stations were added to the water quality sampling regime. These stations are in the waters fronting Awehi gulch about 6.3 km east of Makole. Sample 19 was collected in the wave-wash at the shoreline fronting Awehi Gulch terminus, sample 20 was taken approximately 100 m offshore and sample 21 was collected about 500 m from the shore. The rationale for these stations was to obtain information from an undeveloped drainage system that is considerably larger than either the Hulopoe or Makole drainage basins. The approximate sizes of these drainage basins are: Awehi gulch = 5.07 km^2, Hulopoe gulch = 1.32 km^2, and Makole gulch = 0.65 km^2. Since Awehi gulch is outside of the original study area, the data collected are used for comparative purposes only and are not included in the statistical analyses presented below.

TABLE 1. Chronology of sampling at water quality sampling sites. Note that statistical analyses presented later are carried out only on the first 18 stations. Stations routinely sampled fronting the developed coastline include nos 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18 and as controls station nos 6, 7, 8, 12, and 14. Station nos 19-21 front Awehi Gulch and serve as controls outside of the study area.

	Station Number																				
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
BASELINE PERIOD																					
Dec 89	x	x	x	x	x	x	x	x	x	x	x										
Oct 91	x	x	x	x	x	x	x	x	x	x	x										
Jun 92	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Aug 92	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Jan 93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
DURING GOLF COURSE CONSTRUCTION																					
Jun 93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Oct 93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
POST-CONSTRUCTION PERIOD																					
Dec 93	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Feb 94	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 94	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sep 94	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 94	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar 95	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 95	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sep 95	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 95	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar 96	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 96	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov 96	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 96	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apr 97	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 97	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sep 97	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 97	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar 98	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 98	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov 98	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jan 99	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apr 99	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 99	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sep 99	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jan 00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar 00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sep 00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov 00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 00	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
May 01	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
July 01	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oct 01	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jan 02	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apr 02	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
May 02	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov 02	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar 03	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
May 03	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aug 03	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov 03	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apr 04	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jul 04	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oct 04	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 04	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Feb 05	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun 05	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov 05	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jan 06	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
28 June 06	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
29 June 06	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec 06	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jan 07	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Feb 07	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aug 07	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
25 Jan 08	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
26 Jan 08	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apr-08	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aug-08	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Feb-09	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar-09	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Apr-09	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jul-09	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aug-09	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oct-09	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
May-10	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Oct-10	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov-10	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mar-11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Jun-11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Nov-11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dec-11	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Methods

Unless otherwise noted, samples are collected at the surface (about 20 cm below the air-water interface) to sample any less-saline groundwater that may be entering the ocean. Water quality parameters that were evaluated are specific criteria designated for "open coastal waters" in Title 11, Chapter 54, Amended Administrative Rules for Water Quality Standards. These criteria include ammonia nitrogen, nitrate + nitrite nitrogen, total nitrogen, total phosphorus, chlorophyll-*a* and nephalometric turbidity. Also collected were samples for the non-specific criteria including oxygen, temperature, pH and salinity as well as the nutrients, silica and orthophosphorous at each station.

Water samples are collected in 500 ml acid-washed polyethylene bottles that are triple-rinsed with sample water prior to sample collection. Percent oxygen saturation, pH and temperature are read immediately from these samples. Following this, the water samples are held chilled until returned to the laboratory for further analysis. Subsamples for nutrient analyses are taken in 125 ml acid-washed polyethylene bottles. These samples are filtered through glass fiber filters and are frozen until analysis. Analyses for ammonium, nitrate + nitrite and orthophosphate are carried out using standard techniques; inorganic and total (after oxidation) nutrient analyses are determined using a Techicon AutoAnalyzer. Analyses for total nitrogen and phosphorus are conducted on unfiltered sample water. For purposes of quality assurance/quality control, some samples are collected and measured in duplicate; data are presented as means. The analytical procedures followed those given in Standard Methods (1999), Grasshoff (1983) and Strickland and Parsons (1972).

Turbidity samples are collected as unfiltered water and stored on ice in 125 ml polyethylene bottles until measurements are made. Turbidity is measured on a Monitek Laboratory Nephelometer following the procedures as described in Standard Methods (1999). The instrument is calibrated as specified by the Environmental Protection Agency with standard formazin solutions prior to and after sample measurements. Prior to measurement, samples are throughly mixed to disperse particulate materials and measured in duplicate when all air bubbles disappeared.

Chlorophyll-*a* samples are collected by filtering known volumes of seawater through glass microfiber filters; filters are stored in a frozen state until laboratory analyses are carried out. Laboratory procedures followed Standard Methods (1999) and pigments are extracted and determined fluorometrically. Salinity samples are collected in 125 ml polyethylene bottles in the field, filled completely and capped tightly until measurement on an AGE Salinometer in the laboratory. In the field, oxygen and temperature are measured using a YSI Model 58 meter and pH is determined using a Hanna millivolt pH meter.

RESULTS

A. Geometric Means

Water quality parameters as specified by the State Department of Health (DOH) Water Quality Standards were collected and measured about 20 cm below the water surface at 21 locations along this 9.1 km section of coastline fronting the project site and in a control area for the 13-14 December 2011 survey. An additional site (station 11) is from a faucet at Manele Harbor, station 18 about 200 m offshore of the sand beach at Hulopoe Bay on the bottom (8 m deep) just below station 5, as noted above three samples (nos. 19-21) were collected from the waters fronting Awehi Gulch. Table 2 presents a synopsis of the water chemistry parameters measured at the sample sites on the 13-14 December 2011 survey. In this table, data from the routinely monitored sites (stations 1-18) are separated from the three Awehi gulch stations (nos. 19-21), the Manele Harbor station (no. 13), as well as the single non-marine site (no. 11). The locations of the first 18 monitoring locations are given in Figure 1. Geometric means have been calculated for the routinely monitored sites deleting those as noted above and are given in Table 2. The waters fronting the project site are classified as open coastal waters by the State of Hawai'i (HAR Chapter 11-54) and the standards are given in Table 3 for comparative purposes.

In the 13-14 December 2011 survey, the geometric means for nitrate nitrogen, ammonia nitrogen, total nitrogen, turbidity and chlorophyll-*a* were out of compliance with state "dry" standards when considering all stations together (Table 2). In most previous surveys, the geometric means for turbidity and ammonia nitrogen have exceeded the state "dry" standard (not to exceed) and in some surveys, nitrate nitrogen, total nitrogen and chlorophyll-*a* have also exceeded these standards. In all of the baseline surveys (December 1989 through January 1993 - see Table 4), the geometric means for at least one parameter exceeded the state standards for "dry" coastlines.

In Table 4 geometric means are separated into three categories by sampling date which are: experimental stations fronting the development at Hulopoe Bay (station numbers 1, 2, 3, 4, 5, 9, 10, 15, 16, 17 and 18), control stations without Awehi gulch stations (station numbers 6, 7, 8, 12 and 14) and control stations including Awehi gulch stations (station numbers 6, 7, 8, 12, 14, 19, 20 and 21). The underlined geometric means in Table 4 are those that exceed state standards for "dry" coastlines. In the 13-14 December 2011 survey, the geometric means for nitrate nitrogen, ammonia nitrogen and total nitrogen were out of compliance with state dry standards at all three station groups (i.e., experimental stations fronting the development, control stations as well as with the control plus Awehi stations) while turbidity did not meet standards at the stations fronting the development as well at control plus Awehi station group. Chlorophyll-*a* was out of compliance with dry standards at the control stations and the control plus Awehi gulch stations only (not out of compliance at stations fronting the development). Only the geometric means for

TABLE 2. Summary of the water quality parameters as measured at 21 sites in the study on 13-14 December 2011. In the body of the table concentrations of dissolved nutrients given in ug/l. Geometric means given at the foot of the table for each parameter measured; single underlined values exceed "dry" Department of Health water quality standards. Data from stations not included in the geometric mean analysis are given at the end of the table. ND = Below detection limits.

Station	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [˚C]	Oxygen [% Sat]	pH
1	4.06	6.86	130.34	4.65	10.85	182.84	35.099	1.02	0.295	24.9	99	8.03
2	3.22	3.08	104.86	3.10	9.61	70.84	35.191	0.10	0.127	24.7	100	8.09
3	4.20	1.40	101.92	2.79	9.30	60.20	35.203	0.11	0.132	24.6	100	8.11
4	4.48	0.70	104.58	2.17	9.30	59.36	35.217	0.14	0.116	24.7	101	8.11
5	3.78	0.84	119.84	2.48	10.23	53.48	35.193	0.14	0.118	25.2	100	8.05
6	4.76	10.08	139.44	4.34	11.16	69.44	35.150	0.23	0.189	23.7	99	8.02
7	4.06	2.52	104.02	3.41	10.85	56.56	35.156	0.17	0.195	23.5	100	8.04
8	4.34	4.20	105.56	4.03	11.47	50.68	35.161	0.17	0.210	23.4	101	8.06
9	4.76	0.14	98.28	2.17	10.23	45.08	35.214	0.10	0.115	24.8	100	8.11
10	5.60	6.16	113.54	3.41	10.23	84.84	35.161	0.13	0.110	25.0	100	8.07
12	5.46	4.76	107.94	4.03	9.92	62.44	35.146	0.18	0.158	24.3	100	8.07
14	5.74	0.84	104.30	4.03	11.16	53.20	35.133	0.14	0.192	24.4	99	8.06
15	6.44	5.60	107.52	4.03	9.92	164.92	35.002	0.25	0.169	24.9	99	8.13
16	7.42	5.74	117.74	4.03	10.23	235.76	35.056	0.23	0.171	24.9	99	8.13
17	6.58	6.30	123.62	4.65	11.78	119.84	35.144	1.18	0.294	25.3	99	8.07
18	7.00	1.96	104.86	3.10	9.92	44.80	35.195	0.14	0.102	25.5	99	8.02
Geometric Means	4.98	2.51	111.26	3.43	10.36	76.25	35.151	0.20	0.159	24.6	100	8.07

OTHER SAMPLES

Station	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [˚C]	Oxygen [% Sat]	pH
13	5.74	4.62	123.20	4.65	11.47	116.48	35.166	0.51	0.260	24.3	95	8.05
19	7.28	4.06	112.98	3.41	9.61	41.44	35.179	0.65	0.387	23.5	98	7.93
20	7.56	10.08	113.26	4.34	9.30	45.08	35.194	0.39	0.221	23.7	100	7.87
21	7.42	5.60	102.76	3.72	9.61	36.96	35.205	0.17	0.205	23.9	100	7.95

*NOTE: Chlorophyll-a samples not collected from wells

TABLE 3. Specific criteria specified by the Department of Health water quality standards for open coastal waters as amended in 2004.

Parameter	Geometric mean not to exceed the given value		Not to exceed the given value more than 10% of the time		Not to exceed the given value	
Total Nitrogen	150.00	*	250.00	*	350.00	*
(ug N/L)	110.00	**	180.00	**	250.00	**
Ammonia Nitrogen	3.50	*	8.50	*	15.00	*
(ug NH4-N/L)	2.00	**	5.00	**	9.00	**
Nitrate+Nitrite Nitrogen	5.00	*	14.00	*	25.00	*
(ug[NO3+NO2]-N/L)	3.50	**	10.00	**	20.00	**
Total Phosphorus	20.00	*	40.00	*	60.00	*
(ug P/L)	16.00	**	30.00	**	45.00	**
Chlorophyll-a	0.30	*	0.90	*	1.75	*
(ug/L)	0.15	**	0.50	**	1.00	**
Turbidity (NTU)	0.50	*	1.25	*	2.00	*
	0.20	**	0.50	**	1.00	**

* "Wet" criteria apply when the open coastal waters receive more than three million gallons per day of fresh water discharge per shoreline mile.

** "Dry" criteria apply when the open coastal waters receive less than three million gallons per day of fresh water discharge per shoreline mile.

Applicable to both "wet" and "dry" conditions.

Salinity - Shall not vary more than 10 percent from natural or seasonal changes considering hydrologic input and oceanographic factors.

Orthophosphate was eliminated from the list of requirements in the revised 1988 document but because of its biological importance, it was measured in this study. The old "wet" criteria was 7.00 ug/L and "dry" standard was 5.00ug/L.

TABLE 4. Geometric means calculated for experimental stations (numbers 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18), control stations (numbers 6, 7, 8, 12, 14) and control stations with Awehi gulch stations added (numbers 6, 7, 8, 12, 14, 19, 20, 21). Experimental stations front the development at Hulupoe, control stations are located away from the Hulupoe development. Means exceeding the state standards for dry coastlines are underlined.

Date	Station Group	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [C]	Oxygen [% Sat]	pH
BASELINE													
Dec89	Exp	4.60	2.90	67.18	4.95	9.37	52.43	33.155	0.26	0.424	25.6	99	8.07
	Cont	3.90	1.97	61.70	3.91	8.78	55.87	33.200	0.47	0.540	25.5	101	8.07
Oct91	Exp	2.33	2.69	83.44	4.60	11.04	65.78	34.730	0.26	0.200	27.0	101	8.24
	Cont	1.00	5.17	71.40	5.80	13.31	73.05	34.707	0.25	0.175	29.0	102	8.21
Jun 92	Exp	1.16	1.98	70.70	3.47	9.71	59.59	34.646	0.12	0.100	26.7	102	8.04
	Cont	0.97	2.61	86.45	3.60	9.91	69.47	34.630	0.12	0.110	26.5	102	8.11
Aug92	Exp	2.06	2.44	73.82	3.67	9.70	72.71	34.720	0.11	0.109	27.5	102	8.24
	Cont	1.21	2.41	59.83	3.70	9.34	55.41	34.722	0.12	0.115	27.3	102	8.17
Jan93	Exp	2.12	3.54	81.23	3.50	11.80	78.29	34.822	0.09	0.121	22.6	102	8.12
	Cont	1.72	3.41	77.77	3.39	11.23	120.11	34.810	0.07	0.167	23.7	102	8.12
DURING CONSTRUCTION													
Jun93	Exp	0.91	0.66	83.78	2.53	9.47	35.86	34.565	0.20	0.075	28.1	102	8.06
	Cont	0.34	0.96	86.53	2.54	9.39	52.14	34.597	0.26	0.116	27.2	102	8.15
Oct93	Exp	2.79	2.95	80.15	3.04	8.98	58.34	34.652	0.18	0.082	29.3	102	8.00
	Cont	4.06	4.93	79.55	4.15	9.98	68.27	34.629	0.17	0.112	28.8	103	8.03
AFTER CONSTRUCTION													
Dec93	Exp	1.10	2.03	72.17	3.12	11.49	97.95	34.829	0.09	0.072	25.9	102	8.23
	Cont	0.99	1.57	77.58	3.78	14.18	67.53	34.886	0.09	0.100	25.4	103	8.17
Feb94	Exp	2.46	3.74	80.67	1.57	10.86	90.74	34.699	0.29	0.178	24.5	103	8.06
	Cont	2.55	1.77	80.85	1.92	10.85	86.50	34.668	0.73	0.220	24.4	103	8.14
	Cont w/Awehi	3.40	3.32	88.70	1.94	11.40	86.90	34.506	1.14	0.235	24.3	103	8.12
Jun94	Exp	0.71	4.45	72.34	5.45	9.92	66.25	34.591	0.22	0.105	26.9	103	8.15
	Cont	0.62	7.38	68.20	5.71	10.01	72.01	34.607	0.14	0.120	26.5	102	8.16
	Cont w/Awehi	0.35	4.80	66.95	5.28	9.91	64.36	34.632	0.14	0.121	26.4	102	8.18
Sep94	Exp	1.09	1.47	59.82	3.23	8.34	59.15	34.558	0.17	0.104	28.6	103	8.01
	Cont	1.65	0.84	63.98	3.77	8.06	88.25	34.545	0.23	0.128	28.3	102	8.05
	Cont w/Awehi	1.51	1.83	71.40	3.95	8.57	77.90	34.542	0.21	0.131	28.0	102	8.03
Dec94	Exp	1.33	1.20	67.10	2.87	12.20	88.56	34.781	0.07	0.108	24.9	103	8.10
	Cont	0.91	ND	67.75	3.06	11.25	75.83	34.662	0.07	0.123	24.7	103	8.11
	Cont w/Awehi	0.94	ND	70.92	2.99	11.72	72.80	34.772	0.07	0.136	24.7	103	8.10
Mar95	Exp	0.90	2.85	46.76	4.63	13.13	71.54	34.448	0.10	0.049	24.5	102	8.08
	Cont	2.01	1.56	58.18	6.93	14.51	92.35	34.428	0.12	0.115	24.1	102	8.11
	Cont w/Awehi	1.55	1.45	51.45	6.20	13.83	78.04	34.507	0.13	0.122	23.8	102	8.10
Jun95	Exp	0.79	2.87	133.68	4.04	13.79	80.42	35.411	0.11	0.173	27.0	102	8.04
	Cont	1.29	1.98	141.67	4.44	13.76	77.72	35.376	0.16	0.216	26.7	102	8.09
	Cont w/Awehi	1.51	2.62	141.96	4.63	13.46	79.38	35.516	0.14	0.208	26.5	102	8.07
Sep95	Exp	4.47	9.11	66.95	4.99	13.00	80.40	34.447	0.13	0.175	28.0	102	8.13
	Cont	2.66	7.17	79.56	4.51	12.86	62.46	34.463	0.14	0.256	27.5	102	8.09
	Cont w/Awehi	3.01	7.29	83.07	5.33	13.59	59.83	34.520	0.16	0.264	27.3	102	8.06

TABLE 4. Continued

Date	Station Group	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [C]	Oxygen [% Sat]	pH
Dec95	Exp	1.04	5.81	75.50	5.17	9.57	81.81	34.239	0.10	0.136	26.1	102	8.12
	Cont	1.36	4.88	73.77	5.11	8.53	68.45	34.278	0.11	0.167	25.6	103	8.08
	Cont w/Awehi	1.19	5.22	75.43	4.97	8.89	54.27	34.312	0.03	0.159	25.3	101	8.06
Mar96	Exp	0.99	2.19	73.92	5.38	12.35	72.57	33.541	0.13	0.090	24.5	102	8.11
	Cont	1.73	1.19	77.49	4.70	10.66	129.67	33.571	0.38	0.162	24.3	102	8.10
	Cont w/Awehi	1.41	1.68	79.52	4.72	11.37	102.36	33.590	0.27	0.160	24.1	102	8.08
Jun96	Exp	1.00	1.55	81.75	3.33	8.59	41.29	34.860	0.09	0.050	27.4	102	8.03
	Cont	1.57	1.62	83.69	3.23	8.37	63.13	34.880	0.12	0.080	27.0	102	8.11
	Cont w/Awehi	1.32	1.51	81.38	2.87	7.19	51.23	34.910	0.11	0.080	26.8	103	8.08
Nov96	Exp	2.43	2.28	84.21	2.81	12.59	42.58	34.165	0.34	0.106	27.2	102	8.00
	Cont	1.45	1.11	83.83	2.83	11.13	90.24	34.160	0.47	0.104	27.4	102	7.99
	Cont w/Awehi	1.75	1.13	82.15	2.88	10.86	108.81	34.167	0.44	0.100	27.3	102	7.99
Dec96	Exp	2.53	2.34	75.53	4.60	9.68	77.59	34.740	0.10	0.110	25.3	102	8.17
	Cont	1.38	1.35	74.83	3.74	9.58	75.60	34.760	0.20	0.150	25.1	102	8.07
	Cont w/Awehi	1.60	1.65	76.87	3.67	9.10	83.95	34.758	0.17	0.179	24.9	102	8.08
Apr97	Exp	1.22	2.60	91.45	2.19	9.30	127.83	34.272	0.18	0.156	26.4	102	8.07
	Cont	1.03	2.21	91.72	1.42	8.48	131.50	34.299	0.21	0.126	25.6	102	8.09
	Cont w/Awehi	1.02	2.55	98.29	1.50	8.67	111.38	34.421	0.20	0.147	25.2	102	8.10
Jun97	Exp	1.27	2.68	92.43	1.92	9.04	239.10	34.261	0.25	0.169	26.6	103	8.09
	Cont	1.05	2.30	93.17	1.33	8.17	210.03	34.257	0.37	0.135	26.4	102	8.08
	Cont w/Awehi	1.03	2.65	99.87	1.29	8.35	175.67	34.370	0.33	0.170	26.2	102	8.08
Sep97	Exp	1.38	11.36	98.94	1.54	8.01	22.53	34.389	0.22	0.184	28.1	102	8.11
	Cont	1.87	6.51	87.80	1.32	7.58	35.67	34.373	0.28	0.127	27.5	102	8.12
	Cont w/Awehi	1.48	9.72	105.45	1.74	7.97	22.61	34.407	0.23	0.119	27.4	101	8.11
Dec97	Exp	2.02	1.68	92.57	3.56	9.37	140.12	34.903	0.15	0.179	24.7	102	8.19
	Cont	3.83	3.37	94.11	3.57	9.17	130.14	34.894	0.14	0.103	25.0	101	8.21
	Cont w/Awehi	2.92	2.47	97.40	3.90	10.04	102.63	34.902	0.14	0.113	24.8	102	8.20
Mar98	Exp	2.68	10.72	83.53	3.73	12.70	225.17	34.828	0.09	0.071	25.4	102	8.10
	Cont	2.18	7.59	78.92	4.13	13.35	182.77	34.872	0.09	0.098	25.2	101	8.08
	Cont w/Awehi	1.86	9.14	86.35	4.40	12.52	170.89	34.873	0.11	0.108	25.0	102	8.07
Jun98	Exp	1.17	12.28	73.00	2.69	3.98	213.09	35.078	0.03	0.080	25.8	102	8.12
	Cont	ND	12.16	74.27	2.66	4.95	293.10	34.986	0.03	0.127	25.1	101	8.12
	Cont w/Awehi	ND	11.93	74.34	2.13	4.15	236.39	34.990	0.03	0.125	24.9	101	8.12
Nov98	Exp	1.57	4.63	99.04	3.47	9.97	167.51	35.026	0.04	0.078	26.6	102	8.09
	Cont	1.14	1.54	99.66	9.03	22.15	130.28	35.047	0.06	0.083	26.3	102	8.12
	Cont w/Awehi	1.09	2.07	100.76	5.09	17.37	143.30	35.048	0.07	0.083	26.2	102	8.14
Jan99	Exp	2.37	7.58	130.57	3.65	6.43	175.72	35.118	0.13	0.048	24.9	102	8.19
	Cont	2.97	9.17	120.05	3.90	7.39	161.26	35.161	0.16	0.059	24.3	101	8.15
	Cont w/Awehi	2.55	13.87	108.97	3.44	7.93	145.52	35.163	0.15	0.062	24.2	101	8.13
Apr99	Exp	1.92	1.97	106.20	5.51	7.07	186.99	33.917	0.17	0.061	24.8	102	8.15
	Cont	1.24	1.41	106.64	8.12	9.62	194.76	34.005	0.14	0.066	24.2	102	8.18
	Cont w/Awehi	1.04	1.54	101.43	6.18	8.82	164.89	34.022	0.14	0.063	24.0	102	8.17

TABLE 4. Continued

Date	Station Group	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [C]	Oxygen [% Sat]	pH
Jun99	Exp	1.85	3.57	90.48	1.31	4.48	138.66	34.432	0.07	0.053	26.4	102	8.12
	Cont	2.18	5.59	97.85	1.12	5.22	160.50	34.346	0.05	0.057	25.7	102	8.16
	Cont w/Awehi	2.29	4.88	99.93	1.40	5.65	145.05	34.341	0.05	0.056	25.6	102	8.12
Sep99	Exp	1.56	2.17	99.98	3.98	12.42	83.54	35.003	0.21	0.115	26.6	101	8.02
	Cont	0.95	1.92	93.82	3.82	11.96	58.59	35.057	0.18	0.143	25.7	101	8.06
	Cont w/Awehi	1.17	2.42	98.19	3.90	11.77	52.39	35.066	0.18	0.137	25.6	101	8.03
Jan00	Exp	1.34	1.36	103.46	3.21	12.76	82.00	35.119	0.12	0.137	23.7	101	8.18
	Cont	0.88	1.10	104.69	3.09	12.96	67.44	35.144	0.12	0.199	22.7	102	8.18
	Cont w/Awehi	1.16	1.42	105.64	2.96	12.82	73.71	35.149	0.12	0.192	22.8	101	8.17
Mar00	Exp	1.33	1.87	111.38	4.16	12.60	70.89	35.052	0.12	0.095	24.5	102	8.12
	Cont	1.42	1.46	112.31	3.51	12.47	53.80	35.062	0.13	0.130	23.8	101	8.13
	Cont w/Awehi	0.84	1.54	107.52	2.79	10.54	38.01	35.078	0.10	0.139	23.7	101	8.06
Sep00	Exp	1.79	1.94	107.40	3.79	11.88	93.79	34.907	0.17	0.075	27.6	102	8.10
	Cont	1.42	2.03	115.55	3.75	12.08	81.56	34.918	0.19	0.084	27.2	102	8.13
	Cont w/Awehi	1.26	2.48	118.60	3.72	11.85	66.73	34.944	0.19	0.096	27.0	102	8.11
Nov00	Exp	3.01	2.31	94.79	3.45	11.56	87.34	35.056	0.13	0.130	26.3	101	8.18
	Cont	1.21	2.87	94.36	3.61	11.77	66.42	35.100	0.19	0.147	25.6	101	8.15
	Cont w/Awehi	1.39	3.07	100.18	3.95	12.19	63.67	35.110	0.17	0.131	25.4	101	8.14
Dec00	Exp	1.58	2.27	90.11	2.84	12.69	85.55	34.813	0.12	0.061	26.1	102	8.13
	Cont	0.84	2.54	92.32	2.37	12.02	60.94	34.927	0.16	0.082	25.5	101	8.11
	Cont w/Awehi	0.82	2.54	92.69	2.30	12.23	52.76	34.924	0.14	0.076	25.6	101	8.09
May01	Exp	0.80	0.69	178.33	5.47	12.37	129.24	34.860	0.16	0.081	26.3	101	8.12
	Cont	1.44	0.90	148.58	5.74	12.89	116.29	34.830	0.28	0.102	25.7	101	8.13
	Cont w/Awehi	0.98	1.36	155.52	5.62	12.88	93.62	34.835	0.24	0.101	25.5	101	8.09
July01	Exp	1.18	1.69	160.60	3.48	11.94	98.84	34.916	0.16	0.115	27.4	101	8.06
	Cont	1.69	1.56	158.65	3.72	11.52	102.51	34.905	0.19	0.163	26.5	101	8.06
	Cont w/Awehi	1.53	1.65	167.27	3.83	11.69	80.41	34.904	0.16	0.198	26.2	101	8.04
Oct01	Exp	3.82	1.56	110.96	4.16	10.24	85.82	35.069	0.13	0.222	26.8	100	8.14
	Cont	3.75	1.04	98.61	3.95	10.21	90.11	35.066	8.20	0.178	26.0	99	8.20
	Cont w/Awehi	3.59	1.24	100.42	3.92	10.93	67.83	35.080	8.16	0.214	26.0	100	8.16
Jan02	Exp	6.75	5.25	193.66	5.11	24.11	224.51	34.377	3.63	0.234	24.4	100	8.02
	Cont	15.14	8.49	254.39	4.42	30.40	289.66	34.021	6.37	0.184	24.1	100	7.97
	Cont w/Awehi	13.52	12.94	277.24	4.11	32.55	284.94	34.131	7.95	0.236	24.1	100	7.95
Apr02	Exp	1.35	1.88	98.62	5.11	10.76	114.93	34.875	0.36	0.192	25.8	100	7.95
	Cont	1.49	2.85	107.09	6.28	12.94	93.96	34.886	0.75	0.165	25.4	99	8.03
	Cont w/Awehi	1.25	3.05	120.07	5.66	12.21	78.23	34.895	0.69	0.219	25.1	99	8.02
May02	Exp	9.11	2.42	128.77	5.76	13.31	95.74	34.701	0.36	0.180	27.3	99	7.91
	Cont	8.56	3.49	138.93	7.12	14.83	97.66	34.716	0.78	0.150	26.8	99	8.05
	Cont w/Awehi	9.32	4.18	138.96	6.99	12.85	81.29	34.732	0.60	0.185	26.5	99	8.04
Nov02	Exp	0.62	1.44	181.18	4.23	12.58	113.70	35.057	0.43	0.277	27.1	98	7.94
	Cont	0.82	2.49	293.69	5.95	17.00	109.77	35.063	0.60	0.159	26.9	98	8.04
	Cont w/Awehi	1.25	3.37	239.78	6.09	17.09	116.71	35.065	0.69	0.188	26.6	97	8.05
Mar03	Exp	1.59	1.18	192.76	5.03	13.39	112.81	34.599	0.44	0.208	25.9	99	8.06
	Cont	2.23	1.73	202.09	5.11	13.31	90.25	34.589	0.96	0.155	25.6	98	8.11
	Cont w/Awehi	2.05	1.49	187.24	4.67	12.41	79.18	34.591	0.51	0.160	25.3	98	8.10

TABLE 4. Continued

Date	Station Group	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [C]	Oxygen [% Sat]	pH
May03	Exp	1.51	3.94	97.07	4.59	11.36	84.15	34.960	0.28	0.097	26.0	98	8.23
	Cont	1.50	4.28	90.79	4.72	13.39	84.00	35.043	0.58	0.156	25.6	98	8.21
	Cont w/Awehi	0.92	2.52	103.50	4.31	12.10	68.17	35.052	0.49	0.142	25.5	98	8.21
Aug03	Exp	1.62	1.75	132.27	2.89	7.30	99.85	34.916	0.32	0.102	27.5	99	8.10
	Cont	1.35	3.28	153.05	2.77	7.77	91.34	34.935	0.25	0.097	26.9	98	8.13
	Cont w/Awehi	1.32	2.70	141.79	2.37	7.30	81.44	34.931	0.27	0.104	26.8	98	8.13
Nov03	Exp	2.45	0.70	102.18	5.11	9.22	93.03	35.012	0.23	0.106	26.4	99	8.12
	Cont	1.18	1.82	93.98	4.47	9.47	69.10	35.060	0.23	0.141	25.9	100	8.14
	Cont w/Awehi	2.04	2.11	106.07	4.69	9.71	66.58	35.066	0.35	0.159	25.8	100	8.12
Apr04	Exp	1.72	1.31	94.77	4.41	9.09	105.15	29.817	0.18	0.058	26.3	98	8.10
	Cont	0.94	1.83	90.76	3.81	8.69	90.99	30.106	0.47	0.088	26.0	99	8.09
	Cont w/Awehi	0.74	1.88	94.18	3.69	9.46	84.08	30.152	0.43	0.092	25.7	99	8.10
Jul04	Exp	1.10	0.89	103.27	2.46	8.91	55.33	34.645	0.28	0.096	27.9	100	8.09
	Cont	0.99	0.92	98.00	2.63	8.63	55.44	34.638	0.45	0.099	27.5	100	8.14
	Cont w/Awehi	0.97	0.75	103.25	2.49	7.99	44.98	34.645	0.46	0.106	27.2	100	8.13
Oct04	Exp	2.19	0.85	97.27	3.32	8.02	90.97	34.829	0.21	0.120	27.2	100	8.13
	Cont	1.48	0.41	99.79	3.16	7.94	85.24	34.834	0.19	0.118	27.6	99	8.12
	Cont w/Awehi	1.62	0.61	106.99	3.68	8.14	74.19	34.836	0.18	0.139	27.4	100	8.10
Dec04	Exp	1.39	0.59	116.15	2.22	9.72	74.28	34.866	0.14	0.133	25.9	101	8.10
	Cont	1.35	0.18	98.52	2.06	9.22	71.22	34.864	0.16	0.144	25.6	101	8.13
	Cont w/Awehi	1.35	0.34	97.53	2.07	9.10	59.59	34.872	0.16	0.148	25.4	101	8.12
Feb05	Exp	2.94	1.30	98.59	4.01	7.84	175.56	34.678	0.17	0.093	25.5	100	8.12
	Cont	2.45	0.99	107.87	4.03	8.14	153.32	34.765	0.18	0.134	25.0	100	8.12
	Cont w/Awehi	2.68	1.38	98.08	4.06	7.98	144.17	34.819	0.27	0.195	24.7	100	8.11
Jun05	Exp	0.53	1.38	82.52	3.92	7.89	67.25	34.787	0.16	0.114	27.1	100	8.00
	Cont	0.56	1.43	73.59	3.96	7.50	70.10	34.773	0.23	0.093	26.0	101	8.01
	Cont w/Awehi	1.25	1.12	88.93	3.82	7.40	53.05	34.794	0.22	0.099	25.8	100	8.01
Nov05	Exp	2.86	1.92	76.29	4.04	12.83	60.99	34.964	0.26	0.162	25.9	100	8.05
	Cont	1.74	1.53	59.23	3.16	10.80	65.14	34.975	0.23	0.128	26.2	100	8.06
	Cont w/Awehi	2.36	1.66	65.23	3.16	10.81	50.06	34.980	0.25	0.143	26.0	100	8.05
Jan06	Exp	0.32	0.69	83.96	3.38	8.73	175.48	35.008	0.15	0.125	25.1	100	8.10
	Cont	0.74	0.57	83.16	2.95	8.74	171.02	35.013	0.17	0.123	25.1	101	8.07
	Cont w/Awehi	0.51	0.94	88.06	3.32	9.01	139.95	35.017	0.23	0.152	25.0	101	8.08
28 June 06	Exp	2.69	1.86	95.95	4.71	13.89	77.62	34.798	0.14	0.113	26.5	99	8.05
	Cont	1.77	2.58	85.39	6.27	13.06	80.36	34.551	0.23	0.120	25.4	100	8.06
	Cont w/Awehi	0.75	2.51	88.19	5.85	13.00	52.84	34.657	0.29	0.165	25.3	100	8.03
29 June 06	Exp	0.81	1.93	90.83	4.24	12.70	44.54	34.789	0.15	0.108	26.9	100	8.10
	Cont	0.82	1.68	88.43	4.24	12.88	27.78	34.829	0.23	0.200	25.9	100	8.10
	Cont w/Awehi	1.42	1.97	90.90	4.17	12.68	19.77	34.833	0.27	0.216	25.6	99	8.09
Dec06	Exp	2.96	1.06	133.55	1.71	4.87	60.90	34.924	0.08	0.182	26.2	99	8.08
	Cont	0.69	0.79	153.34	1.63	5.61	34.26	34.963	0.10	0.180	26.0	99	8.06
	Cont w/Awehi	0.40	0.80	170.10	1.69	5.76	32.54	34.962	0.14	0.194	25.8	99	8.06
Jan07	Exp	1.19	1.10	211.46	5.09	12.33	119.44	34.952	0.15	0.172	25.6	99	8.04
	Cont	0.48	0.43	223.24	4.61	12.93	145.96	34.969	0.20	0.151	24.8	99	8.04
	Cont w/Awehi	0.40	0.80	211.79	4.55	12.48	107.81	34.976	0.24	0.179	24.8	99	8.02

TABLE 4. Continued

Date	Station Group	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [C]	Oxygen [% Sat]	pH
Feb07	Exp	6.89	0.76	93.19	4.22	9.65	121.87	34.984	0.23	0.195	24.7	100	8.12
	Cont	4.86	0.22	87.74	5.38	9.23	94.95	35.022	0.24	0.171	24.5	99	8.07
	Cont w/Awehi	5.21	0.34	89.08	4.52	7.80	83.63	35.023	0.24	0.175	24.2	99	8.05
Aug07	Exp	0.45	1.17	119.61	3.38	10.45	64.02	34.951	0.13	0.132	27.2	100	8.08
	Cont	0.61	0.92	130.70	3.49	10.80	74.67	34.948	0.24	0.154	26.7	99	8.04
	Cont w/Awehi	0.44	0.47	130.64	3.39	10.21	67.87	34.955	0.25	0.157	26.7	99	8.03
25 Jan 08	Exp	2.06	1.58	168.07	3.98	11.96	222.10	34.978	0.14	0.136	24.9	100	8.14
	Cont	1.24	1.62	172.59	4.61	12.45	182.09	35.059	0.25	0.179	24.3	99	8.10
	Cont w/Awehi	1.32	1.71	178.59	4.91	11.70	163.82	35.068	0.25	0.164	24.1	99	8.10
26 Jan 08	Exp	1.84	0.67	150.49	4.20	10.01	128.78	35.030	0.15	0.178	24.5	99	8.13
	Cont	1.68	0.67	130.08	3.92	9.91	123.34	35.058	0.24	0.110	24.7	98	8.11
	Cont w/Awehi	1.62	0.53	143.33	4.06	10.15	115.30	35.060	0.34	0.120	24.3	99	8.09
Apr-08	Exp	3.39	9.07	102.84	4.24	10.49	123.49	34.587	0.14	0.179	24.0	100	8.10
	Cont	2.38	11.87	98.17	2.97	9.89	78.60	34.875	0.21	0.224	24.0	99	8.08
	Cont w/Awehi	2.27	13.80	107.68	2.77	10.18	69.37	34.926	0.29	0.258	24.1	99	8.05
Aug-08	Exp	0.95	0.73	144.09	1.25	9.65	71.27	34.972	0.31	0.149	26.8	99	8.11
	Cont	0.40	0.75	144.51	1.37	10.00	72.64	34.967	0.30	0.129	26.6	99	8.08
	Cont w/Awehi	0.37	0.01	141.87	1.52	9.93	65.25	34.976	0.40	0.152	26.4	99	8.08
Feb-09	Exp	4.49	0.58	73.17	2.87	10.76	99.38	35.075	0.11	0.159	23.7	100	8.11
	Cont	3.22	0.49	69.59	3.19	11.09	76.84	35.111	0.14	0.236	22.8	100	8.09
	Cont w/Awehi	3.08	0.82	80.21	3.20	11.86	73.19	35.103	0.29	0.283	23.1	100	8.09
Mar-09	Exp	2.11	1.09	105.63	2.61	9.03	145.75	35.095	0.20	0.166	23.9	99	8.12
	Cont	0.96	0.87	104.70	2.70	9.52	97.30	35.150	0.22	0.242	23.4	99	8.11
	Cont w/Awehi	0.94	0.83	115.56	2.69	9.63	83.42	35.158	0.25	0.256	23.3	99	8.10
Apr-09	Exp	2.60	1.43	83.48	16.73	37.14	193.19	35.112	0.18	0.133	23.8	100	8.13
	Cont	1.38	1.38	84.44	5.35	11.90	90.27	35.164	0.17	0.114	23.2	100	8.09
	Cont w/Awehi	1.55	1.27	88.68	5.15	10.89	77.94	35.179	0.18	0.144	23.0	100	8.08
Jul-09	Exp	2.34	1.54	126.60	4.96	11.49	121.36	34.958	0.16	0.086	26.7	99	8.07
	Cont	1.74	1.65	137.58	4.83	11.65	101.33	35.030	0.15	0.124	26.0	99	8.08
	Cont w/Awehi	1.65	1.46	132.75	4.91	10.73	82.07	35.065	0.14	0.139	25.5	99	8.05
Aug-09	Exp	2.11	0.92	91.72	4.90	11.93	83.56	35.037	0.15	0.128	26.3	99	8.09
	Cont	1.93	0.78	96.81	4.78	12.08	81.13	35.027	0.15	0.104	26.1	99	8.06
	Cont w/Awehi	1.89	0.99	106.95	4.75	11.92	74.20	35.030	0.15	0.123	26.1	99	8.05
Oct-09	Exp	1.28	0.69	128.92	3.80	11.40	89.60	35.253	0.18	0.149	26.9	100	8.08
	Cont	1.24	0.62	124.81	4.18	12.12	112.43	35.211	0.19	0.140	26.2	99	8.09
	Cont w/Awehi	1.40	0.93	133.32	4.15	11.54	92.40	35.212	0.19	0.161	26.0	99	8.07
May-10	Exp	2.96	1.00	118.10	4.37	11.09	138.49	35.000	0.25	0.145	24.9	100	8.10
	Cont	1.08	1.00	117.13	4.10	11.09	117.22	35.033	0.25	0.143	24.5	99	8.07
	Cont w/Awehi	1.42	1.19	137.77	4.06	11.37	102.82	35.055	0.30	0.166	24.5	99	8.05
Oct-10	Exp	2.83	1.10	138.01	3.76	15.41	77.41	35.053	0.16	0.125	25.8	99	8.10
	Cont	1.93	0.86	140.95	3.44	16.84	58.53	35.079	0.18	0.180	25.4	99	8.08
	Cont w/Awehi	1.66	0.90	138.55	3.34	16.67	55.10	35.084	0.19	0.196	25.4	99	8.08
Nov-10	Exp	2.78	1.19	129.60	3.47	10.54	95.11	35.081	0.13	0.081	25.9	99	8.10
	Cont	2.04	0.68	137.74	3.42	11.68	107.99	35.089	0.21	0.126	24.8	99	8.06
	Cont w/Awehi	2.46	1.05	139.87	3.69	11.38	90.24	35.102	0.18	0.127	25.0	99	8.04

TABLE 4. Continued

Date	Station Group	Nitrate N	Ammonia N	Total N	Ortho-P	Total P	Silicate	Salinity [o/oo]	Turbidity [NTU]	Chlorophyll a (ug/l)	Temp [C]	Oxygen [% Sat]	pH
Mar-11	Exp	2.88	1.99	91.98	2.02	9.43	160.32	35.140	0.22	0.178	25.2	98	8.06
	Cont	0.98	2.96	87.80	2.04	9.74	108.43	35.170	0.38	0.217	24.3	98	7.83
	Cont w/Awehi	1.32	4.99	96.32	2.43	10.17	105.48	35.170	0.47	0.256	24.2	98	7.89
Jun-11	Exp	0.75	1.48	73.97	4.86	12.03	115.54	34.775	0.16	0.081	25.5	100	8.02
	Cont	1.08	1.14	75.60	4.88	12.21	122.85	34.808	0.24	0.151	24.9	99	8.01
	Cont w/Awehi	1.30	1.27	80.05	4.66	11.71	112.24	34.823	0.30	0.152	24.8	99	7.99
Nov-11	Exp	1.21	1.01	105.60	3.05	9.90	79.74	35.114	0.28	0.172	25.9	98	8.02
	Cont	0.74	0.44	95.09	2.20	8.93	72.99	35.123	0.26	0.171	25.5	99	8.04
	Cont w/Awehi	1.34	1.23	104.24	3.83	10.86	124.27	35.129	0.23	0.205	25.4	99	7.84
Dec-11	Exp	5.05	2.20	111.14	3.21	10.12	86.29	35.152	0.21	0.148	25.0	100	8.08
	Cont	4.83	3.36	111.50	3.96	10.90	58.09	35.149	0.18	0.188	23.9	100	8.05
	Cont w/Awehi	5.67	4.21	110.77	3.90	10.35	50.98	35.165	0.23	0.212	23.8	100	8.00

the parameter total phosphorus were in compliance at all three station groups in the December 2011 survey (Table 4). It should be noted that only on four occasions (December 1994, June 1996, April 1999 and August 2009) were all parameters at experimental and control stations in compliance with the state dry standards while only once (January 2002) were all parameters out of compliance at control and experimental stations due to extreme high rainfall and runoff.

There have been 78 different survey periods since the commencement of this monitoring program. In all but four occasions one or more parameters have not met the state dry coastline water quality standards thus lack of compliance appears to be commonplace. Total nitrogen has been out of compliance on twenty-seven surveys; in two surveys the lack of compliance in total nitrogen occurred only at experimental stations fronting the development, in three surveys the noncompliance occurred at control stations only and on twenty-two surveys the lack of compliance with total nitrogen occurred at both stations groups. Interestingly, most of the noncompliance with total nitrogen has occurred in the 2001-2003 period and again in the December 2006-November 2010 period (see discussion below).

In general, if a parameter is out of compliance on a particular date, the lack of compliance occurs among both the control and experimental station groups (Table 4). Examples supporting this statement are found with most parameters. In the baseline period, both turbidity and chlorophyll-*a* were out of compliance during two of the five baseline surveys at both control and experimental (i.e., those fronting the development) stations and at one additional period at control stations only. Since the commencement of construction at Hulopoe Bay in January 1993, turbidity has been out of compliance on 27 occasions at stations fronting the development and on 44 occasions at control stations. Examining these during construction data further (Table 4), turbidity was out of compliance on three occasions at stations fronting development only, twenty instances at control stations only and twenty-four occasions at both the control and Hulopoe Bay stations. These data suggest that if noncompliance in turbidity is going to occur along the south coast of Lana'i Island, it occurs on a coast-wide basis rather than just at stations fronting the development only. Examining turbidity further in many of the past surveys, higher turbidity occurs during wave events as well as following high rainfall events. Impinging surf serves to resuspend particulate materials already in the marine environment. Surf emanating from the WSW through the ESE is not unusual and thus finding noncompliance in turbidity at all or some of the three groups of stations is not unexpected.

Inspection of Table 4 indicates that turbidity has been out of compliance with every station group during all surveys since October 2001 survey up until the October 2004 survey. During this time period many of the noncompliant turbidity geometric means were found at control stations both with and without Awehi Gulch stations (Table 4) suggesting that the lingering impacts of the 29 January 2002 and subsequent 2002 rainfall events were more apparent at these stations than at stations fronting the development at Hulopoe Bay. The lack of compliance with state standards is not unexpected given the fact that turbid water from the January 2002 and later rainfall events persisted until August 2003 along the south side of the island and turbidity continued to persist along the eastern shoreline up to just before the June 2005 survey. What is surprising is the fact that high turbidity waters persisted along the south side of Lana'i for 18 months. In January 2002, all parameters were out of compliance with state standards which is the first time in the 264-month period of this study that this has happened. The January 2002 data probably represent the "worst case" extreme. However, with the passage of time since the high rainfall events in 2002, more parameters have been in compliance in more recent surveys relative to past surveys in 2002 (Table 4).

There are several trends apparent in Table 4. First, ammonia nitrogen for all three station groups (i.e., controls alone, controls with Awehi as well as with the experimental stations) has been out of compliance for most survey periods (albeit not in most 2004-2011 surveys). From December 1989 through December 2011, there have been 78 sampling events and ammonia nitrogen exceeded state standards 40 of the 78 times. Secondly, the parameters total nitrogen, turbidity and chlorophyll-*a* have exceeded state standards on many sampling dates. However, inspection of these data show that more often than not, if the geometric mean of a standard is exceeded at the experimental stations on a given date, it is also often exceeded at the control stations on that date. A case in point is evident with the parameter turbidity as described above where it was out of compliance with the state dry standards on 59 of 78 surveys; only on 3 surveys (or 5% of the total) was turbidity only out of compliance at stations fronting the development only, on 19 surveys or 32% of the total was it only out of compliance at control stations only and on 37 of 78 surveys (or 63%) was it out of compliance at both control as well as stations fronting the development. In Table 4 there are 174 instances where a parameter exceeded state standards in the experimental and/or control stations. In 99 of the 174 instances (or 57%) both experimental and control stations exceeded the standards for a parameter on a given date and there were 56 times (or 32%) that only the control stations exceeded the standards and the experimental stations did not. On 19 instances (or 11%) the experimental stations exceeded the standards and the control stations did not. If left to chance, one would expect an even distribution of non-compliance with respect to experimental and control stations. However, for any sampling date and parameter, the non-compliance at both experimental and control stations is significantly greater than expected ($X^2 = 7.8678$, 1 df, $P<0.01$) suggesting that when a parameter is above state standards it occurs coast-wide and is not related to the development at Hulopoe.

The individual values as well as the geometric means for ammonia nitrogen through most of the survey periods has been relatively high. For example, in the December 1995 sample period, ammonia nitrogen concentrations for every sample individually exceeded state standards. Ammonia is a product of organism metabolism (excretion) and can be an indicator of sewage input if concurrent measurements of nitrate nitrogen, silica and orthophosphate are likewise high and salinity reduced (due to freshwater with sewage) which has not been the case here. Ammonia nitrogen is frequently out of compliance with water quality standards along undeveloped coastlines and this may be due to the local abundance of fish (see discussion below).

On every instance where total nitrogen was out of compliance at experimental stations, it was also out of compliance at control stations except in the October 2001 and the December 2004 surveys. Nitrate nitrogen shows a similar trend; it has been out of compliance on eleven of 78 surveys with noncompliance occurring at both control and experimental stations. On two occasions it was out of compliance at experimental stations only and on two instances was noncompliance found at control stations only.

These data suggest two points. The first is that in most instances where the geometric means exceeded state standards, these occurred at all station groups which suggests that the increases and decreases in measured concentrations are due to coast-wide phenomena, not something happening differentially at just the experimental sites that front the development. Secondly, it should be noted that a visual inspection of Table 4 will show state standards being exceeded with just as much regularity in the period preceding any golf course development as after it. The data suggest little, if any, relationship with the development causing higher geometric means. However, these generalities must be tempered by the April 2009 survey results where the geometric mean for total phosphorus exceeded state open coastal water quality standards only at stations fronting the development at Hulopoe. The noncompliant geometric mean is highest (37.14 ug/l) recorded to date (see the April 2009 survey report). Similarly, the concentration of orthophosphorous was elevated at sites fronting Hulopoe in the April 2009 survey where at six stations the grand mean concentration of orthophosphorous was 52.34 ug/l in the April 2009 survey while the long-term mean for ortho-P at these sites is 4.57 ug/l. Interestingly, there was no elevation of any of the other measured nutrients at any of the other sites in the April 2009 survey and at the six locations showing high ortho-P and total-P concentrations, other nutrients were not elevated. However these high concentrations disappeared with the subsequent (August 2009 and later) surveys where the grand mean for ortho-P at the above six sites returned to 4.50 ug/l.

B. Rainfall and Runoff

Sampling following rainfall events has shown that the concentrations of a number of parameters will be greater particularly adjacent to shore, thus concentration gradients are seen suggesting that the source of this material is from land due to runoff. In these situations, salinity is often depressed close to shore and some parameters (ammonia nitrogen, nitrate nitrogen, silica, turbidity and chlorophyll-*a*) will be greater. Heavy rainfall occurred prior to the February 1994 and January 2002 surveys and these gradients were present. The higher concentrations adjacent to shore that decrease in a seaward direction are related to the natural input of storm water runoff and/or groundwater from land. These natural inputs from land are responsible for the geometric means of some parameters often exceeding state water quality standards for "dry" coastlines. "Dry" coastlines are defined (in HAR§11-54-6) as those receiving less than three million gallons of freshwater discharge per shoreline mile which is probably the case for the south shore of Lana'i. Both silica and nitrate+nitrite nitrogen usually exist in high concentration in groundwater owing to metabolism of organic material and mineral dissolution; these ions are in low concentration in open ocean waters and hence they (along with salinity) may serve as tracers for freshwater (groundwater or stream) input into oceanic settings.

Table 5 presents the recorded monthly rainfall for the gage located at the Lana'i City Airport. Also given in this table is the daily rainfall recorded at the STP gage for the month of December 2011 up to the most recent survey date; note that the rainfall data for the Lanai Airport are no longer being collected on a regular basis. Up through the June 1996 report, we had used an automatic recording rainfall gage located adjacent to the Manele Bay Golf Course as a source of rainfall data. Despite the fact that the golf course gage is down slope or closer to the shoreline than the gage located at the STP, the readings appeared to be extremely low. Examination of the data suggested that the golf course gage was not accurate prompting our use of the data from the STP gage which is used now for the collection of the Manele Bay data as given in Table 5.

In 1996, 1,069.10 mm or 42.09 inches were recorded at the airport and 805.69 mm or 31.72 inches were recorded at the STP above the golf course. In 1997 the totals were about one-half that amount with 530.85 mm (20.90 inches) at the airport and 467.61 mm (or 18.41 inches) at the STP. Again in 1998 the annual rainfall totals continued their downward trend with 173.72 mm (6.84 inches) recorded at the airport gage and 86.11 mm or 3.39 inches measured at the STP. The 1999 rainfall totals are similar; the total at the STP was 125.72 mm (4.95 inches) and at the airport gage recorded a total of 129.03 mm (5.08 inches). In 2000 the airport gage recorded 205.87 mm (8.11 inches) and the STP gage noted 158.24 mm (6.23 inches) and in 2001 the STP gage recorded 240.03 mm while the airport gage noted close to twice that amount (446.54 mm). In 2002, the Airport gage totaled 653.03 mm while the Manele STP gage recorded 778.00 mm, in 2003 the Airport gage noted 321.30 mm of rainfall (note missing data) and the Manele gage had 174.50 mm of rainfall. The 2004 rainfall data for the Airport are incomplete (missing 3 months) but recorded 461.78 mm while the STP gage accumulated 756.92 mm. Again in 2005, only rainfall data was collected at the STP gage where 389.89 mm was recorded for the year. In 2006, 421.39 mm was recorded at the STP gage and in 2007 the STP gage noted 481.33 mm (18.95 inches) for the year. It should be noted that 271.78 mm (10.70 inches) fell in December 2007 with almost half of that total falling in a single day (4 December 2007). A similar pattern occurred in 2008 where 64 percent of the total annual rainfall occurred in the month of December. In 2009 the STP gage noted 233.43 mm (9.19 inches) for the year with 40 percent of

TABLE 5. Rainfall recorded from the Lana'i City Airport (elevation=390m) and the sewage treatment plant (STP) above Manele Bay Golf Course at Hulopoe Bay by month for Years 2000 to 2011. Also given is the daily rainfall for the month of December 2011. "Missing" indicates that no data were collected. Golf course rainfall data courtesy of Aqua Engineers, Inc. and the most recent airport data is courtesy of the National Climatic Data Center, NOAA.

Month	Airport (mm)	STP (mm)
2000		
January	5.08	0.00
February	9.65	0.00
March	2.54	6.10
April	3.30	1.52
May	0.10	0.00
June	2.56	0.00
July	1.80	0.00
August	6.10	3.05
September	36.83	12.70
October	65.02	38.35
November	70.10	96.52
December	2.79	0.00
Totals	205.87	158.24
2002		
January	141.73	234.70
February	15.75	3.30
March	121.92	12.19
April	57.40	34.29
May	52.83	105.41
June	30.23	0.00
July	22.86	0.00
August	14.73	0.00
September	Missing	37.59
October	136.91	340.36
November	40.13	10.16
December	18.54	0.00
Totals	653.03	778.00
2004		
January	173.48	359.41
February	Missing	134.62
March	82.04	38.10
April	18.80	10.16
May	70.36	45.72
June	17.02	2.54
July	2.03	0.00
August	32.26	25.40
September	27.43	12.70
October	Missing	60.96
November	Missing	29.21
December	38.35	38.10
Totals	461.78	756.92
2006		
January	8.13	10.16
February	Missing	10.16
March	237.24	266.70
April	0.00	0.00
May	11.68	2.54
June	0.51	0.00
July	Missing	0.00
August	Missing	0.00
September	Missing	0.00
October	77.47	63.25
November	127.76	68.58
December	Missing	0.00
Totals		421.39
2008		
January	Missing	0.00
February	Missing	22.86
March	Missing	0.00
April	Missing	35.05
May	Missing	0.51
June	Missing	13.97
July	Missing	14.48
August	Missing	0.00
September	Missing	4.57
October	Missing	2.54
November	Missing	1.52
December	Missing	168.15
Totals		263.65

Month	Airport (mm)	STP (mm)
2001		
January	2.03	26.16
February	27.69	1.27
March	44.96	13.21
April	54.10	0.00
May	54.61	7.62
June	55.88	8.89
July	29.21	2.54
August	15.24	0.00
September	32.26	0.00
October	12.95	0.00
November	87.38	160.02
December	30.23	20.32
Totals	446.54	240.03
2003		
January	113.28	17.78
February	72.90	46.99
March	61.21	26.16
April	51.05	11.43
May	0.00	0.00
June	11.68	7.62
July	0.00	0.00
August	Missing	0.00
September	Missing	7.62
October	Missing	2.54
November	11.18	0.00
December	Missing	54.36
	321.30	174.50
2005		
January	Missing	162.56
February	Missing	33.02
March	80.26	88.90
April	2.79	2.54
May	12.95	1.27
June	0.51	5.08
July	Missing	0.00
August	Missing	20.32
September	Missing	0.00
October	Missing	0.00
November	127.76	66.04
December	4.83	10.16
Totals	229.11	389.89
2007		
January	Missing	21.59
February	Missing	0.00
March	Missing	93.98
April	Missing	0.00
May	Missing	0.00
June	Missing	0.00
July	Missing	0.00
August	Missing	6.35
September	Missing	2.54
October	Missing	0.00
November	Missing	85.09
December	Missing	271.78
Totals		481.33
2009		
January	Missing	93.22
February	Missing	2.54
March	Missing	39.37
April	Missing	10.16
May	Missing	10.16
June	Missing	0.00
July	Missing	12.70
August	Missing	29.21
September	Missing	0.00
October	Missing	2.54
November	Missing	2.54
December	Missing	30.99
Totals		233.43

December	Airport (mm)	STP (mm)
1	Missing	0.00
2	Missing	0.00
3	Missing	0.00
4	Missing	0.00
5	Missing	0.00
6	Missing	0.00
7	Missing	0.00
8	Missing	0.00
9	Missing	0.00
10	Missing	0.00
11	Missing	0.00
12	Missing	0.00
13	Missing	0.00
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
Totals	Missing	0.00

Month	Airport (mm)	STP (mm)
2011		
January	Missing	207.01
February	Missing	52.07
March	Missing	38.10
April	Missing	7.62
May	Missing	0.00
June	Missing	0.00
July	Missing	0.00
August	Missing	0.00
September	Missing	0.00
October	Missing	12.70
November	Missing	0.00
December		
Totals		317.50
2010		
January	Missing	5.59
February	Missing	1.78
March	Missing	3.81
April	Missing	0.00
May	Missing	0.00
June	Missing	0.00
July	Missing	5.08
August	Missing	0.00
September	Missing	5.08
October	Missing	2.54
November	Missing	5.08
December	Missing	151.13
Totals		180.09

this falling in January 2009). In 2010, 180.09 mm (7.09 inches) was recorded for the year at the Manele STP gage with 84% of this rainfall occurring in the month of December. In January 2011 relatively higher than normal rainfall occurred (207.01 mm or 8.15 inches) which decreased to 2.05 inches in February. Rainfall in March 2011 was 38.10 mm (1.5 inches), in May through September no rain was recorded and the lack of rainfall continued until 22 October when 12.7 mm (0.5-inch) was recorded but no rain fell subsequently through 13 December 2011 (Table 5).

As noted above, recording rainfall at the Lanai City Airport became sporadic commencing in 2005 thus recent information is lacking from this site. However rainfall is recorded at the Manele STP gage and is used in the discussion below. Recorded rainfall from the Manele gage is courtesy of Aqua Engineers, Inc.

Not unexpectedly, rainfall at the coast (golf course) is usually lower than at the inland (airport) station and this has probably been the case through most of this study. However, showers arriving from the south (or kona rains) may cause more rainfall on the coast than inland as occurred in the January 2002 survey where 5.58 inches were recorded at the airport and 9.24 inches at Hulopoe Bay. This happened again in October 2002 where over the 14-17 October period, 13.10 inches was measured at the Manele gage and no rainfall was recorded at the airport gage during this period.

In most Hawaiian settings, rainfall is seasonal with the peak falling in the November- February (winter) period. Inspection of the January-December 1996 rainfall (Table 5, earlier reports) shows that at the airport gage 69% of the rainfall occurred in November and December and in 1997, 38% of the annual total rainfall occurred in the month of January with much of this rainfall occurring in short 1 to 5 day periods. Heavy rainfall causes surface runoff which is a mechanism transporting materials to the ocean. Evident in Table 5 from previous reports and herein, is the fact that rainfall is highly variable in time and space on Lana'i. The month of May 1996 recorded only 0.25 mm of rainfall at the airport and 17.78 mm at the golf course; in June 1996, 54.60 mm fell at the airport and the STP gage recorded only 0.25 mm (Table 5, earlier reports). More than 106 mm (4.21 inches) was recorded at the airport gage in the 4 days preceding the January 2002 survey with 210 mm (8.27 inches) at Hulopoe Bay making this sample period the "wettest" period just preceding our sampling. At that time, there was evidence of recent discharge from the intermittent streams along the coast as has been the case during other earlier surveys carried out directly following wet periods (e.g., February 1994). These data suggest that rainfall on the coast at Hulopoe Bay is often much less than encountered at more inland, higher elevation sites, but high rainfall can fall on the coast (October 2002) and that variability in rainfall is the norm.

Despite the variability in recorded rainfall between locations, there are some interesting correlations that do exist between reported rainfall at the Airport gage and one of the measured parameters when considered over the first 15 years of this study. Regressing daily average rainfall as determined from the Lana'i Airport data spanning from 4 to 45 days preceding our sampling periods (up through December 2004 but not including later time periods because of a lack of rainfall data) against the mean value of measured water chemistry parameters during each sample period, there is a significant positive relationship between mean daily rainfall and nitrate nitrogen ($r=0.41$, 48 df, $P<0.001$). Regression these same data and including the more recent data up to present (December 2011) surveys using the rainfall recorded at the STP gage for a 14 to 40 day period prior to each sampling event, we find that the relationship between rainfall and mean nitrate nitrogen concentration is significant ($r=0.44$, 59 df, $P<0.0005$), as are the relationships between total nitrogen ($r=0.48$, 59 df, $P<0.0001$), total phosphorus ($r=0.40$, 59 df, $P<0.002$), silica ($r=0.28$, 58 df, $P<0.03$) and turbidity ($r=0.68$, 59 df, $P<0.0001$).

Highest turbidities in this study have been encountered at the shoreline stations adjacent to the intermittent stream mouths (station nos. 1 - Hulopoe gulch, 6 - Makole gulch and 19 - Awehi gulch). The significant relationships are probably explained by surface water runoff as occurs with heavy rainfall prior to the sampling. Three groups of samples are collected fronting natural intermittent streambeds; sample numbers 1 through 4 are taken in Hulopoe Bay fronting and offshore of the gulch just west of the hotel, sample numbers 6 through 8 are offshore of unnamed intermittent stream bed at Makole about 500 m west of Kawaiu Gulch, and sample numbers 19 through 21 having been collected from the waters fronting Awehi Gulch. Both the Makole and Awehi gulch samples are from waters with no anthropogenic disturbance to the surrounding lands, hence serve as control sites. Samples 1, 6 and 19 are taken at the shoreline (in the shore break), sample 2 about 60 m offshore, samples 7 and 20 at 100 m offshore, sample 3 at 300 m offshore and samples 4, 8 and 21 at about 500-700 m offshore. Thus the presence of gradients in the vicinity of these natural sources of runoff and probable groundwater input are not surprising.

C. Impacts to Water Quality - Statistical Results

1. Comparison of Before to After Golf Course Construction (All Sites)

Table 6 summarizes the water quality results for the five sample periods that comprise the golf course preconstruction baseline. In the body of the table are given the geometric means for the parameters combining all 18 stations for a given sample period. If we assume that these baseline data are representative of the water quality conditions prior to the commencement of golf course and residential construction, we may statistically compare these baseline data to those from the later sample dates during (i.e., the June and October 1993 data) and following completion of golf course and commencement of residential construction (i.e., December 1993 through December 2011 data). In this analysis, the nonparametric Wilcoxon Two-Sample Test is used to detect differences in the arithmetic means of water quality parameters comparing these

TABLE 6. Summary of the water quality parameters measured during five sample periods (December 1989 October 1991, June and August 1992 as well as January 1993) that comprise the golf course/residential preconstruction baseline. In the body of the table are given geometric means (in ug/l), unless otherwise noted. The overall baseline geometric mean is given in the far right column. Underlined values exceeds "dry" DOH standards. Data drawn from earlier reports.

Parameter	Dec89	Oct91	Jun92	Aug92	Jan93	All Station Baseline Geom Mean
Nitrate N	4.27	1.80	1.22	1.82	2.09	2.04
Ammonia N	2.32	3.27	2.34	2.38	3.62	2.73
Total N	65.49	79.63	76.34	69.44	81.10	73.97
Ortho P	4.61	4.93	3.61	3.72	3.49	4.03
Total P	9.19	11.68	9.85	9.61	11.59	10.33
Silica	53.44	67.88	63.26	70.28	96.40	68.92
Turbidity (NTU)	0.31	0.26	0.13	0.12	0.08	0.16
Chlorophyll-a	0.460	0.190	0.114	0.132	0.142	0.180
Salinity (o/oo)	33.200	34.720	34.640	34.714	34.803	34.415
Temperature (`C)	25.6	27.6	26.4	27.5	23.1	26.1
Oxygen (% Sat)	100	101	102	103	102	102
pH	8.07	8.23	8.13	8.23	8.12	8.16

TABLE 7. Wilcoxon Two Sample Test results comparing arithematic mean concentrations of water quality parameters in the period proceeding golf course construction (December 1989 - January 1993, n=68) to all subsequent sample periods (during and after golf course construction - June 1993 through December 2011, n=1169). These data combine all routinely sampled control and experimental stations (i.e., station nos. 1-18). All means in the body of the table are ug/l unless otherwise noted.

Parameter	Preconstruction Mean	Subsequent Period Mean	Significantly Different?	
Nitrate N	3.06	2.59	NO	P > 0.07
Ammonia N	3.08	3.20 Postconstruction mean significantly greater	**YES**	P < 0.0001
Total N	75.61	108.39 Postconstruction mean significantly greater	**YES**	P < 0.0001
Ortho P	4.05	4.21	NO	P > 0.48
Total P	10.46	11.24	NO	P > 0.15
Silica	84.90	118.49 Postconstruction mean significantly greater	**YES**	P < 0.0001
Salinity (o/oo)	34.497	34.746 Postconstruction mean significantly greater	**YES**	P < 0.0001
Turbidity (NTU)	0.26	0.47 Postconstruction mean significantly greater	**YES**	P < 0.004
Chlorophyll-a	0.192	0.146 Preconstruction mean significantly greater	**YES**	P < 0.02
Temperature (C)	26.0	25.9	NO	P > 0.11
Oxygen (% Sat)	101.7	100.5 Preconstruction mean significantly greater	**YES**	P < 0.0001
pH (units)	8.14	8.09 Preconstruction mean significantly greater	**YES**	P < 0.0001

means from the two groups of sample dates (i.e., preconstruction versus during-after construction) and the results are given in Table 7. Statistically significant differences between the pre-construction and the during-after construction periods were detected for the following parameters: ammonia nitrogen ($P<0.0001$), total nitrogen ($P<0.0001$), silica ($P<0.0001$), salinity ($P<0.0001$), turbidity ($P<0.004$), chlorophyll-*a* ($P<0.02$), percent saturation of dissolved oxygen ($P<0.0001$) and pH ($P<0.0001$). The during-after construction means greater than the preconstruction means are for ammonia nitrogen (preconstruction = 3.08 ug/l, post-construction = 3.20 ug/l), total nitrogen (pre-construction = 75.91 ug/l, post-construction = 108.39 ug/l), silica (pre-construction = 84.90 ug/l, post-construction = 118.49 ug/l), turbidity (pre-construction = 0.26 NTU, post-construction = 0.47 NTU) and salinity (pre-construction = 34.497 ppt, post-construction = 34.746 ppt; see Table 7). The statistically greater post-construction means for ammonia nitrogen, total nitrogen, silica and salinity are within the expected range for near-shore marine waters, are not related to the development and operation of the golf course and have no negative impact on marine biota (see discussion below). The statistically greater post-construction mean for turbidity is probably related to the long-term persistence of turbidity along the south shore of Lanai in the 2002-2003 period. The statistically greater pre-construction mean for chlorophyll-*a*, percent saturation of dissolved oxygen concentration and pH again are not related to the golf course at Hulopoe and are also well within the normal ranges found in Hawaiian waters.

2. Comparison of "Experimental" and "Control" Sites

a. Chronological Analyses

One approach to address the question of change or impact due to the construction and operation of the golf course, is to separate control and experimental sample stations and look for significant changes in some chronological order. Water pollution from anthropogenic sources such as golf courses is chronic in nature thus change should be occurring through time (i.e., an upward trend through time). Table 8 presents the results of a Kruskal-Wallis Analysis of Variance and a Student-Newman-Kuels (SNK) Test applied to the experimental stations (numbers 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18) and to the control stations (numbers 6, 7, 8, 12, 14) for each of the parameters measured in this study. The Kruskal-Wallis ANOVA can determine if significant differences exist among the means of a parameter but cannot discern which means differ significantly from the others. Within a parameter, the SNK Test groups sample date means that are not statistically different from one another and separates those groups which are. Using these two statistical tests, we address the question "Has there been any statistically significant changes in water quality at stations adjacent to (experimental) or away from (control) the development since the beginning of the monitoring program (December 1989) to present (December 2011)?" The results of the ANOVA show that the means by date for every parameter

TABLE 8. Student-Newman-Keuls (SNK) Test applied to all sample locations fronting the development at Hulopoe Bay (stations 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18) addressing the question "Has there been any statistically significant changes at the stations adjacent to the development since the beginning of the monitoring program (December 1989) to present?" In the body of the table are given the sample date and arithematic mean for a given parameter on that date. Means are expressed in ug/l unless otherwise noted. Letters with the same designation show means and sample dates that are related; changes in letter designation show where significant differences exist. Overlaps in the letters indicate a lack of significant differences; in such cases, only the extremes may be significantly different. The most recent sample date is shown in bolded letters. For the experimental stations note that the June and October 1993 represent "during" golf course construction and subsequent sample dates represent the post-construction period while all others represent the baseline period. Also presented in this table are the SNK results from an analysis of data from control stations (nos. 6, 7, 8, 12, 14) for comparative purposes. Table continued on the next 12 pages. ND = below limits of detection.

TABLE CONTINUED ON NEXT PAGE

TABLE 8. Continued.

EXPERIMENTAL STATIONS
NITRATE (P>0.0001)

DATE	MEAN					
May 02	9.88	A				
Feb 07	8.90	A	B			
Jan 02	7.58	A	B	C		
Dec 89	6.08		B	C	D	
Feb 94	5.70		B	C	D	E
Feb-09	5.45		B	C	D	E
Dec-11	5.23		B	C	D	E
Sep 95	5.12		B	C	D	E
Jul-09	4.97		B	C	D	E
Mar-11	4.81		B	C	D	E
Jun 06A	4.60		B	C	D	E
Apr 08	4.54		B	C	D	E
Apr-09	4.48		B	C	D	E
Dec 96	4.42		B	C	D	E
Oct 01	4.10			C	D	E
May-10	3.98			C	D	E
Mar 98	3.82			C	D	E
Mar-09	3.72			C	D	E
Nov 03	3.67			C	D	E
Dec 06	3.62			C	D	E
Jan 99	3.55			C	D	E
Nov 96	3.51			C	D	E
Nov 00	3.48			C	D	E
Jan 93	3.44			C	D	E
Feb 05	3.32			C	D	E
Apr 04	3.30			C	D	E
Dec 93	3.28			C	D	E
Oct 93	3.27			C	D	E
Nov 05	3.26			C	D	E
Oct-10	3.26			C	D	E
Nov-10	3.04			C	D	E
Oct 91	2.91			C	D	E
Aug 92	2.79			C	D	E
Jun 99	2.67			C	D	E
Apr 99	2.56			C	D	E
Mar 00	2.55			C	D	E
Oct 04	2.55			C	D	E
Dec 00	2.52			C	D	E
Dec 97	2.52			C	D	E
Jan 08A	2.50			C	D	E
Aug-09	2.23			C	D	E
Sep 00	2.11			C	D	E
Jan 07	2.06				D	E
Jan 08B	1.95				D	E
Mar 03	1.95				D	E
Apr02	1.92				D	E
Jun 06B	1.84				D	E
Jul 01	1.81				D	E
Sep 99	1.76				D	E
May 03	1.74				D	E
Aug 03	1.71				D	E
Jan 00	1.69				D	E
Jun 92	1.69				D	E
Nov 02	1.67				D	E
Jun 97	1.55				D	E
Dec 04	1.55				D	E
Jun 94	1.54				D	E
Apr 97	1.45				D	E
Nov 98	1.42				D	E
Jun 05	1.40				D	E
Nov-11	1.39				D	E
Oct-09	1.37				D	E
May01	1.21				D	E
Jun 93	1.17				D	E
Sep 97	1.17				D	E
Jul 04	1.17				D	E
Aug-08	1.11				D	E
Dec 95	0.94				D	E
Jan 06	0.83				D	E
Dec 94	0.94				D	E
Jun-11	0.89				D	E
Jun 98	0.76				D	E
Mar 96	0.75				D	E
Aug 07	0.69				D	E
Jun 95	0.55				D	E
Sep 94	0.31				D	E
Mar 95	0.10					E
Jun 96	0.09					E

CONTROL STATIONS
NITRATE (P>0.0006)

DATE	MEAN			
Jan 02	16.26	A		
May 02	8.60		B	
Dec 97	6.33		B	C
Oct 93	6.31		B	C
Mar 95	5.49		B	C
Feb 07	5.26		B	C
Dec 89	5.20		B	C
Dec-11	4.87		B	C
Oct 01	4.17		B	C
Jun 99	3.58		B	C
Jan 99	3.50		B	C
Feb-09	3.38		B	C
Jul 01	3.33		B	C
Sep 95	3.02		B	C
Feb 94	2.97		B	C
Jun 92	2.91		B	C
Mar 98	2.77		B	C
Jan 93	2.60		B	C
Feb 05	2.57		B	C
Jun 95	2.54		B	C
Jun 06A	2.54		B	C
Jun 06B	2.51		B	C
Mar 96	2.46		B	C
Nov-10	2.46		B	C
Apr 08	2.44		B	C
Jul-09	2.29		B	C
Mar 03	2.25		B	C
Nov 05	2.11		B	C
Oct-10	2.07		B	C
Aug-09	1.99		B	C
Jan 08B	1.95		B	C
May 03	1.95		B	C
Sep 97	1.93		B	C
Apr 02	1.91		B	C
Aug 92	1.88		B	C
Oct 91	1.86		B	C
Nov 02	1.86		B	C
Jan 00	1.79		B	C
Oct-09	1.79		B	C
Jun 94	1.74			C
Dec 04	1.71			C
Nov 96	1.65			C
Oct 04	1.64			C
Apr-09	1.63			C
Mar 00	1.62			C
Nov 03	1.61			C
Jun 96	1.60			C
Nov 00	1.54			C
Sep 94	1.54			C
Sep 00	1.51			C
Jun-11	1.48			C
Apr 99	1.48			C
Dec 06	1.47			C
Dec 00	1.46			C
Aug 07	1.45			C
May-10	1.40			C
Aug 03	1.38			C
Jan 08A	1.28			C
Mar-11	1.26			C
Apr 04	1.24			C
May01	1.23			C
Mar-09	1.21			C
Sep 99	1.18			C
Jan 07	1.07			C
Dec 96	1.04			C
Jun 05	1.02			C
Jul 04	0.99			C
Nov-11	0.92			C
Dec 95	0.87			C
Dec 93	0.87			C
Jan 06	0.60			C
Jun 93	0.81			C
Nov 98	0.59			C
Jun 97	0.56			C
Apr 97	0.53			C
Aug-08	0.44			C
Dec 94	0.34			C
Jun 98	0.00			C

Interpretation:

Greatest mean nitrate concentrations at stations fronting the development are in May 2002, however the mean nitrate concentrations measured at control stations are greater in the January 2002 sample period. December 2011 mean nitrate concentrations fronting development are in the upper quarter of the range at experimental and control sites.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
AMMONIA (P>0.0001)

DATE	MEAN				
Jan 99	15.68	A			
Sep 97	14.24	A	B		
Jun 98	12.41	A	B	C	
Mar 98	12.10	A	B	C	
Sep 95	10.34		B	C	D
Apr 08	9.82			C	D
Jan 02	6.42		E		D
Jun 99	6.40		E		D
Nov 98	6.24		E		D
Jun 94	6.22		E		D
Dec 95	6.00		E		D
Feb 94	4.51		E		
Nov 05	4.24		E		
Jan 93	4.10		E		
May 03	4.08		E		
Jun 97	3.95		E		
May 02	3.83		E		
Apr 97	3.73		E		
Oct 91	3.69		E		
Mar95	3.53		E		
Dec-11	3.52		E		
Jun 95	3.48		E		
Nov 96	3.45		E		
Oct 93	3.22		E		
Mar-11	3.21		E		
Dec 96	2.99		E		
Mar 96	2.78		E		
Nov 00	2.71		E		
Dec 89	2.68		E		
Aug 92	2.60		E		
Nov 02	2.56		E		
Aug 03	2.55		E		
Dec 00	2.46		E		
Dec 93	2.38		E		
Apr 02	2.34		E		
Sep 99	2.34		E		
Apr 99	2.34		E		
Jul 01	2.34		E		
Dec 97	2.28		E		
Jul-09	2.38		E		
Mar 03	2.22		E		
Sep 00	2.18		E		
Jun 06B	2.13		E		
Jun 92	2.12		E		
Jun 06A	2.08		E		
Mar 00	2.06		E		
Jun 05	2.01		E		
Jan 08A	1.86		E		
Sep 94	1.83		E		
Oct 01	1.77		E		
Jun-11	1.71		E		
Apr-09	1.68		E		
Nov 03	1.65		E		
Mar-09	1.64		E		
Oct-10	1.54		E		
Feb 05	1.53		E		
Apr 04	1.53		E		
Nov-11	1.52		E		
Jan 00	1.50		E		
Aug-08	1.46		E		
Nov-10	1.38		E		
Dec 06	1.34		E		
Aug 07	1.32		E		
Jan 07	1.30		E		
Jun 96	1.30		E		
May-10	1.27		E		
Aug-09	1.27		E		
Feb 07	1.20		E		
Oct 04	1.11		E		
Jul 04	1.09		E		
Jan 06	1.01		E		
Oct-09	0.97		E		
Jan 08B	1.02		E		
Dec 04	0.92		E		
Jun 93	0.90		E		
May 01	0.85		E		
Feb-09	0.74		E		
Dec 94	0.54		E		

CONTROL STATIONS
AMMONIA (P>0.0001)

DATE	MEAN			
Jan 99	24.33	A		
Apr 08	13.58	B		
Jun 98	12.26	B	C	
Jan 02	9.90	B	C	D
Jun 99	8.26	B	C	D
Jun 94	7.80	B	C	D
Mar 98	7.70	B	C	D
Sep 95	7.50	B	C	D
Nov 02	7.30	B	C	D
Sep 97	7.00	B	C	D
Apr 02	5.48		C	D
Oct 91	5.35		C	D
Mar-11	5.35		C	D
Dec 95	5.10		C	D
May 02	5.01		C	D
Oct 93	4.98		C	D
Aug 03	4.87		C	D
Nov 00	4.68		C	D
May 03	4.66		C	D
Dec-11	4.48		C	D
Dec 97	4.12		C	D
Jan 93	3.64			D
Jun 92	2.96			D
Nov 03	2.95			D
Jun 06A	2.83			D
Jun 05	2.78			D
Mar 03	2.74			D
Jun 97	2.63			D
Dec 00	2.60			D
Aug 92	2.58			D
Jul 01	2.52			D
Jan 08A	2.52			D
Apr 97	2.46			D
Sep 00	2.16			D
Jul-09	2.10			D
Dec 89	2.05			D
Nov 05	2.00			D
Sep 99	1.99			D
Jun 95	1.99			D
Apr 04	1.93			D
Jun 06B	1.91			D
Feb 94	1.76			D
Dec 93	1.68			D
Mar 00	1.65			D
Apr-09	1.43			D
Jun 96	1.43			D
Jun-11	1.37			D
Mar-09	1.34			D
Feb 05	1.32			D
Oct-10	1.32			D
Oct 01	1.32			D
Mar 95	1.26			D
Aug-08	1.25			D
Jan 00	1.23			D
Nov 98	1.18			D
Aug 07	1.13			D
May-10	1.12			D
Apr 99	1.12			D
Jan 06	1.10			D
Dec 06	1.05			D
Aug-09	1.01			D
Oct-09	0.99			D
Nov-10	0.98			D
Dec 96	0.84			D
Oct 04	0.83			D
Jan 07	0.78			D
Jun 93	0.78			D
Feb 07	0.73			D
Nov-11	0.73			D
Jan 08B	0.73			D
Dec 04	0.62			D
Feb-09	0.57			D
Jul 04	0.57			D
Mar 96	0.48			D
May 01	0.36			D
Nov 96	0.34			D
Sep 94	0.08			D
Dec 94	0.00			D

Interpretation:

The mean concentration of ammonia was highest recorded for this study in the January 1999 survey at both experimental and control stations. Highest mean concentration recorded at control stations. Mean ammonia concentrations in the December 2011 surveys are in the upper quarter of the range at both experimental and control stations.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
TOTAL NITROGEN (P>0.0001)

DATE	MEAN								
Jan 07	212.69	A							
Jan 02	199.09	A	B						
Mar 03	195.96	A	B						
Nov 02	184.93	A	B	C					
May 01	184.62	A	B	C					
Jan 08A	169.18		B	C	D				
Jul 01	161.53			C	D	E			
Jan 99	160.30			C	D	E			
Jan 08B	151.80			C	D	E	F		
Aug-08	145.10	G			D	E	F		
Oct-10	138.49	G	H		D	E	F		
Dec 06	137.15	G	H	I	D	E	F		
Jun 95	136.36	G	H	I	D	E	F		
Aug 03	134.60	G	H	I	D	E	F		
May 02	131.21	G	H	I	DJ	E	F		
Oct-09	130.03	G	H	I	DJ	EK	F		
Nov-10	129.82	G	H	I	DJ	EK	F		
Jul-09	127.30	G	H	I	J	EK	FL		
Aug 07	124.15	G	H	I	J	EK	FL	M	
Dec 04	120.79	G	H	I	J	EK	FL	M	N
May-10	118.48	G	H	I	J	K	FL	M	N
Oct 01	112.81	GO	H	I	J	K	FL	M	N
Dec-11	111.55	GO	H	I	J	K	FL	M	N
Mar 00	111.52	GO	H	I	J	K	FL	M	N
Apr 99	109.57	GO	H	I	J	K	FL	M	N
Sep 00	108.56	GO	HP	I	J	K	L	M	N
Mar-09	107.19	GO	HP	I	J	K	L	M	N
Nov-11	106.58	GO	HP	I	J	K	L	M	N
Sep 97	106.18	GO	HP	I	J	K	L	M	N
Jul 04	103.97	GO	HP	I	J	K	L	M	N
Jan 00	103.65	GO	HP	I	J	K	L	M	N
Nov 03	103.42	GO	HP	I	J	K	L	M	N
Apr 08	103.23	GO	HP	I	J	K	L	M	N
Feb 05	101.63	GO	HP	I	J	K	L	M	N
Apr 02	101.17	GO	HP	I	J	K	L	M	N
Sep 99	100.24	GO	HP	I	J	K	L	M	N
Nov 98	99.27	O	HP	I	J	K	L	M	N
Oct 04	98.79	O	HP	I	J	K	L	M	N
Jun 06A	98.55	O	HP	I	J	K	L	M	N
May 03	98.03	O	HP	I	J	K	L	M	N
Apr 04	97.90	O	HP	I	J	K	L	M	N
Nov 05	97.10	O	HP	I	J	K	L	M	N
Nov 00	95.10	O	HP	I	J	K	L	M	N
Feb 07	94.03	O	HP	I	J	K	L	M	N
Dec 97	93.94	O	HP	I	J	K	L	M	N
Jun 97	92.66	O	HP	IQ	J	K	L	M	N
Mar-11	92.51	O	HP	IQ	J	K	L	M	N
Aug-09	92.50	O	HP	IQ	J	K	L	M	N
Jun 06B	91.32	O	HP	IQ	J	K	L	M	N
Apr 97	91.26	O	HP	IQ	J	K	L	M	N
Jun 99	90.73	O	P	IQ	J	K	L	M	N
Dec 00	90.31	O	P	IQ	J	K	L	M	N
Jan 06	84.74	O	P	Q	J	K	L	M	N
Mar 98	84.56	O	P	Q	J	K	L	M	N
Oct 91	84.56	O	P	Q	J	K	L	M	N
Nov 96	84.33	O	P	Q	J	K	L	M	N
Jun 93	83.98	O	P	Q	J	K	L	M	N
Apr-09	83.77	O	P	Q	J	K	L	M	N
Jun 96	83.75	O	P	Q	J	K	L	M	N
Jun 05	83.20	O	P	Q	J	K	L	M	N
Jan 93	81.63	O	P	Q		K	L	M	N
Feb 94	81.29	O	P	Q			L	M	N
Oct 93	80.58	O	P	Q			L	M	N
Aug 92	77.24	O	P	Q				M	N
Dec 96	75.70	O	P	Q				M	N
Dec 95	75.61	O	P	Q				M	N
Feb-09	75.08	O	P	Q					N
Jun-11	74.14	O	P	Q					N
Jun 98	73.09	O	P	Q					N
Dec 93	72.64	O	P	Q					N
Jun 94	72.45	O	P	Q					N
Jun 92	72.39	O	P	Q					N
Mar 96	71.49	O	P	Q					N
Sep 95	68.04	O	P	Q					
Dec 89	67.62	O	P	Q					
Dec 94	67.25	O	P	Q					
Sep 94	59.95		P	Q					
Mar 95	46.91			Q					

CONTROL STATIONS
TOTAL NITROGEN (P>0.0001)

DATE	MEAN											
Nov 02	305.45	A										
Jan 02	258.27		B									
Jan 07	225.96			C								
Mar 03	203.87			C								
Jan 08A	172.70				D							
Jul 01	159.72				D	E						
May 01	157.72				D	E	F					
Aug 03	155.37				D	E	F	G				
Dec 06	155.18				D	E	F	G				
Aug-08	145.07				D	E	F	G	H			
Oct-10	142.63				D	E	F	G	H	I		
Jun 95	142.22				D	E	F	G	H	I		
May 02	139.89				D	E	F	G	H	I	J	
Jul-09	139.05				D	E	F	G	H	I	J	
Nov-10	136.86				D	E	F	G	H	I	J	K
Aug 07	133.22	L			D	E	F	G	H	I	J	K
Jan 08B	130.56	L	M		D	E	F	G	H	I	J	K
Oct-09	125.58	L	M	N		E	F	G	H	I	J	K
Jan 99	121.38	L	M	N	O	E	F	G	H	I	J	K
May-10	117.91	L	M	N	O	EP	F	G	H	I	J	K
Sep 00	115.72	L	M	N	O	EP	FQ	G	H	I	J	K
Mar 00	112.84	L	M	N	O	P	FQ	GR	H	I	J	K
Dec-11	112.25	L	M	N	O	P	FQ	GR	H	I	J	K
Feb 05	110.35	L	M	N	O	P	Q	GR	H	I	J	K
Apr 99	107.74	L	M	N	O	P	Q	R	H	I	J	K
Apr 02	107.52	L	M	N	O	P	Q	R	H	I	J	K
Oct 04	106.93	L	M	N	O	P	Q	R	H	I	J	K
Jan 00	104.92	L	M	N	O	P	Q	R	H	I	J	K
Mar-09	104.86	L	M	N	O	P	Q	R	H	I	J	K
Oct 01	100.20	L	M	N	O	P	Q	R	H	I	J	K
Nov 98	99.96	L	M	N	O	P	Q	R	H	I	J	K
Dec 04	98.84	L	M	N	O	P	Q	R	H	I	J	K
Jul 04	98.73	L	M	N	O	P	Q	R	H	I	J	K
Apr 08	98.36	L	M	N	O	P	Q	R	H	I	J	K
Jun 99	98.28	L	M	N	O	P	Q	R	H	I	J	K
Aug-09	97.44	L	M	N	O	P	Q	R	H	I	J	K
Dec 97	95.23	L	M	N	O	P	Q	R	H	I	J	K
Nov-11	95.14	L	M	N	O	P	Q	R	H	I	J	K
Nov 03	95.03	L	M	N	O	P	Q	R	H	I	J	K
Nov 00	94.67	L	M	N	O	P	Q	R	H	I	J	K
Sep 99	93.88	L	M	N	O	P	Q	R		I	J	K
Jun 97	93.21	L	M	N	O	P	Q	R		I	J	K
Dec 00	92.51	L	M	N	O	P	Q	R		I	J	K
May 03	92.48	L	M	N	O	P	Q	R		I	J	K
Apr 97	91.76	L	M	N	O	P	Q	R		I	J	K
Apr 04	91.50	L	M	N	O	P	Q	R		I	J	K
Jun 06B	88.70	L	M	N	O	P	Q	R			J	K
Mar-11	88.45	L	M	N	O	P	Q	R			J	K
Sep 97	88.34	L	M	N	O	P	Q	R			J	K
Jun 92	88.30	L	M	N	O	P	Q	R			J	K
Feb 07	88.03	L	M	N	O	P	Q	R			J	K
Jun 93	86.30	L	M	N	O	P	Q	R				K
Jun 06A	86.20	L	M	N	O	P	Q	R				K
Apr-09	84.98	L	M	N	O	P	Q	R				K
Jun 96	84.56	L	M	N	O	P	Q	R				K
Nov 96	83.86	L	M	N	O	P	Q	R				K
Jan 06	82.60	L	M	N	O	P	Q	R				
Feb 94	80.92	L	M	N	O	P	Q	R				
Sep 95	80.36	L	M	N	O	P	Q	R				
Oct 93	80.19	L	M	N	O	P	Q	R				
Mar 98	79.04		M	N	O	P	Q	R				
Jan 93	78.04		M	N	O	P	Q	R				
Mar 96	77.70		M	N	O	P	Q	R				
Dec 93	77.67		M	N	O	P	Q	R				
Jun 05	76.11			N	O	P	Q	R				
Jun-11	75.71			N	O	P	Q	R				
Dec 96	74.87			N	O	P	Q	R				
Jun 98	74.31			N	O	P	Q	R				
Dec 95	74.09			N	O	P	Q	R				
Oct 91	71.96			N	O	P	Q	R				
Feb-09	71.18				O	P	Q	R				
Jun 94	68.70				O	P	Q	R				
Dec 94	68.21				O	P	Q	R				
Sep 94	64.18					P	Q	R				
Dec 89	61.83						Q	R				
Aug 92	59.89							R				
Nov 05	59.61							R				
Mar 95	59.37							R				

Interpretation:

Total nitrogen concentrations have the highest values at control stations. In the December 2011 surveys, mean values are near the upper third of the range at control and experimental stations. No evidence of increase in concentrations through time.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
ORTHOPHOSPHORUS (P>0.0001)

DATE	MEAN		
Apr-09	30.74	A	
May 02	6.26		B
Nov 05	6.05		B
Apr 99	5.69		B
May 01	5.58		B
Mar 96	5.52		B
Jun 94	5.49		B
Nov 03	5.35		B
Dec 95	5.24		B
Apr 02	5.22		B
Mar 03	5.22		B
Jan 02	5.19		B
Jan 07	5.14		B
Dec 89	5.08		B
Sep 95	5.08		B
Jul-09	5.07		B
Aug-09	4.93		B
Jun-11	4.90		B
May 03	4.82		B
Oct 91	4.80		B
Jun 06A	4.79		B
Dec 96	4.79		B
Mar 95	4.74		B
Apr 04	4.62		B
Nov 02	4.58		B
May-10	4.42		B
Feb 07	4.42		B
Mar 00	4.34		B
Apr 08	4.33		B
Jun 06B	4.31		B
Jan 08B	4.21		B
Oct 01	4.20		B
Dec 97	4.11		B
Jun 95	4.09		B
Feb 05	4.08		B
Sep 99	4.00		B
Jan 08A	3.99		B
Jun 05	3.95		B
Jan 99	3.86		B
Jan 93	3.83		B
Oct-09	3.82		B
Oct-10	3.81		B
Sep 00	3.80		B
Mar 98	3.78		B
Nov 98	3.69		B
Aug 92	3.69		B
Jul 01	3.58		B
Jun 96	3.55		B
Nov-10	3.50		B
Jun 92	3.49		B
Nov 00	3.47		B
Jan 06	3.41		B
Aug 07	3.40		B
Oct 04	3.34		B
Dec-11	3.32		B
Jan 00	3.27		B
Sep 94	3.27		B
Jun 98	3.21		B
Dec 93	3.16		B
Nov-11	3.16		B
Oct 93	3.10		B
Dec 94	3.07		B
Aug 03	2.98		B
Dec 00	2.96		B
Nov 96	2.90		B
Feb-09	2.74		B
Mar-09	2.74		B
Apr 97	2.65		B
Jul 04	2.55		B
Jun 93	2.54		B
Dec 04	2.36		B
Jun 97	2.34		B
Mar-11	2.56		B
Dec 06	1.74		B
Feb 94	1.68		B
Aug-08	1.36		B
Sep 97	1.27		B
Jun 99	1.01		B

CONTROL STATIONS
ORTHOPHOSPHORUS (P>0.0001)

DATE	MEAN		
Nov 98	20.52	A	
Apr 99	8.25		B
May 02	8.00		B
Nov 02	7.96		B
Feb 07	7.16		B
Mar 95	7.13		B
Apr 02	6.92		B
Jun 06A	6.43		B
May 01	5.89		B
Oct 91	5.85		B
Jun 94	5.82		B
Apr-09	5.43		B
Mar 03	5.28		B
Dec 95	5.15		B
May 03	5.04		B
Jun-11	4.90		B
Jul-09	4.86		B
Aug-09	4.80		B
Mar 96	4.71		B
Jan 07	4.64		B
Jan 08A	4.63		B
Jan 02	4.59		B
Nov 03	4.57		B
Jun 95	4.53		B
Sep 95	4.53		B
Jun 06B	4.31		B
Oct 93	4.28		B
Oct-09	4.24		B
Mar 98	4.22		B
May-10	4.15		B
Jan 99	4.15		B
Feb 05	4.10		B
Jun 05	4.00		B
Dec-11	3.97		B
Oct 01	3.97		B
Jan 08B	3.94		B
Dec 89	3.93		B
Sep 94	3.91		B
Apr 04	3.91		B
Dec 97	3.91		B
Sep 99	3.84		B
Jul 01	3.84		B
Dec 93	3.84		B
Sep 00	3.78		B
Dec 96	3.78		B
Aug 92	3.72		B
Jan 93	3.72		B
Jun 92	3.70		B
Nov 00	3.66		B
Mar 00	3.53		B
Nov-10	3.53		B
Aug 07	3.50		B
Oct-10	3.47		B
Jun 96	3.44		B
Jan 06	3.23		B
Dec 94	3.22		B
Feb-09	3.21		B
Nov 05	3.21		B
Oct 04	3.20		B
Apr 08	3.17		B
Jan 00	3.10		B
Nov 96	2.91		B
Aug 03	2.84		B
Jun 98	2.79		B
Jul 04	2.76		B
Mar-09	2.72		B
Jun 93	2.60		B
Mar-11	2.42		B
Dec 00	2.42		B
Nov-11	2.23		B
Feb 94	2.17		B
Dec 04	2.13		B
Dec 06	1.64		B
Aug-08	1.51		B
Apr 97	1.43		B
Jun 97	1.18		B
Sep 97	0.81		B
Jun 99	0.56		B

Interpretation:

The April 2009 mean concentrations of orthophosphorus at experimental stations is the highest recorded value during the study period. Orthophosphorous concentrations at control stations are near the middle of the range while experimental mean concentrations are in the lower third of the range during the December 2011 survey period.

TABLE 8. Continued.

EXPERIMENTAL STATIONS

TOTAL PHOSPHORUS (P>0.0001)

DATE	MEAN							
Apr-09	37.66	A						
Jan 02	24.72		B					
Oct-10	15.47			C				
Nov 05	14.32			C				
Nov 96	14.32			C	D			
Jun 06A	14.06			C	D			
Jun 95	13.87			C	D			
Mar 03	13.64			C	D			
May 02	13.61			C	D			
Mar 95	13.16			C	D			
Sep 95	13.02			C	D			
Mar 98	12.91			C	D			
Nov 02	12.88			C	D			
Jan 00	12.77			C	D	E		
Jun 06B	12.71			C	D	E		
Dec 00	12.71			C	D	E		
Mar 00	12.68			C	D	E		
Mar 96	12.63			C	D	E		
May 01	12.60			C	D	E		
Sep 99	12.43			C	D	E	F	
Jan 07	12.37			C	D	E	F	
Dec 94	12.26			C	D	E	F	
Jan 93	12.06			C	D	E	F	G
Jun-11	12.03			C	D	E	F	G
Jul 01	12.00			C	D	E	F	G
Jan 08A	11.98			C	D	E	F	G
Aug-09	11.95			C	D	E	F	G
Sep 00	11.89			C	D	E	F	G
Nov 00	11.58			C	D	E	F	G
Dec 93	11.53			C	D	E	F	G
Jul-09	11.50			C	D	E	F	G
May 03	11.50			C	D	E	F	G
Oct-09	11.41			C	D	E	F	G
Oct 91	11.16			C	D	E	F	G
May-10	11.13			C	D	E	F	G
Feb 94	10.95			C	D	E	F	G
Apr 02	10.82			C	D	E	F	G
Feb-09	10.76			C	D	E	F	G
Nov-10	10.57			C	D	E	F	G
Apr 08	10.51			C	D	E	F	G
Feb 07	10.51			C	D	E	F	G
Aug 07	10.48			C	D	E	F	G
Nov 98	10.37			C	D	E	F	G
Oct 01	10.26			C	D	E	F	G
Dec-11	10.14			C	D	E	F	G
Jan 08B	10.09			C	D	E	F	G
Dec 97	10.06			C	D	E	F	G
Jun 94	9.98			C	D	E	F	G
Nov-11	9.92			C	D	E	F	G
Dec 96	9.84			C	D	E	F	G
Dec 04	9.81			C	D	E	F	G
Jun 92	9.76			C	D	E	F	G
Aug 92	9.75			C	D	E	F	G
Apr 04	9.74			C	D	E	F	G
Aug-08	9.70			C	D	E	F	G
Dec 95	9.58			C	D	E	F	G
Jun 93	9.53			C	D	E	F	G
Mar-11	9.50			C	D	E	F	G
Apr 97	9.41			C	D	E	F	G
Dec 89	9.39			C	D	E	F	G
Nov 03	9.36			C	D	E	F	G
Jun 97	9.19			C	D	E	F	G
Mar-09	9.05			C	D	E	F	G
Jul 04	8.99			C	D	E	F	G
Oct 93	8.99			C	D	E	F	G
Jan 06	8.74			C	D	E	F	G
Jun 96	8.62			C	D	E	F	G
Sep 94	8.43			C	D	E	F	G
Sep 97	8.15			C	D	E	F	G
Oct 04	8.06			C	D	E	F	G
Feb 05	7.92			C	D	E	F	G
Jun 05	7.92			C	D	E	F	G
Aug 03	7.33				D	E	F	G
Apr 99	7.19				D	E	F	G
Jan 99	6.85				D	E	F	G
Dec 06	6.85					E	F	G
Jun 99	4.71						F	G
Jun 98	4.40							G

CONTROL STATIONS

TOTAL PHOSPHORUS (P>0.0001)

DATE	MEAN			
Jan 02	31.50	A		
Nov 98	30.63	A		
Nov 02	18.54		B	
Oct-10	16.99		B	C
May 02	13.16		B	C
Mar 95	14.63		B	C
Dec 93	14.26		B	C
May 03	13.89		B	C
Jun 95	13.83		B	C
Mar 03	13.52		B	C
Apr 02	13.45		B	C
Mar 98	13.45		B	C
Oct 91	13.43		B	C
Jun 06A	13.08		B	C
Jan 07	13.02		B	C
May 01	12.96		B	C
Jan 00	12.96		B	C
Jun 06B	12.90		B	C
Sep 95	12.90		B	C
Mar 00	12.52		B	C
Jan 08A	12.52		B	C
Jun-11	12.21		B	C
Oct-09	12.15		B	C
Aug-09	12.09		B	C
Sep 00	12.09		B	C
Dec 00	12.03		B	C
Sep 99	11.97		B	C
Apr-09	11.90		B	C
Nov 00	11.78		B	C
Jul-09	11.66		B	C
Nov-10	11.59		B	C
Jul 01	11.53		B	C
Jan 93	11.47		B	C
Dec 94	11.28		B	C
Nov 96	11.16		B	C
Feb-09	11.10		B	C
May-10	11.10		B	C
Feb 94	10.92		B	C
Dec-11	10.91		B	C
Nov 05	10.85		B	C
Aug 07	10.85		B	C
Feb 07	10.73		B	C
Mar 96	10.66		B	C
Oct 01	10.23		B	C
Jun 94	10.10		B	C
Oct 93	10.04		B	C
Aug-08	10.04		B	C
Jun 92	9.94		B	C
Mar-11	9.92		B	C
Jan 08B	9.92		B	C
Apr 08	9.92		B	C
Dec 97	9.67		B	C
Apr 99	9.67		B	C
Nov 03	9.61		B	C
Dec 96	9.61		B	C
Mar-09	9.55		B	C
Jun 93	9.42		B	C
Aug 92	9.36		B	C
Dec 04	9.24		B	C
Nov-11	8.93		B	C
Apr 04	8.80		B	C
Dec 89	8.78		B	C
Jan 06	8.74		B	C
Jul 04	8.68		B	C
Dec 95	8.56		B	C
Apr 97	8.56		B	C
Jun 96	8.37		B	C
Jun 97	8.25		B	C
Sep 94	8.25		B	C
Feb 05	8.18		B	C
Oct 04	8.00		B	C
Aug 03	7.81		B	C
Jan 99	7.81		B	C
Sep 97	7.75		B	C
Jun 05	7.50		B	C
Dec 06	7.50			C
Jun 99	5.27			C
Jun 98	5.15			C

Interpretation:

The April 2009 mean total phosphorus concentrations were the highest recorded at experimental sites. December 2011 mean total phosphorus values for experimental and control stations are in the middle of the range.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
SILICA (P>0.0001)

DATE	MEAN							
Jun 98	299.19	A						
Jun 97	287.18	A	B					
Jan 02	264.76	A	B	C				
Apr-09	245.14	A	B	C	D			
Jan 08A	236.12	A	B	C	D	E		
Mar 98	234.26	A	B	C	D	E		
Nov 98	203.46	A	B	C	D	E	F	
Apr 99	193.99	A	B	C	D	E	F	G
Jan 99	182.53	A	B	C	D	E	F	G
Feb 05	181.76	A	B	C	D	E	F	G
Jan 06	180.53	A	B	C	D	E	F	G
Mar-11	172.48		B	C	D	E	F	G
Mar-09	164.19		B	C	D	E	F	G
Apr 97	157.61			C	D	E	F	G
Sep 99	153.16			C	D	E	F	G
Sep 00	150.84			C	D	E	F	G
May-10	148.48			C	D	E	F	G
Apr 08	147.52			C	D	E	F	G
Dec 97	147.08			C	D	E	F	G
Feb 07	145.85			C	D	E	F	G
May 01	145.55			C	D	E	F	G
Jun 99	145.32			C	D	E	F	G
Jul-09	145.17			C	D	E	F	G
Mar 03	134.50			C	D	E	F	G
Apr 02	134.23			C	D	E	F	G
Jan 08B	131.75			C	D	E	F	G
Jun-11	128.27			C	D	E	F	G
Jan 07	127.37			C	D	E	F	G
Apr 04	126.64			C	D	E	F	G
Feb 94	125.57			C	D	E	F	G
Nov 02	125.29			C	D	E	F	G
Dec 93	123.38			C	D	E	F	G
Feb-09	115.00				D	E	F	G
May 03	109.86				D	E	F	G
May 02	109.40				D	E	F	G
Dec 96	105.99				D	E	F	G
Nov 03	105.28				D	E	F	G
Jul 01	104.03				D	E	F	G
Aug 03	103.30				D	E	F	G
Aug 92	102.89				D	E	F	G
Dec-11	102.00				D	E	F	G
Nov-10	99.86				D	E	F	G
Dec 94	99.86				D	E	F	G
Dec 00	98.18				D	E	F	G
Jan 00	97.31				D	E	F	G
Dec 95	95.96				D	E	F	G
Jun 95	95.94				D	E	F	G
Nov 00	94.79				D	E	F	G
Oct 01	93.44				D	E	F	G
Oct 04	92.53				D	E	F	G
Oct-09	91.36					E	F	G
Jan 93	90.47					E	F	G
Jun 06A	89.19					E	F	G
Oct-10	89.01					E	F	G
Sep 95	88.86					E	F	G
Mar 00	86.70					E	F	G
Nov-11	85.96					E	F	G
Aug-09	85.08					E	F	G
Mar 96	81.39					E	F	G
Dec 04	81.23					E	F	G
Mar 95	75.43						F	G
Aug-08	73.99						F	G
Oct 91	73.48						F	G
Dec 89	70.56						F	G
Jun 05	70.40						F	G
Jun 94	70.02						F	G
Jun 92	67.73						F	G
Dec 06	67.22						F	G
Oct 93	67.17						F	G
Nov 96	66.00						F	G
Nov 05	65.81						F	G
Aug 07	64.99						F	G
Sep 94	62.01						F	G
Jul 04	59.31						F	G
Jun 06B	57.63						F	G
Jun 96	49.89						F	G
Jun 93	41.72							G
Sep 97	37.49							G

CONTROL STATIONS
SILICA (P>0.0001)

DATE	MEAN				
Jun 98	352.24	A			
Jan 02	297.65	A	B		
Jun 97	232.79		B	C	
Apr 99	196.90		B	C	D
Jan 07	192.34		B	C	D
Jan 99	168.62		B	C	D
Mar 98	184.02		B	C	D
Jan 08A	183.45		B	C	D
Jun 99	180.71		B	C	D
Jan 06	170.95		B	C	D
Apr 97	166.26		B	C	D
Mar 96	159.77		B	C	D
Feb 05	154.80		B	C	D
Dec 97	151.42		B	C	D
Mar 95	149.02			C	D
Jun-11	140.84			C	D
Nov 98	132.05			C	D
Nov 96	127.96			C	D
May 01	127.06			C	D
Jan 93	125.50			C	D
Jan 08B	125.17			C	D
Nov 02	123.57			C	D
May-10	119.84			C	D
Jun 95	118.44			C	D
Oct-09	115.61			C	D
Oct 93	114.86			C	D
Jul 01	109.76			C	D
Mar-11	109.26			C	D
May 02	106.51			C	D
Jul-09	106.31			C	D
Apr 02	104.61			C	D
Nov-10	104.05			C	D
Sep 94	102.48			C	D
Feb 07	101.15			C	D
Mar-09	100.42			C	D
May 03	96.70			C	D
Dec 96	96.43			C	D
Oct 01	95.98			C	D
Apr 04	94.61			C	D
Feb 94	94.58			C	D
Aug 03	93.15			C	D
May 03	92.54			C	D
Apr-09	92.44			C	D
Sep 00	88.76			C	D
Jun 92	88.80			C	D
Oct 04	86.37			C	D
Jun 06A	86.20			C	D
Oct 91	85.77			C	D
Aug-09	82.36			C	D
Dec 89	82.32			C	D
Apr 08	80.96			C	D
Feb-09	80.16			C	D
Dec 94	79.69			C	D
Dec 04	78.81			C	D
Jun 94	77.55			C	D
Aug 07	77.33			C	D
Dec 95	77.06			C	D
Jun 96	75.77			C	D
Nov-11	74.09			C	D
Aug-08	73.84			C	D
Jun 05	73.74			C	D
Jan 00	72.80			C	D
Nov 03	71.36			C	D
Nov 00	68.77			C	D
Nov 05	70.00			C	D
Dec 93	68.77			C	D
Sep 95	67.65			C	D
Dec 00	64.46			C	D
Aug 95	63.78			C	D
Jun 93	61.82			C	D
Sep 99	61.43			C	D
Mar 00	61.32			C	D
Jul 04	60.64			C	D
Sep 97	60.48			C	D
Oct-10	59.19			C	D
Dec-11	58.46			C	D
Dec 06	34.49				D
Jun 06B	32.33				D

Interpretation

The December 2011 data was in the middle of the range at experimental sites while control mean concentrations occurred near the bottom of the range. Highest concentrations encountered at control stations. No evidence of impact due to development.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
SALINITY o/oo (P>0.0001)

DATE	MEAN									
Jun 95	35.412	A								
Oct-09	35.253	A	B							
Dec-11	35.152	A	B	C						
Mar-11	35.140	A	B	C						
Jan 00	35.119	A	B	C						
Jan 99	35.118	A	B	C						
Nov-11	35.114	A	B	C						
Apr-09	35.112	A	B	C						
Mar-09	35.095	A	B	C	D					
Nov-10	35.081	A	B	C	D	E				
Jun 98	35.075	A	B	C	D	E				
Feb-09	35.076	A	B	C	D	E				
Oct 01	35.069	A	B	C	D	E				
Nov 02	35.057	A	B	C	D	E	F			
Nov 00	35.056	A	B	C	D	E	F			
Oct-10	35.052	A	B	C	D	E	F			
Mar 00	35.052	A	B	C	D	E	F			
Aug-09	35.036	A	B	C	D	E	F			
Jan 08B	35.030	A	B	C	D	E	F			
Nov 98	35.026	A	B	C	D	E	F			
Nov 03	35.012	A	B	C	D	E	F			
Jan 06	35.008	A	B	C	D	E	F			
Sep 99	35.003	A	B	C	D	E	F			
May-10	35.000	A	B	C	D	E	F			
Feb 07	34.984	A	B	C	D	E	F			
Jan 08A	34.978	A	B	C	D	E	F			
Aug-08	34.972	A	B	C	D	E	F			
Nov 05	34.964	A	B	C	D	E	F			
May 03	34.960	A	B	C	D	E	F			
Jul-09	34.958	A	B	C	D	E	F			
Jan 07	34.952	A	B	C	D	E	F			
Aug 07	34.951	A	B	C	D	E	F			
Dec 06	34.924		B	C	D	E	F	G		
Jul 01	34.916		B	C	D	E	F	G		
Aug 03	34.916		B	C	D	E	F	G		
Sep 00	34.907		B	C	D	E	F	G	H	
Dec 97	34.903		B	C	D	E	F	G	H	
Apr 02	34.875		B	C	D	E	F	G	H	
Dec 04	34.866		B	C	D	E	F	G	H	
Jun 96	34.863		B	C	D	E	F	G	H	
May 01	34.860		B	C	D	E	F	G	H	
Dec 93	34.829		B	C	D	E	F	G	H	I
Oct 04	34.829		B	C	D	E	F	G	H	I
Mar 98	34.828		B	C	D	E	F	G	H	I
Jan 93	34.822		B	C	D	E	F	G	H	I
Dec 00	34.813		B	C	D	E	F	G	H	I
Jun 06A	34.798		B	C	D	E	F	G	H	I
Jun 06B	34.789		B	C	D	E	F	G	H	I
Jun 05	34.787		B	C	D	E	F	G	H	I
Dec 94	34.781		B	C	D	E	F	G	H	I
Jun-11	34.775		B	C	D	E	F	G	H	I
Dec 96	34.743			C	D	E	F	G	H	I
Oct 91	34.730			C	D	E	F	G	H	I
Aug 92	34.721			C	D	E	F	G	H	I
May 02	34.701	J		C	D	E	F	G	H	I
Feb 94	34.699	J		C	D	E	F	G	H	I
Feb 05	34.678	J	K	C	D	E	F	G	H	I
Oct 93	34.652	J	K	CL	D	E	F	G	H	I
Jun 92	34.646	J	K	CL	D	E	F	G	H	I
Jul 04	34.645	J	K	CL	D	E	F	G	H	I
Mar 03	34.600	J	K	L	D	E	F	G	H	I
Jun 94	34.591	J	K	L	D	E	F	G	H	I
Apr 08	34.588	J	K	L		E	F	G	H	I
Jun 93	34.565	J	K	L	M		F	G	H	I
Sep 94	34.558	J	K	L	M		F	G	H	I
Mar 95	34.448	J	K	L	M			G	H	I
Sep 95	34.447	J	K	L	M			G	H	I
Jun 99	34.432	J	K	L	M				H	I
Sep 97	34.389	J	K	L	M					I
Jan 02	34.377	J	K	L	M					I
Apr 97	34.272	J	K	L	M					
Jun 97	34.261		K	L	M					
Dec 95	34.239			L	M					
Nov 96	34.165				M					
Apr 99	33.918					N				
Mar 96	33.541						O			
Dec 89	33.157							P		
Apr 04	29.900								Q	

CONTROL STATIONS
SALINITY o/oo (P>0.0001)

DATE	MEAN							
Jun 95	35.376	A						
Oct-09	35.211	A	B					
Mar-11	35.170	A	B	C				
Apr-09	35.164	A	B	C				
Jan 99	35.161	A	B	C				
Mar-09	35.150	A	B	C	D			
Dec-11	35.149	A	B	C	D			
Jan 00	35.144	A	B	C	D			
Nov-11	35.123	A	B	C	D			
Feb-09	35.111	A	B	C	D			
Nov 00	35.100	A	B	C	D			
Nov-10	35.093	A	B	C	D			
Oct-10	35.079	A	B	C	D			
Oct 01	35.066	A	B	C	D			
Nov 02	35.063	A	B	C	D			
Mar 00	35.062	A	B	C	D			
Nov 03	35.060	A	B	C	D			
Jan 08A	35.059	A	B	C	D			
Jan 08B	35.058	A	B	C	D			
Sep 99	35.057	A	B	C	D			
Nov 98	35.047	A	B	C	D			
May 03	35.043	A	B	C	D			
May-10	35.033	A	B	C	D			
Jul-09	35.030	A	B	C	D			
Aug-09	35.027	A	B	C	D			
Feb 07	35.022	A	B	C	D			
Jan 06	35.012	A	B	C	D			
Jun 98	34.998	A	B	C	D			
Nov 05	34.975	A	B	C	D			
Jan 07	34.969	A	B	C	D			
Aug-08	34.967	A	B	C	D			
Dec 06	34.975	A	B	C	D			
Aug 07	34.948	A	B	C	D			
Aug 03	34.935	A	B	C	D			
Dec 00	34.927	A	B	C	D			
Sep 00	34.918	A	B	C	D			
Jul 01	34.905	A	B	C	D			
Dec 97	34.894	A	B	C	D			
Apr 02	34.886	A	B	C	D			
Dec 93	34.886	A	B	C	D			
Apr 08	34.875	A	B	C	D			
Mar 98	34.872	A	B	C	D			
Dec 02	34.864	A	B	C	D			
Oct 04	34.834	A	B	C	D			
May 01	34.830	A	B	C	D			
Jun 06B	34.829	A	B	C	D			
Jan 93	34.810	A	B	C	D			
Jun-11	34.808	A	B	C	D			
Jun 05	34.773	A	B	C	D			
Feb 05	34.765	A	B	C	D			
Dec 96	34.758	A	B	C	D			
Aug 92	34.722	A	B	C	D			
May 02	34.716	A	B	C	D			
Oct 91	34.707	A	B	C	D			
Feb 94	34.669	A	B	C	D			
Dec 94	34.663	A	B	C	D			
Jul 04	34.638	A	B	C	D			
Jun 92	34.630	A	B	C	D			
Oct 93	34.629	A	B	C	D			
Jun 94	34.607	A	B	C	D			
Jun 93	34.597	A	B	C	D			
Mar 03	34.589	A	B	C	D			
Jun 06A	34.555	A	B	C	D			
Sep 94	34.545	A	B	C	D			
Sep 95	34.463	A	B	C	D	E		
Jun 96	34.440	A	B	C	D	E		
Mar 95	34.428	A	B	C	D	E		
Sep 97	34.373	A	B	C	D	E		
Jun 99	34.346	A	B	C	D	E		
Apr 97	34.299	A	B	C	D	E		
Dec 95	34.278	A	B	C	D	E		
Jun 97	34.257	A	B	C	D	E		
Nov 96	34.160		B	C	D	E		
Jan 02	34.021			C	D	E		
Apr 99	34.005				D	E		
Mar 96	33.571					E	F	
Dec 89	33.200						F	
Apr 04	30.277							G

Interpretation:

The changes in mean salinity are small with little variation suggesting little freshwater input along the coast. Both experimental and control site salinities are similar for many sample dates suggesting coastwide trends. Lowest mean salinities recorded to date occurred in the April 2004 survey.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
TURBIDITY (P>0.0001)

DATE	MEAN		
Jan 02	5.33	A	
May 02	1.16		B
Mar 03	1.11		B
Nov 02	0.99		B
Feb 94	0.79		B
Apr 02	0.73		B
May 03	0.69		B
Jun 97	0.65		B
Apr 04	0.57		B
Oct 91	0.53		B
Nov-11	0.48		B
Nov 03	0.48		B
Aug 03	0.46		B
Feb 07	0.45		B
Sep 99	0.41		B
Mar-11	0.40		B
Aug-08	0.39		B
Jul 04	0.35		B
Jun 93	0.35		B
Nov 96	0.35		B
May-10	0.34		B
Nov 05	0.34		B
Dec 89	0.32		B
Dec-11	0.32		B
Sep 97	0.31		B
Sep 94	0.30		B
Jun 94	0.30		B
Apr 97	0.29		B
Jun 06A	0.29		B
Feb 05	0.28		B
Apr-09	0.28		B
Apr 99	0.27		B
Jul-09	0.26		B
Jan 07	0.26		B
Mar-09	0.25		B
Jun 06B	0.23		B
Oct 04	0.23		B
Oct 93	0.23		B
Oct-09	0.22		B
Jun 99	0.22		B
Jun 05	0.21		B
Sep 00	0.21		B
May 01	0.20		B
Dec 96	0.20		B
Dec 04	0.20		B
Jul 01	0.19		B
Apr 08	0.19		B
Jan 06	0.19		B
Aug-09	0.18		B
Jan 08B	0.19		B
Jun-11	0.18		B
Oct-10	0.17		B
Jan 99	0.17		B
Mar 96	0.17		B
Dec 97	0.17		B
Oct 01	0.16		B
Dec 00	0.16		B
Mar 00	0.16		B
Sep 95	0.16		B
Jun 92	0.15		B
Jan 08B	0.15		B
Aug 92	0.15		B
Dec 95	0.15		B
Aug 07	0.15		B
Nov 00	0.14		B
Nov-10	0.14		B
Jun 95	0.14		B
Jan 00	0.14		B
Dec 94	0.13		B
Feb-09	0.13		B
Mar 95	0.13		B
Jan 93	0.12		B
Dec 93	0.11		B
Jun 96	0.11		B
Mar 98	0.11		B
Dec 06	0.10		B
Nov 98	0.10		B
Jun 98	0.06		B

CONTROL STATIONS
TURBIDITY (P>0.009)

DATE	MEAN		
Jan 02	9.12	A	
Feb 94	8.22	A	
Apr 02	3.32		B
Nov 02	3.20		B
May 02	2.52		B
Mar 96	1.91		B
Mar 03	1.88		B
Mar-11	1.48		B
Dec 89	1.48		B
Apr 04	1.47		B
May 03	1.23		B
Jun 97	0.98		B
Jul 04	0.60		B
Dec 96	0.55		B
Nov 96	0.53		B
Feb 07	0.49		B
Sep 97	0.47		B
Apr 97	0.43		B
Oct 91	0.43		B
Sep 94	0.42		B
Jan 08A	0.41		B
Jun 06A	0.40		B
Nov 05	0.39		B
Jun 93	0.39		B
Jan 08B	0.36		B
Oct-09	0.30		B
Aug 03	0.36		B
May-10	0.35		B
Nov-11	0.35		B
Aug-08	0.35		B
May 01	0.33		B
Jun 06B	0.32		B
Aug 07	0.30		B
Jun 05	0.29		B
Oct 01	0.29		B
Sep 99	0.29		B
Feb 05	0.28		B
Jan 07	0.28		B
Nov 03	0.28		B
Jun-11	0.28		B
Apr 08	0.27		B
Mar-09	0.27		B
Dec 00	0.26		B
Nov 00	0.26		B
Sep 00	0.26		B
Jan 06	0.26		B
Nov-10	0.25		B
Oct 04	0.24		B
Apr-09	0.24		B
Jun 95	0.23		B
Jul 01	0.23		B
Jun 99	0.23		B
Mar 95	0.21		B
Jan 99	0.21		B
Jul-09	0.20		B
Aug-09	0.20		B
Oct-10	0.20		B
Feb-09	0.20		B
Dec 04	0.19		B
Oct 93	0.19		B
Apr 99	0.186		B
Dec-11	0.18		B
Jun 94	0.16		B
Dec 97	0.16		B
Sep 95	0.16		B
Dec 06	0.14		B
Jun 96	0.13		B
Jun 92	0.13		B
Mar 00	0.13		B
Jan 00	0.13		B
Aug 92	0.13		B
Dec 95	0.13		B
Mar 98	0.11		B
Dec 94	0.10		B
Dec 93	0.09		B
Jan 93	0.08		B
Nov 98	0.08		B
Jun 98	0.04		B

Interpretation:

Lack of chronological order suggests that turbidity at the experimental stations has not been affected by the development. Highest turbidities have been at control stations with February 1994 and January 2002 being significantly greater than all other sample dates which is related to terrigeneous input during rainfall. Data tend to track among dates for sample sites suggesting coastwide trends.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
CHLOROPHYLL -a (P>0.0001)

DATE	MEAN					
Dec 89	0.493	A				
Mar 03	0.406	A	B			
Nov 02	0.359		B	C		
Jan 02	0.277		B	C	D	
Apr 97	0.271		B	C	D	E
Oct 01	0.262		B	C	D	E
Jun 97	0.235			C	D	E
Feb 07	0.229			C	D	E
Apr 02	0.227			C	D	E
Oct 91	0.213			C	D	E
Sep 97	0.209			C	D	E
May 02	0.209			C	D	E
Jan 08B	0.203			C	D	E
Mar-11	0.200			C	D	E
Jun 95	0.198			C	D	E
Dec 06	0.197			C	D	E
Nov 05	0.194			C	D	E
Apr 08	0.192			C	D	E
Nov-11	0.187			C	D	E
Jan 07	0.187			C	D	E
Mar-09	0.185			C	D	E
Dec 97	0.183			C	D	E
Sep 95	0.181			C	D	E
Feb 94	0.180			C	D	E
Aug-08	0.172			C	D	E
Feb-09	0.166			C	D	E
Oct-09	0.164				D	E
Dec-11	0.159				D	E
May-10	0.157				D	E
Aug-09	0.152				D	E
Aug 07	0.147				D	E
Apr-09	0.141				D	E
Jan 08A	0.140				D	E
Jun 05	0.139				D	E
Jan 00	0.138				D	E
Dec 95	0.138				D	E
Dec 04	0.136				D	E
Jan 06	0.136				D	E
Oct 04	0.132				D	E
Oct-10	0.131				D	E
Jan 93	0.127				D	E
Jul 01	0.126				D	E
Sep 99	0.123				D	E
Aug 03	0.118				D	E
Jun 06A	0.118				D	E
Jun 94	0.118				D	E
Aug 92	0.117				D	E
Jun 06B	0.116				D	E
Jul 04	0.116				D	E
Nov 03	0.115				D	E
Dec 96	0.114				D	E
Sep 94	0.113				D	E
Dec 94	0.111				D	E
May 03	0.110				D	E
Nov 96	0.108				D	E
Feb 05	0.106				D	E
Jun 92	0.105				D	E
Mar 00	0.101				D	E
Jul-09	0.096				D	E
Mar 96	0.092				D	E
Nov 98	0.091				D	E
Oct 93	0.088				D	E
May 01	0.086				D	E
Nov 00	0.086				D	E
Jun-11	0.086				D	E
Jun 98	0.083				D	E
Nov-10	0.082				D	E
Sep 00	0.080				D	E
Jun 93	0.080				D	E
Mar 98	0.079				D	E
Dec 93	0.077				D	E
Dec 00	0.064				D	E
Apr 99	0.064				D	E
Apr 04	0.062				D	E
Jun 99	0.057				D	E
Jun 96	0.054					E
Jan 99	0.051					E
Mar 95	0.050					E

CONTROL STATIONS
CHLOROPHYLL -a (P>0.0001)

DATE	MEAN						
Dec 89	0.540	A					
Sep 95	0.266		B				
Mar-09	0.247		B	C			
Feb-09	0.244		B	C			
Feb 94	0.243		B	C			
Mar-11	0.237		B	C	D		
Jun 95	0.232		B	C	D	E	
Apr 08	0.229		B	C	D	E	F
Jan 00	0.212		B	C	D	E	F
Jun 06B	0.201		B	C	D	E	F
Jan 02	0.196		B	C	D	E	F
Oct-10	0.192		B	C	D	E	F
Apr 02	0.190		B	C	D	E	F
Dec-11	0.189		B	C	D	E	F
Feb 07	0.189		B	C	D	E	F
Dec 06	0.187		B	C	D	E	F
Oct 01	0.186		B	C	D	E	F
Jan 93	0.184		B	C	D	E	F
Oct 91	0.180		B	C	D	E	F
Jan 08A	0.179		B	C	D	E	F
Nov 02	0.178		B	C	D	E	F
Nov 00	0.177		B	C	D	E	F
Nov-11	0.177		B	C	D	E	F
May 02	0.171		B	C	D	E	F
Mar 96	0.171		B	C	D	E	F
Jul 01	0.168		B	C	D	E	F
Dec 95	0.167		B	C	D	E	F
Mar 03	0.167		B	C	D	E	F
Dec 96	0.162		B	C	D	E	F
May 03	0.160		B	C	D	E	F
Aug 07	0.159		B	C	D	E	F
Jun-11	0.158		B	C	D	E	F
Jan 07	0.156		B	C	D	E	F
Sep 94	0.156		B	C	D	E	F
Jun 97	0.152		B	C	D	E	F
Nov 03	0.150		B	C	D	E	F
Mar 00	0.149		B	C	D	E	F
May-10	0.149		B	C	D	E	F
Dec 04	0.147		B	C	D	E	F
Mar 95	0.147		B	C	D	E	F
Sep 99	0.146		B	C	D	E	F
Nov 05	0.144		B	C	D	E	F
Oct-09	0.142		B	C	D	E	F
Feb 05	0.142		B	C	D	E	F
Apr 97	0.137		B	C	D	E	F
Jan 06	0.133		B	C	D	E	F
Aug-08	0.132		B	C	D	E	F
Jun 98	0.131		B	C	D	E	F
Sep 97	0.129		B	C	D	E	F
Nov-10	0.128		B	C	D	E	F
Oct 04	0.126		B	C	D	E	F
Jul-09	0.126		B	C	D	E	F
Dec 94	0.125		B	C	D	E	F
Jun 93	0.124		B	C	D	E	F
Jun 06A	0.123		B	C	D	E	F
Jun 94	0.123		B	C	D	E	F
Aug 92	0.121		B	C	D	E	F
Oct 93	0.120		B	C	D	E	F
Jun 92	0.120		B	C	D	E	F
Apr-09	0.117		B	C	D	E	F
Aug-09	0.112		B	C	D	E	F
Jan 08B	0.111		B	C	D	E	F
Jul 04	0.107		B	C	D	E	F
Dec 97	0.107		B	C	D	E	F
May 01	0.106		B	C	D	E	F
Nov 96	0.106		B	C	D	E	F
Dec 93	0.105		B	C	D	E	F
Aug 03	0.103		B	C	D	E	F
Mar 98	0.101		B	C	D	E	F
Jun 05	0.099		B	C	D	E	F
Apr 04	0.094			C	D	E	F
Dec 00	0.091			C	D	E	F
Sep 00	0.087			C	D	E	F
Nov 98	0.084			C	D	E	F
Jun 96	0.084			C	D	E	F
Apr 99	0.068				D	E	F
Jun 99	0.065					E	F
Jan 99	0.060						F

Interpretation:

Chlorophyll-a is not showing any significant trends associated with the development if chronology of any increase is relevant. Greatest mean concentration was encountered at the control stations. December 2011 mean value for experimental and control stations were in upper third of the range.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
TEMPERATURE `C (P>0.0001)

DATE	MEAN	GROUPING
Oct 93	29.3	A
Sep 94	28.6	B
Sep 97	28.1	C
Jun 93	28.1	C
Sep 95	28.0	C
Jul 04	27.9	CD
Sep 00	27.6	D E
Aug 92	27.5	D E F
Aug 03	27.5	D E F
Jun 96	27.4	E F G
Jul 01	27.4	E F G H
May 02	27.3	E F G H I
Oct 04	27.2	E F G H I J
Aug 07	27.2	E F G H I J
Nov 96	27.2	E F G H I J
Nov 02	27.1	E F G H I J K
Jun 05	27.1	E F G H I J K L
Oct 91	27.0	E F G H I J K L
Jun 95	27.0	F G H I J K L
Jun 06B	26.9	G H I J K L
Jun 94	26.9	G H I J K L M
Oct-09	26.9	H I J K L M N
Aug-08	26.8	I J K L M N
Oct 01	26.8	O J K L M N
Jun 92	26.7	O J K L M N
Jul-09	26.7	O P J K L M N
Jun 97	26.6	O P K L M N
Sep 99	26.6	O P K L M N
Nov 98	26.6	O P Q K L M N
Jun 06A	26.5	O P Q L M N
Jun 99	26.4	O P Q R M N
Apr 97	26.4	O P Q R S N
Nov 03	26.4	O P Q R S N
Aug-09	26.3	O P Q R S N
May 01	26.3	O P Q R S N
Nov 00	26.3	O P Q R S N
Apr 04	26.3	O P Q R S T
Dec 06	26.2	P Q R S T U
Dec 95	26.1	P Q R S T U
Dec 00	26.1	Q R S T U V
May 03	25.9	R S T U V
Nov 05	25.9	R S T U V W
Dec 93	25.9	R S T U V W
Mar 03	25.9	R S T U V W
Nov-11	25.87	R S T U V W
Dec 04	25.9	R S T U V W X
Nov-10	25.8	R S T U V W X
Jun 98	25.8	S T U V W X
Apr 02	25.8	S T U V W X
Oct-10	25.8	T U V W X
Dec 89	25.6	Y U V W X
Jan 07	25.6	Y Z V W X
Feb 05	25.5	Y Z V W X
Jun-11	25.5	Y Z V W X
Mar 98	25.4	Y Z AA W X
Dec 96	25.3	Y Z AA BB X
Mar-11	25.2	Y Z AA BB CC
Jan 06	25.1	Z AA BB CC
Dec-11	25.0	AA BB CC DD
Jan 08A	24.9	AA BB CC DD
Dec 94	24.9	AA BB CC DD
Jan 99	24.9	BB CC DD EE
May-10	24.9	BB CC DD EE
Apr 99	24.8	CC DD EE
Dec 97	24.7	CC DD EE
Feb 07	24.7	CC DD EE
Mar 95	24.5	DD EE
Mar 00	24.5	DD EE
Mar 96	24.5	DD EE
Feb 94	24.5	DD EE
Jan 08B	24.5	DD EE
Jan 02	24.4	EE
Apr 08	24.0	FF
Mar-09	23.9	FF
Apr-09	23.8	FF
Jan 00	23.7	FF
Feb-09	23.7	FF
Jan 93	22.7	GG

CONTROL STATIONS
TEMPERATURE `C (P>0.0001)

DATE	MEAN	GROUPING
Oct 91	29.0	A
Oct 93	28.8	A B
Sep 94	28.3	B
Oct 04	28.3	C
Sep 95	27.5	C
Jul 04	27.5	C D
Sep 97	27.5	C D
Nov 96	27.4	C D E
Aug 92	27.3	C D E
Sep 00	27.2	C D E F
Jun 93	27.2	C D E F
Jun 96	27.0	C D E F G
Aug 03	26.9	C D E F G
Nov 02	26.9	C D E F G H
May 02	26.8	C D E F G H I
Aug 07	26.7	C D E F G H I
Jun 95	26.7	D E F G H I
Aug-08	26.6	E F G H I J
Jun 92	26.5	F G H I J K
Jul 01	26.5	F G H I J K
Jun 94	26.5	F G H I J K
Jun 97	26.4	F G H I J K L
Nov 98	26.3	M G H I J K L
Oct-09	26.2	M G H I J K L
Nov 05	26.2	M G H I J K L
Aug-09	26.1	M N H I J K L
Dec 06	26.0	M N H I J K L
Oct 01	26.0	M N H I J K L
Jul-09	26.0	M N H I J K L
Apr 04	26.0	M N I J K L
Jun 05	26.0	M N O I J K L
Nov 03	25.9	M N O P I J K L
Jun 06B	25.9	M N O P I J K L
Jun 99	25.7	M N O P Q J K L
Sep 99	25.7	M N O P Q J K L
May 01	25.7	M N O P Q J K L
Nov 00	25.6	M N O P Q K L
Dec 04	25.6	M N O P Q R K L
Apr 97	25.6	M N O P Q R K L
Dec 95	25.6	M N O P Q R S K L
May 03	25.6	M N O P Q R S K L
Mar 03	25.6	M N O P Q R S K L
Dec 89	25.5	M N O P Q R S L
Dec 00	25.5	M N O P Q R S L
Nov-11	25.5	M N O P Q R S L
Oct-10	25.4	M N O P Q R S T
Jun 06A	25.4	M N O P Q R S T
Apr 02	25.4	M N O P Q R S T
Dec 93	25.4	M N O P Q R S T
Jan 06	25.2	N O P Q R S T U
Mar 98	25.2	N O P Q R S T U V
Jun 98	25.1	N O P Q R S T U V
Dec 96	25.1	N O P Q R S T U V
Feb 05	25.0	W O P Q R S T U V
Dec 97	25.0	W P Q R S T U V
Jun-11	24.9	W X Q R S T U V
Nov-10	24.9	W X Q R S T U V
Jan 07	24.8	W X Y Q R S T U V
Jan 08B	24.7	W X Y Z R S T U V
Dec 94	24.7	W X Y Z AA S T U V
May-10	24.5	W X Y Z AA BB T U V
Feb 07	24.5	W X Y Z AA BB T U V
Feb 94	24.4	W X Y Z AA BB U V
Jan 08A	24.3	W X Y Z AA BB U V
Jan 99	24.3	W X Y Z AA BB U V
Mar-11	23.3	W X Y Z AA BB U V
Mar 96	24.3	W X Y Z AA BB V
Apr 99	24.2	W X Y Z AA BB CC
Jan 02	24.1	X Y Z AA BB CC
Mar 95	24.1	X Y Z AA BB CC
Apr 08	24.0	X Z AA BB CC
Dec-11	23.9	Z AA BB CC DD
Mar 00	23.8	AA BB CC DD
Jan 93	23.7	BB CC DD
Mar-09	23.4	CC DD EE
Apr-09	23.2	DD EE FF
Feb-09	22.8	EE FF
Jan 00	22.7	FF

Interpretation:

Temperature is not related to the development but probably more to seasonal changes. The range encountered here is typical of Hawaiian nearshore waters. Both the experimental and control site temperatures are close on many sample dates suggesting coastwide trends.

TABLE 8. Continued.

EXPERIMENTAL STATIONS
OXYGEN % Sat (P>0.0001)

DATE	MEAN						
Jun 94	103	A					
Apr 97	103	A					
Jun 97	103	A					
Feb 94	103	A					
Sep 94	103	A					
Dec 94	103	A					
Sep 95	102	A					
Dec 93	102	A					
Jun 96	102	A					
Nov 96	102	A					
Jun 95	102	A					
Mar 96	102	A					
Oct 93	102	A					
Dec 95	102	A					
Aug 92	102	A					
Mar 95	102	A					
Jun 99	102	A					
Dec 96	102	A	B				
Mar 98	102	A	B				
Nov 98	102	A	B				
Dec 97	102	A	B				
Jan 93	102	A	B	C			
Jun 92	102	A	B	C			
Apr 99	102	A	B	C			
Jun 98	102	A	B	C			
Sep 97	102	A	B	C			
Sep 00	102	A	B	C	D		
Jun 93	102	A	B	C	D	E	
Jan 99	102	A	B	C	D	E	F
Mar 00	102	AG	B	C	D	E	F
Dec 00	102	AG	B	C	D	E	F
Oct 91	101	AG	BH	C	D	E	F
May 01	101	AG	BH	C	D	E	F
Nov 00	101	AG	BH	CI	DJ	E	F
Jan 00	101	AG	BH	CI	DJ	E	F
Jul 01	101	AG	BH	CI	DJ	EK	F
Sep 99	101	AG	BH	CI	DJ	EK	F
Dec 04	101	AG	BH	CI	DJ	EK	FL
Apr 02	100	AG	BH	CI	DJ	EK	FL
Nov05	100	GM	BH	CI	DJ	EK	FL
Dec 89	100	GM	BH	CI	DJ	EK	FL
Jun 05	100	GM	HN	CI	DJ	EK	FL
Jan 06	100	GM	HN	IO	DJ	EK	FL
Feb 05	100	GM	HN	IO	JP	EK	FL
Feb-09	100	GM	HN	IO	JP	K	FL
Jul 04	100	GM	HN	IO	JP	K	L
Oct 01	100	GM	HN	IO	JP	K	L
Jan 02	100	GM	HN	IO	JP	K	L
Oct 04	100	M	HN	IO	JP	K	L
Feb 07	100	M	HN	IO	JP	K	L
Aug 07	100	M	HN	IO	JP	K	L
Jan 08A	100	M	HN	IO	JP	KQ	L
Apr 08	100	M	HN	IO	JP	KQ	L
Apr-09	100	M	HN	IO	JP	KQ	L
May-10	100	M	N	IO	JP	KQ	L
Jun 06B	100	M	N	IO	JP	KQ	LR
Jun-11	100	M	N	O	JP	KQ	LR
Oct-09	100	M	N	O	P	KQ	LR
Jun 06A	100	M	N	O	P	KQ	LR
Dec-11	100	M	N	O	P	KQ	LR
May 02	99	M	N	O	P	KQ	LR
Jan 08B	99	M	N	O	P	Q	LR
Aug-08	99	MS	N	O	P	Q	R
Dec 06	99	MS	N	O	P	Q	R
Nov-10	99	MS	N	O	P	Q	R
Mar-09	99	MS	N	O	P	Q	R
Oct-10	99	MS	N	O	P	Q	R
Nov 03	99	MS	N	O	P	Q	R
Aug-09	99	MS	N	O	P	Q	R
Aug 03	98	S	N	O	P	Q	R
Mar 03	98	S	N	O	P	Q	R
Jan 07	98	S	N	O	P	Q	R
Jul-09	98	S		O	P	Q	R
Nov-11	98	S			P	Q	R
Nov 02	98	S			P	Q	R
Apr 04	98	S				Q	R
Mar-11	98	S					R
May 03	98	S					

CONTROL STATIONS
OXYGEN % Sat (P>0.0001)

DATE	MEAN						
Feb 94	103	A					
Dec 94	103	A					
Dec 95	103	A					
Dec 93	103	A	B				
Oct 93	103	A	B				
Aug 92	102	A	B				
Jun 96	102	A	B	C			
Sep 94	102	A	B	C			
Apr 97	102	A	B	C			
Jun 94	102	A	B	C			
Jan 93	102	A	B	C	D		
Jun 97	102	A	B	C	D		
Mar 96	102	A	B	C	D		
Jun 95	102	A	B	C	D		
Jun 92	102	A	B	C	D		
Sep 95	102	A	B	C	D		
Dec 96	102	A	B	C	D		
Nov 96	102	A	B	C	D		
Jun 93	102	A	B	C	D		
Sep 00	102	A	B	C	D		
Nov 98	102	A	B	C	D	E	
Apr 99	102	A	B	C	D	E	F
Mar 95	102	A	B	C	D	E	F
Jun 99	102	A	B	C	D	E	F
Jan 00	102	A	B	C	D	E	F
Sep 97	102	A	B	C	D	E	F
Mar 98	101	AG	B	C	D	E	F
Dec 97	101	AG	B	C	D	E	F
Nov 00	101	AG	B	C	D	E	F
Jun 98	101	AG	BH	C	D	E	F
Oct 91	101	AG	BH	C	D	E	F
Jan 99	101	AG	BH	C	D	E	F
Sep 99	101	AG	BH	C	D	E	F
May 01	101	AG	BH	C	D	E	F
Dec 00	101	AG	BH	C	D	E	F
Dec 04	101	AG	BH	C	D	E	F
Mar 00	101	AG	BH	CI	D	E	F
Jul 01	101	AG	BH	CI	D	E	F
Jan 06	101	AG	BH	CI	D	E	F
Jun 05	101	AG	BH	CI	D	E	F
Jul 04	100	AG	BH	CI	DJ	E	F
Apr-09	100	AG	BH	CI	DJ	E	F
Jan 02	100	G	BH	CI	DJ	E	F
Nov 03	100	G	BH	CI	DJ	E	F
Jun 06A	100	G	H	CI	DJ	E	F
Jun 06B	100	G	H	CI	DJ	E	F
Nov05	100	G	H	CI	DJ	E	F
Oct 01	99	G	H	CI	DJ	E	F
Jan 08A	99	G	H	CI	DJ	E	F
Feb 05	99	G	H	CI	DJ	E	F
Feb-09	99	G	H	CI	DJ	E	F
Dec-11	99	G	H	CI	DJ	E	F
Oct 04	99	G	H	CI	DJ	E	F
Aug-08	99	G	H	CI	DJ	E	F
Dec 89	99	G	H	CI	DJ	E	F
Apr 08	99	G	H	I	DJ	E	F
Dec 06	99	G	H	I	DJ	E	F
Aug-09	99	G	H	I	DJ	E	F
Aug 07	99	G	H	I	DJ	E	F
Nov-11	99	G	H	I	DJ	E	F
Oct-09	99	G	H	I	J	E	F
Jan 07	99	G	H	I	J	E	F
Feb 07	99	G	H	I	J	E	F
Jun-11	99	G	H	I	J	E	F
May-10	99	G	H	I	J	E	F
Apr 02	99	G	H	I	J	E	F
May 02	99	G	H	I	J	E	F
Apr 04	99	G	H	I	J		F
Jul-09	99		H	I	J		F
Oct-10	99		H	I	J		
Nov-10	99		H	I	J		
Mar-09	99		H	I	J		
Jan 08B	99		H	I	J		
Aug 03	98		H	I	J		
May 03	98			I	J		
Mar-11	98			I	J		
Mar 03	98				J		
Nov 02	98				J		

Interpretation:

The development is having no discernible impact on lowering the concentration of dissolved oxygen in adjacent waters. Mean oxygen concentrations are well within the normal range for nearshore marine waters (e.g. in excess of 100% saturation) and mean concentrations track closely on many sample dates suggesting coastwide trends for both control and experimental stations.

Continued.

EXPERIMENTAL STATIONS
pH Units (P>0.0001)

DATE	MEAN										
Aug 92	8.24	A									
Oct 91	8.24	A									
May 03	8.23	A									
Dec 93	8.23	A									
Dec 97	8.19	A	B								
Jan 99	8.18	A	B								
Nov 00	8.18	A	B	C							
Jan 00	8.18	A	B	C							
Dec 96	8.17	A	B	C	D						
Jun 94	8.15		B	C	D	E					
Apr 99	8.15		B	C	D	E					
Jan 08A	8.14		B	C	D	E					
Oct 01	8.14		B	C	D	E					
Jan 08B	8.13		B	C	D	E	F				
Sep 95	8.13		B	C	D	E	F				
Oct 04	8.13		B	C	D	E	F				
Apr-09	8.13		B	C	D	E	F				
Dec 00	8.13		B	C	D	E	F	G			
Mar 00	8.12		B	C	D	E	F	G			
May 01	8.12		B	C	D	E	F	G			
Jan 93	8.12		B	C	D	E	F	G			
Dec 95	8.12		B	C	D	E	F	G			
Feb 05	8.12		B	C	D	E	F	G	H		
Jun 98	8.12		B	C	D	E	F	G	H	I	
Jun 99	8.12		B	C	D	E	F	G	H	I	
Mar-09	8.12		B	C	D	E	F	G	H	I	
Nov 03	8.12		B	C	D	E	F	G	H	I	
Feb 07	8.12		B	C	D	E	F	G	H	I	
Feb-09	8.12		B	C	D	E	F	G	H	I	
Sep 97	8.11		B	C	D	E	F	G	H	I	J
Mar 96	8.11		B	C	D	E	F	G	H	I	J
Aug-08	8.11		B	C	D	E	F	G	H	I	J
Jan 06	8.10		B	C	D	E	F	G	H	I	J
Nov-10	8.10		B	C	D	E	F	G	H	I	J
Jun 06B	8.10		B	C	D	E	F	G	H	I	J
Apr 04	8.10		B	C	D	E	F	G	H	I	J
Apr 08	8.10		B	C	D	E	F	G	H	I	J
Mar 98	8.10	K	B	C	D	E	F	G	H	I	J
Dec 94	8.10	K	B	C	D	E	F	G	H	I	J
Dec 04	8.10	K	B	C	D	E	F	G	H	I	J
Oct-10	8.10	K	B	C	D	E	F	G	H	I	J
Sep 00	8.10	K	B	C	D	E	F	G	H	I	J
Aug 03	8.10	K	B	C	D	E	F	G	H	I	J
May-10	8.10	K	B	C	D	E	F	G	H	I	J
Jun 97	8.09	K	B	C	D	E	F	G	H	I	J
Nov 98	8.09	K	B	C	D	E	F	G	H	I	J
Jul 04	8.09	K	B	C	D	E	F	G	H	I	J
Aug-09	8.09	K	B	C	D	E	F	G	H	I	J
Dec-11	8.08	K		C	D	E	F	G	H	I	J
Dec 06	8.08	K			D	E	F	G	H	I	J
Aug 07	8.08	K			D	E	F	G	H	I	J
Mar 95	8.08	K			D	E	F	G	H	I	J
Oct-09	8.08	K			D	E	F	G	H	I	J
Dec 89	8.07	K				E	F	G	H	I	J
Jul-09	8.07	K				E	F	G	H	I	J
Apr 97	8.07	K				E	F	G	H	I	J
Jun 93	8.06	K				E	F	G	H	I	J
Mar-11	8.06	K				E	F	G	H	I	J
Mar 03	8.06	K				E	F	G	H	I	J
Feb 94	8.06	K				E	F	G	H	I	J
Jul 01	8.06	K				E	F	G	H	I	J
Jun 06A	8.06	K				E	F	G	H	I	J
Jan 07	8.04	K					F	G	H	I	J
Jun 95	8.04	K					F	G	H	I	J
Jun 92	8.04	K					F	G	H	I	J
Jun 96	8.03	K					F	G	H	I	J
Sep 99	8.02	K	L					G	H	I	J
Nov-11	8.02	K	L					G	H	I	J
Jun-11	8.02	K	L						H	I	J
Jan 02	8.02	K	L							I	J
Sep 94	8.01	K	L								J
Nov 96	8.00	K	L								
Nov 05	8.00	K	L								
Jun 05	8.00	K	L								
Oct 93	8.00		L								
Apr 02	7.95		L	M							
Nov 02	7.94		L	M							
May 02	7.91			M							

CONTROL STATIONS
pH Units (P>0.0001)

DATE	MEAN							
May 03	8.21	A						
Oct 91	8.21	A						
Dec 97	8.21	A	B					
Oct 01	8.20	A	B	C				
Apr 99	8.18	A	B	C	D			
Jan 00	8.18	A	B	C	D			
Dec 93	8.17	A	B	C	D			
Aug 92	8.17	A	B	C	D			
Jun 99	8.16	A	B	C	D			
Jun 94	8.16	A	B	C	D	E		
Jun 93	8.15	A	B	C	D	E		
Nov 00	8.15	A	B	C	D	E		
Jan 99	8.15	A	B	C	D	E		
Nov 03	8.14	A	B	C	D	E	F	
Jul 04	8.14	A	B	C	D	E	F	
Feb 94	8.14	A	B	C	D	E	F	
Aug 03	8.13	A	B	C	D	E	F	
Mar 00	8.13	A	B	C	D	E	F	
May 01	8.13	A	B	C	D	E	F	
Sep 00	8.13	A	B	C	D	E	F	
Dec 04	8.13	A	B	C	D	E	F	
Jun 98	8.12	A	B	C	D	E	F	
Oct 04	8.12	A	B	C	D	E	F	
Feb 05	8.12	A	B	C	D	E	F	
Nov 98	8.12	A	B	C	D	E	F	
Sep 97	8.12	A	B	C	D	E	F	
Jan 93	8.12	A	B	C	D	E	F	
Dec 94	8.11	A	B	C	D	E	F	
Dec 00	8.11	A	B	C	D	E	F	
Mar-09	8.11	A	B	C	D	E	F	
Jan 08B	8.11	A	B	C	D	E	F	
Mar 03	8.11	A	B	C	D	E	F	
Jun 96	8.11	A	B	C	D	E	F	
Mar 95	8.11	A	B	C	D	E	F	
Jun 92	8.11	A	B	C	D	E	F	
Mar 96	8.10	A	B	C	D	E	F	
Jan 08A	8.10	A	B	C	D	E	F	
Jun 06B	8.10	A	B	C	D	E	F	
Oct-09	8.10	A	B	C	D	E	F	
Apr 97	8.09	A	B	C	D	E	F	
Feb-09	8.09	A	B	C	D	E	F	
Apr-09	8.09	A	B	C	D	E	F	
Apr 04	8.09	A	B	C	D	E	F	
Jun 95	8.09	A	B	C	D	E	F	
Sep 95	8.09	A	B	C	D	E	F	
Aug-08	8.08	A	B	C	D	E	F	
Mar 98	8.08	A	B	C	D	E	F	
Jun 97	8.08	A	B	C	D	E	F	
Jul-09	8.08	A	B	C	D	E	F	
Dec 95	8.08	A	B	C	D	E	F	
Oct-10	8.08	A	B	C	D	E	F	
Apr 08	8.08	A	B	C	D	E	F	
Dec 96	8.07	A	B	C	D	E	F	
Jan 06	8.07	A	B	C	D	E	F	
Feb 07	8.07	A	B	C	D	E	F	
May-10	8.07	A	B	C	D	E	F	
Dec 89	8.07	A	B	C	D	E	F	
Jul 01	8.06	A	B	C	D	E	F	
Nov 05	8.06	A	B	C	D	E	F	
Aug-09	8.06	A	B	C	D	E	F	
Jun 06A	8.06	A	B	C	D	E	F	
Nov-10	8.06	A	B	C	D	E	F	
Sep 99	8.06	A	B	C	D	E	F	
Dec 06	8.06	A	B	C	D	E	F	
Sep 94	8.05	A	B	C	D	E	F	
Dec-11	8.05	A	B	C	D	E	F	
May 02	8.05	A	B	C	D	E	F	
Nov-11	8.04	A	B	C	D	E	F	
Aug 07	8.05	A	B	C	D	E	F	
Jan 07	8.05		B	C	D	E	F	
Nov 02	8.04		B	C	D	E	F	
Oct 93	8.03			C	D	E	F	
Apr 02	8.03				D	E	F	
Jun-11	8.01				D	E	F	
Jun 05	8.01				D	E	F	
Nov 96	7.99					E	F	
Jan 02	7.97						F	
Mar-11	7.84							G

Interpretation:
Lack of significant chronological order with the various sampling dates suggests that pH has not been impacted by the development. The mean pH values measured in this study are in the normal range encountered in Hawaiian nearshore waters.

differ significantly. However, the SNK Test found very few instances where clear statistical separation exists among the dates at either stations fronting the development or at control stations. The lack of clear statistical separation with the SNK Test is due to overlap among most dates (shown by overlapping letter designations in Table 8). Despite some statistical separation, it should be noted that (1) there is no evidence of increases or decreases in mean concentrations over time for any of the parameters in Table 8 and (2) the greatest sample date means are found at control sites for nitrate nitrogen, ammonia nitrogen, total nitrogen, silica, turbidity and chlorophyll-*a* which could suggest that natural inputs from land may be greater fronting control sites. The greatest sample date means for orthophosphorous, total phosphorus, salinity, temperature and pH are found at stations fronting the development. However, the differences between highest means by date at sites fronting the development relative to those at control sites are very small for salinity (35.412 ppt versus 35.376 ppt), temperature (29.3°C versus 29.0°C) and for pH (8.24 units versus 8.21 units) and have no biological impact.

The mean concentrations of both ortho-P and total-P were the highest to date for stations fronting the development in the April 2009 survey. In both cases, the April 2009 means are statistically greater than any of the other survey means measured since the commencement of this monitoring program in December 1989. The April 2009 means for phosphorus from the control stations were not elevated with the April 2009 mean ortho-P value lying in the upper third of the range and for total-P near the middle part of the range for the control station group (Table 8). As noted previously, the statistically greater means in April 2009 are due to exceptional elevation of both ortho-P and total-P at six of the eleven sample sites fronting the development. These high means in all but two sample sites (Station Nos. 2 and 5) were found at sites in proximity to the shoreline (Station nos. 1, 10, 16 and 17) suggesting that the source of these nutrients was from activities occurring on land. As in most of the previous surveys, there was little to no depression in salinity in proximity to the shoreline suggesting that no unusual freshwater input had occurred (i.e. surface runoff) and none of the other measured components were elevated at these six sample sites which further suggests that if the high phosphorus values were due to fertilizers, the fertilizers used had low nitrogen content. But again, it must be stressed that the usual carrier for the high ortho-P and total-P from land to the sea is freshwater arriving as groundwater or surface sheet flow from irrigation or rainfall sources and this was not evident in the salinity data. Irrespective of the source(s) of phosphorus seen in the April 2009 survey, the concentrations were back to normal levels in the subsequent surveys (July 2009 through December 2011).

As noted in the companion biological monitoring report, a golden algal species, *Chrysocystis fragilis*, had appeared at the Kaluakoi biological sample site (Station 9) in the April 2009 survey. However by the July 2009 survey, this alga had diminished in coverage but had increased in its geographical distribution and remained unchanged in subsequent surveys and finally disappearing in the March 2011 survey and this is unchanged with the most recent (December 2011) survey. There is no evidence to link the increase in phosphorus fronting the development in April 2009 to the appearance of this alga which is a species commonly found throughout the Hawaiian Islands.

The mean concentrations of parameters in the December 2011 survey were primarily spread from the upper third to the lower third of the range of values for all parameters for samples collected at sites fronting the development as well as at control sites (see Table 8). Discounting phosphorus at stations fronting the development in April 2009 as discussed above, the important point throughout this 264-month study is if these means were high or low at stations fronting the development, they were for the most part, similarly elevated or depressed at control stations away from the development. Inspection of Table 8 shows that there is no statistically significant separation among sample dates preceding golf course construction (December 1989 through January 1993) to those during construction (June and October 1993) or after completion of golf course construction (December 1993, to present) for any of the parameters supporting the contention that the development is not having an impact on water quality. The parallel increases or decreases in mean concentrations of materials at both control and experimental stations for a given sample date suggests that changes in these parameters appears to occur on a coast-wide or seasonal basis rather than inputs differentially occurring at stations fronting the development. These comments apply to all parameters, stations and sample dates with the exception of the April 2009 ortho-P and total-P from sample sites fronting the development and subsequent sampling in July, August, October 2009, May, October, November 2010, March, June, November and December 2011 confirms that these concentrations of phosphorus have come back to the usual levels.

b. Comparisons by Time: Entire Period, Period Prior to Construction, and Period Since Commencement of Construction

The question of whether the construction and operation of the Manele Bay Golf Course has had an impact on the water quality of Hulopoe Bay may be addressed by statistically comparing the means of water quality parameters at the stations in Hulopoe Bay (i.e., the experimental stations, nos. 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18) to the means of these parameters at control stations removed from the Hulopoe Bay development (station nos. 6, 7, 8, 12, 14). This analysis may be made considering three periods of time: spanning the entire period of this study (from December 1989 through December 2011), the preconstruction period (from December 1989 through January 1993), and the post-golf course construction period (since January 1993 to present). The results of the Wilcoxon 2-Sample Test applied to mean parameter values at stations adjacent to development (experimental) to those away from development (controls) over the entire period of this study are presented in Table 9. In this analysis, there are significant differences with nitrate, turbidity, chlorophyll-*a*, temperature, and the mean percent saturation of dissolved oxygen. Chlorophyll-*a* is significantly greater at control stations ($P<0.0001$) as is

TABLE 9. Results of the Wilcoxon 2-Sample Test examining mean concentrations of measured water quality parameters at experimental stations fronting the development (at Hulopoe Bay - station nos. 1,2, 3, 4, 5, 9, 10, 15, 16, 17, 18) and control stations away from development (station nos. 6, 7, 8, 12,14). This analysis considers the time period from December 1989 through December 2011 (78 sample dates). All values in the body of the table are in ug/l unless otherwise noted.

Parameter	Experimental Station Mean (n=851)	Control Station Mean (n=386)	Significantly Different?		
Nitrate N	2.75	2.32	**YES**	P <	0.01
	Nitrate is significantly greater at experimental stations (by 0.43 ug/l)				
Ammonia N	3.22	3.14	NO	P >	0.14
Total N	106.23	107.38	NO	P >	0.86
Ortho P	4.21	4.19	NO	P >	0.86
Total P	11.14	11.33	NO	P >	0.43
Silica	120.00	109.23	NO	P >	0.18
Salinity (o/oo)	34.727	34.741	NO	P >	0.16
Turbidity (NTU)	0.36	0.69	**YES**	P <	0.006
	Turbidity is significantly greater at control stations (by 0.33 NTU)				
Chlorophyll-a	0.147	0.152	**YES**	P <	0.0001
	Chlorophyll-a is significantly greater at control stations (by 0.005ug/l)				
Temp (C)	26.0	25.6	**YES**	P <	0.0001
	Temperature is significantly greater at experimental stations (by 0.4 C)				
Oxygen (% Sat)	100.7	100.4	**YES**	P <	0.03
	Dissolved oxygen is significantly greater at experimental stations (by 0.3%)				
pH (Units)	8.09	8.09	NO	P >	0.88

turbidity (P<0.006). Mean percent saturation of dissolved oxygen and temperature are significantly greater at stations fronting the development (P<0.01 and P<0.0001 respectively) while nitrate nitrogen is significantly greater (2.75 ug/l versus 2.32 ug/l) at stations fronting the development albeit these mean nitrate values are well below the open coastal dry water quality standard of 3.50 ug/l. Since the differences in mean nitrate concentrations are small (here 0.43 ug/l) between control and experimental sample sites, the significant differences for nitrate are probably due to naturally-occurring minor fluctuations in the concentration of this nutrient rather than to construction activities.

Table 10 presents the results of this analysis for the period preceding any golf course construction at Hulopoe Bay. In this analysis salinity was significantly greater (by 0.136 ppt) at experimental stations (those adjacent to development) and mean dissolved oxygen concentration was significantly greater (by 0.7%) at control stations.

Table 11 presents the results of the Wilcoxon 2-Sample Test applied to the data for the period from the commencement of golf course construction in January 1993 to present. This analysis found that turbidity was significantly higher at post-golf course construction control stations (by 0.34 NTU), chlorophyll-*a* was significantly greater (by 0.005 ug/l) at post-golf course construction control stations, temperature was significantly higher at post-golf course construction experimental stations by 0.4°C, mean percent saturation of dissolved oxygen was significantly greater at stations fronting the development by 0.2% and mean nitrate nitrogen was significantly greater by 0.43 ug/l at stations fronting the development in the post-construction period. Despite the statistically significant greater mean nitrate nitrogen at stations fronting the development, the differences in control and experimental means are small (0.43 ug/l) and are below the open coastal water quality standards (here 2.72 ug/l versus the standard of 3.50 ug/l). None of these changes are due to the development but represent seasonal and coast-wide trends. Albeit these differences are statistically significant, they are small and not biologically relevant.

In the past ammonia nitrogen has been elevated at both control and experimental stations with the greatest elevation occurring at control stations well away from the development (see Table 8). As noted above, ammonia nitrogen is a product of organism metabolism and may be naturally elevated due to aggregations of fish or it may be derived from the input of sewage (in the waters fronting the development or from the use of urea fertilizer adjacent to the ocean. If sewage is the source, salinity should be differentially lower at experimental stations (not true, see Table 8), silica, nitrate and orthophosphate should be elevated at experimental stations (not true, see Table 8 and discussion below).

If the source of ammonia nitrogen is from the golf course, a possible route would be via soil washed from the golf course to the sea during heavy rainfall. To test this hypothesis, we collected 1.5 liters of soil from the mouths of the intermittent stream beds above the high tide

TABLE 10. Results of the Wilcoxon 2-Sample Test examining mean concentrations of measured water quality parameters at experimental stations fronting the development (at Hulopoe Bay - station nos. 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18) and control stations away from development (station nos. 6, 7, 8, 12, 14). This analysis considers the time prior to any golf course construction (from December 1989 through January 1993). All values in the body of the table are in ug/l unless otherwise noted.

Parameter	Experimental Station Mean (n=47)	Control Station Mean (n=21)	Significantly Different?	
Nitrate N	3.19	2.77	NO	$P > 0.33$
Ammonia N	3.01	3.24	NO	$P > 0.56$
Total N	76.79	72.98	NO	$P > 0.34$
Ortho P	4.05	4.05	NO	$P > 0.97$
Total P	10.45	10.50	NO	$P > 0.77$
Silica	82.56	90.15	NO	$P > 0.62$
Salinity (o/oo)	34.568	34.432	**YES**	$P < 0.002$
nificantly greater at experimental stations (0.136 o/oo)				
Turbidity (NTU)	0.34	0.29	NO	$P > 0.50$
Chlorophyll-a	0.166	0.155	NO	$P > 0.50$
Temp (C)	26.4	27.0	NO	$P > 0.21$
Oxygen (% Sat)	102.1	102.8	**YES**	$P < 0.04$
tration is significantly greater at control stations (0.7%)				
pH (Units)	8.14	8.11	NO	$P > 0.12$

TABLE 11. Results of the Wilcoxon 2-Sample Test examining mean concentrations of measured water quality parameters at experimental stations fronting the development (at Hulopoe Bay - station nos. 1,2, 3, 4, 5, 9, 10, 15, 16, 17, 18) and control stations away from development (station nos. 6, 7, 8, 12, 14). This analysis considers the time since the commencement of golf course construction (since June 1993 to the present December 2011 survey). All values in the body of the table are in ug/l unless otherwise noted.

Parameter	Experimental Station Mean (n=804)	Control Station Mean (n=365)	Significantly Different?	
Nitrate N	2.72	2.29	**YES**	P < 0.02
Nitrate N is significantly higher at post-construction experimental stations (by 0.43 ug/l)				
Ammonia N	3.24	3.13	NO	P > 0.11
Total N	107.95	109.37	NO	P > 0.96
Ortho P	4.22	4.20	NO	P > 0.85
Total P	11.18	11.39	NO	P > 0.39
Silica	122.19	110.33	NO	P > 0.12
Salinity (o/oo)	34.741	34.756	NO	P > 0.14
Turbidity (NTU)	0.37	0.71	**YES**	P < 0.004
Turbidity is significantly higher at post-construction control stations (by 0.34NTU)				
Chlorophyll-a	0.144	0.149	**YES**	P < 0.0001
at post-construction control stations (by 0.005 ug/l)				
Temp (`C)	26.0	25.6	**YES**	P < 0.0001
t post-construction experimental stations (by 0.4 `C)				
Oxygen (% Sat)	100.6	100.4	**YES**	P < 0.03
ter at post-construction experimental stations (by 0.2%)				
pH (Units)	8.09	8.09	NO	P > 0.91

marks at Hulopoe and the Makole control site in September 1997. Five hundred ml of soil from each site was mixed with 750 ml of seawater from station 4 (i.e., collected about one kilometer from shore) and allowed to soak for an 11-hour period at which time the liquid leachate was sampled for nutrient concentrations. The results of the nutrient analyses are given in Table 12. Based on these samples, the Hulopoe Gulch sample suggests that little if any nitrogen or phosphorus nutrients are being carried to the sea via the soil. The leachate from the control site at Makole Gulch contained extremely high concentrations of nitrogen and phosphorus nutrients. This result is puzzling in that it suggests high nutrient concentrations should be present along the shore at Makole which is not the case. To further substantiate or refute the September 1997 results, pairs of soil samples were collected from the same locations in December 1997. These soil samples were analyzed by the University of Hawaii Agricultural Diagnostic Service Center for phosphorus, nitrate and ammonia nitrogen. The results of this analysis (Table 12) confirm the leachate findings where nutrient concentrations are considerably higher in the soil from the control site at Makole than at Hulopoe.

In the past, ammonia nitrogen concentrations increased at all stations but have been most apparent at stations fronting the development at Hulopoe Bay; more recently the concentration of this nutrient decreased (third and fourth quarter 2007) but was elevated in the first quarter 2008 (April) survey and decreased in recent surveys (since August 2008 to present). The sources of these changes are unknown but they do not appear to be from land-derived input or the reuse of treated sewage effluent as an irrigant. Thus the increase is attributed to an unidentified natural source such as from the metabolic activities of fishes, invertebrates or spinner porpoises in Hulopoe Bay. On 14 January 1999 school of the big-eye scad or akule was encountered over the sand in the inner part of Hulopoe Bay. Several water quality samples were collected in the vicinity of this school and the mean concentration of ammonia nitrogen measured in proximity to the school was 6.21 ug/l which is more than three times greater than the state standard. These data support the contention that the relatively high concentrations of ammonia nitrogen measured in this study are from natural sources. None of these analyses suggest that the construction and subsequent operation of the golf course at Hulopoe Bay has caused a biologically meaningful statistically significant change in any water quality parameter. Other than the ortho-P and total-P at sites fronting the development in April 2009 and ammonia nitrogen and total nitrogen (discussed below), the values reported above are well within the normal range seen in marine environments and the statistically significant changes are not linked to changes in land use.

c. Short-Term Changes In Water Quality

As noted above, scheduling problems precluded the field sampling for the first quarter 2006 in the January through March period and again over the last two quarters of 2007 and 2008. Because our understanding of short-term variability in water quality parameters is limited, we

TABLE 12. Results of soil leaching experiment using seawater from an offshore station (no.4), allowing leaching from soil to water over an eleven-hour period and sampling the leachate (water) for nitrogen and phosphorus in September 1997. Soil samples are from the intermittent streambeds at Makole (control site) and Hulopoe (experiment site adjacent to the golf course and hotel). Note that two water samples were taken from the Hulopoe Gulch leachate. At the bottom of the table are nutrient data taken from pairs of soil samples collected from the same sites in December 1997 and analyzed by the University of Hawaii Agricultural Diagnostic Service Center. All values are in ug/l.

Location	Nitrate N	Ammonia N	Total N	Ortho P	Total P	Silica
Station 4						
Water	ND	6.16	81.90	ND	6.82	15.68
LEACHING EXPERIMENT						
Makole Gulch Soil						
(Control)	14210.00	1123.50	15414.00	348.75	480.50	3864.00
Hulopoe Gulch Soil						
Sample A	24.64	6.44	112.98	7.44	17.36	661.92
Sample B	19.32	5.46	87.08	6.51	17.05	657.44

SOIL ANALYSIS

Location	Nitrate N	Ammonia N	Phosphorus
Makole Gulch Soil (Control)			
Sample A	612.00	289.00	197.00
Sample B	883.00	285.00	209.00
Mean	747.50	287.00	203.00
Hulopoe Gulch Soil			
Sample A	487.00	2.00	10.00
Sample B	90.00	ND	9.00
Mean	288.50	1.00	9.50

elected to carry out two quarterly sampling events spaced one day apart to examine this variability, thus minimally fulfilling the quarterly sampling requirements but gaining insight into this variability. Accordingly, a complete set of water quality samples (21 sites) were completed on 28 June 2006 and a second full set of samples were collected on the following day (29 June) to cover the first and second quarters of 2006. This again was undertaken on 25 January 2008 and on the following day (26 January) to cover the third and fourth quarters of 2007. In the case of the last two quarterly surveys for 2008, sampling was carried out on 3 February 2009 with the expectation that a third set of water quality samples spaced one day apart would be collected. However, sampling was curtailed by an incident involving a Hawaiian monk seal forcing us from the water. Later the same day under very hazardous sea conditions, the chartered vessel broke down and required towing, thus ending the February 2009 survey with only one set of water samples. As a consequence, the second set of samples was collected 35 days later (on 10 March 2009) for comparative purposes. Because of the long period between the two (3 February and 10 March 2009) surveys, these data have not been considered in the analyses of samples collected at two closely spaced points in time.

Similarly, the marine biological survey work was doubled up and the results of the short-term (28-30 June 2006 and 25-27 January 2008) variability are given in the companion marine biological report. However, the difficulties with the monk seal curtailed biological sampling on the 3 February 2009 survey thus two complete biological field surveys were carried out on 10-12 March 2009 and were presented in the companion report.

Inspection of the means of water quality parameters by survey date as given in Table 8 show that means vary considerably from quarter to quarter irrespective of proximity to the development at Hulopoe Bay. Usually, the measured concentrations for most parameters track between sites fronting the development to those measured at control sites for a given date but variability is relatively high between dates (Table 8). The question addressed in this examination of short-term variability is, "Is the variability in measured concentrations similarly large at short time scales (ca. 24 hours) as seen on longer (quarterly) time scales?" To address this question, water quality samples were collected on two occasions spaced one day apart as noted above and the means of each parameter from each date were compared using the nonparametric Wilcoxon Two-Sample Test. The results of this test are given in Table 13 for the June 2006 data and in Table 14 for the January 2008 data. In June 2006 (Table 13), the mean concentrations for orthophosphorous and silica were significantly greater on 28 June than on 29 June and the means for temperature and pH were significantly greater on 29 June over 28 June. In the case of the January 2008 surveys (Table 14), the means for ammonia nitrogen, total nitrogen, total phosphorus, silica and temperature were all significantly greater on 25 January relative to the following day (26 January). Inspection of the June 2006 data (Table 13) suggests that despite statistical separation among the means of these four parameters over a two-day period, the numeric differences are not that large. However, data from the January 2008 surveys (Table 14)

TABLE 13. Wilcoxon Two-Sample Test results comparing arithematic mean concentrations of water quality parameters between 28 June and 29 June 2006 (n=32). These data combine routinely sampled control and experimental stations (ie, station nos. 1- 18). All means in the body of the table are ug/l unless otherwise noted.

Parameter	28 June 2006 Mean	29 June 2006 Mean	Significantly Different?	
Nitrate N	3.95	2.07	NO	$P > 0.09$
Ammonia N	2.31	2.06	NO	$P > 0.56$
Total N	94.69	90.50	NO	$P > 0.92$
Ortho P	5.30	4.30	**YES**	$P < 0.03$
	28 June 2006 mean significantly higher			
Total P	13.76	12.77	NO	$P > 0.10$
Silica	88.26	49.72	**YES**	$P < 0.009$
	28 June 2006 mean significantly higher			
Salinity (o/oo)	34.722	34.801	NO	$P > 0.65$
Turbidity (NTU)	0.32	0.26	NO	$P > 0.57$
Chlorophyll-a	0.120	0.142	NO	$P > 0.27$
Temperature (°C)	26.2	26.6	**YES**	$P < 0.02$
	29 June 2006 mean significantly higher			
Oxygen (% Sat)	99.5	99.7	NO	$P > 0.56$
pH (units)	8.05	8.10	**YES**	$P < 0.0003$
	29 June 2006 mean significantly higher			

TABLE 14. Wilcoxon Two-Sample Test results comparing arithematic mean concentrations of water quality parameters between 25 January and 26 January 2008 (n=32). These data combine routinely sampled control and experimental stations (ie, station nos. 1- 18). All means in the body of the table are ug/l unless otherwise noted.

Parameter	25 January 2008 Mean	26 January 2008 Mean	Significantly Different?	
Nitrate N	2.11	1.95	NO	$P > 0.51$
Ammonia N	2.05	0.92	**YES**	$P < 0.008$
	25 January 2008 mean significantly higher			
Total N	170.28	145.16	**YES**	$P < 0.003$
	25 January 2008 mean significantly higher			
Ortho P	4.19	4.13	NO	$P > 0.79$
Total P	12.15	10.04	**YES**	$P < 0.0001$
	25 January 2008 mean significantly higher			
Silica	219.66	129.69	**YES**	$P < 0.0001$
	25 January 2008 mean significantly higher			
Salinity (o/oo)	35.004	35.039	NO	$P > 0.29$
Turbidity (NTU)	0.23	0.24	NO	$P > 0.73$
Chlorophyll-a	0.152	0.174	NO	$P > 0.53$
Temperature (°C)	24.8	24.6	**YES**	$P < 0.05$
	25 January 2008 mean significantly higher			
Oxygen (% Sat)	99.8	99.1	NO	$P > 0.80$
pH (units)	8.13	8.12	NO	$P > 0.88$

suggest a greater fluctuation between the two sample days. Perhaps more importantly, none of the means were identical between the two sample periods which supports the contention that variability in these water quality parameters on short temporal scales appears to be the norm and encountering statistically significant differences between different dates does not mean that the water quality is necessarily degrading.

d. Recent Changes in Total Nitrogen

Table 15 presents a summary of mean total nitrogen (TN) concentrations at stations fronting the development and at control stations in two time periods: preconstruction and during construction. Inspection of this table shows that TN has increased since the time construction began relative to the preconstruction period when considering all stations together (Table 15, top). However, examination of the mean total TN values for all stations fronting the development relative to the mean TN values for the control stations shows the control stations to have greater means when considering all survey periods together (Table 15, middle). Furthermore, inspection of the mean total nitrogen values for stations fronting the development relative to the control stations mean value in the period since the commencement of construction to present (Table 15, bottom), shows that the greatest mean values are again found at control stations suggesting that increases have occurred coast-wide and not differentially greater at stations fronting the development. Finally, inspection of the mean TN values from each survey period (Table 8) indicates an increasing trend with some 2001-2003 and 2007-2008 surveys. The question may be raised, what has caused the fluctuations in total nitrogen over time?

Total nitrogen is a measure of all forms (inorganic and organic) of nitrogen present in a sample. If the water sample is filtered prior to analysis, the analysis will yield total dissolved nitrogen (TDN) and if it is not filtered as in the present case, it yields total nitrogen (TN). Subtracting the inorganic nitrate and ammonia nitrogen from total nitrogen yields total organic nitrogen (TON). Again, if the sample is filtered yielding total dissolved nitrogen, subtracting the inorganic nitrogen (nitrate and ammonia nitrogen) yields dissolved organic nitrogen (DON), i.e.,

$$DON = TN\ (filtered) - NO_3 - NH_4$$ (See Smith *et al.* 1987; Sharp *et al.* 2002).

Similarly,

$$TON = TN - NO_3 + NH_4$$

In marine environments DON commonly makes up 70 to over 90% of the total nitrogen fraction that is measured (Sommerville and Preston 2001). Dissolved organic nitrogen (DON) is a subset of total organic nitrogen (TON) thus with DON in the expected range of 70 to 90% of the total nitrogen fraction, TON should be greater. In the Lana'i samples, TON comprises about

TABLE 15. Grand mean values of total nitrogen or TN, total organic nitrogen (TON), nitrate nitrogen (NO_3) and ammonia nitrogen (NH_4) from samples collected in the waters fronting Hulopoe Bay (station numbers 1-5, 9, 10, 15-18) and the control site stations (nos. 6-8, 12 and 14) in the pre-golf/residential construction and the during golf/residential construction periods. Data are presented as inorganic and organic fractions in ug/l with the percent contribution of each fraction. Also given are the sample sizes (n) in parentheses.

	Inorganic Fraction				**Organic Fraction**	
Site/Time	**TN**	**NO_3**	**NH_4**	**Percent Inorganic**	**TON**	**Percent Organic**
1. All Stations						
All Preconstruction Stations (n=68)	75.61	3.06	3.08	8.1	69.47	91.8
All During Construction Stations (n=1169)	108.39	2.59	3.20	5.4	102.60	94.6
2. All Survey Periods						
All Hulopoe Stations (n=851)	106.23	2.75	3.22	5.6	100.26	94.4
All Control Stations (n=386)	107.38	2.32	3.14	5.1	101.92	94.9
3. During Construction Only						
Hulopoe Stations (n=804)	107.95	2.72	3.24	5.5	101.99	94.5
Control Stations (n=365)	109.37	2.29	3.13	5.0	103.95	95.0

94-95% of the TN and the inorganic fraction is from 5 to about 6% of the total (see Table 15). Thus the majority of the TN in waters along the south shore of Lana'i is from organic sources (TON). In marine habitats, sources of TON include the bacterial breakdown of plant and animal protein materials from organic molecules to amino acids. On land, sources of TON include the same sources (i.e., breakdown of animals and plants) and again require the action of bacteria (Sommerville and Preston 2001).

Table 15 presents the results of calculations determining the percent of total nitrogen that is inorganic from the organic fraction. In the preconstruction period, the inorganic fraction of TN is 8.1% of the total and in the during construction period, it is 5.4%; at stations fronting the development it is 5.6% and at control stations it is 5.1%. In the during construction period, the calculated inorganic fraction is 5.5% at stations fronting the development and 5.0% at control stations. Fertilizers applied to golf courses are usually comprised of inorganic forms of nitrogen and phosphorus; the nitrogen component is usually in the form of nitrate and/or ammonium nitrogen and the phosphorus is in the biologically active orthophosphorous form. Fertilizers used on the Manele Golf Course are in the inorganic form. Since more than 94% of the TN measured in the ocean fronting the Hulopoe Bay development is (1) in the organic form, (2) has mean concentrations no different at control sites and (3) has shown no continuing temporal increase in more than 20 years of monitoring, the golf course is probably not contributing to the TN measured along the south coast of Lana'i. However, inspection of TN data in past reports as well in the present one, shows an obvious oscillations in TN in the waters along the south Lana'i coastline (Tables 8 and 16). Inspection of this in Table 16 suggests that TN began increasing in late 1999 and remained at a greater concentration through mid-2003 and declined in concentrations in 2004-06 but then increased in the December 2006 and January 2007 surveys. However, in the February 2007 survey, mean TN again decreased to previous low mean values but by August 2007 was once again elevated and remained so through the August 2008 survey, then decreasing in the February 2009 survey and again rising a month later (March 2009) and declined in subsequent surveys (April, July and August 2009) but again increased with the October 2009, dropping with the March and June 2011 surveys but once again rising in the November and December 2011 surveys (see Table 16). It should also be pointed out that if the TN is either elevated or depressed at stations fronting the development on a given survey it often tracks in a similar fashion at the control stations for that date (Table 16).

If the increases in TN in Lana'i waters were from land sources, there should be an evident gradient present with greatest concentrations in samples collected adjacent to land. In some surveys this appears to be the case but in many others, the greatest elevation in TN occurs at stations well offshore. Thus offshore of Hulopoe gulch, the gradient has been evident with greatest concentrations close to shore in some surveys while in other surveys (and locations) the gradient was reversed where greatest concentrations were found in samples collected at greatest

TABLE 16. Mean total nitrogen (TN) measured at eleven stations fronting the development at Hulopoe Bay and eight control stations located east of Hulopoe from 38 survey periods over a 19-year period to demonstrate the temporal changes in TN through this period of time. Data are given in ug/l and are from previous reports.

Survey Date	Hulopoe Station Survey Means Mean TN	Control Station Means Mean TN
Dec 2011	111.55	112.25
Nov 2011	106.58	105.77
Jun 2011	74.14	75.71
Mar 2011	92.51	82.41
Nov 2010	129.82	134.31
Oct 2010	138.01	138.55
May 2010	118.48	117.91
Oct 2009	130.03	125.58
Aug 2009	92.50	97.44
Jul 2009	105.67	107.01
Apr 2009	107.29	108.77
Mar 2009	109.10	121.01
Feb 2009	70.98	80.59
Aug 2008	145.10	145.07
Apr 2008	102.84	107.68
Jan 2008A	169.18	172.70
Jan 2008B	151.80	130.56
Aug 2007	124.15	133.22
Feb 2007	94.03	88.03
Jan 2007	211.46	211.79
Dec 2006	133.55	170.10
Jun 2006B	91.32	88.70
Jun 2006A	98.55	86.20
Jan 2006	84.74	82.60
Nov 2005	97.10	59.61
Feb 2005	101.63	110.35
Oct 2004	98.79	106.93
Jul 2004	103.97	98.73
Nov 2003	103.42	95.03
Mar 2003	195.96	203.87
Nov 2002	184.93	305.45
May 2002	131.21	139.89
Oct 2001	112.81	100.20
Mar 2000	111.52	112.84
Sep 1999	100.24	93.88
Nov 1998	99.27	99.96
Apr 1997	91.26	91.76
Jun 1996	83.75	84.56
Feb 1994	81.29	80.92
Aug 1992	77.24	59.89

distance from land. If the gradient is present, it is usually evident at both stations fronting the development as well as at control stations suggesting inputs on a coast-wide basis which may be related to runoff occurring with high rainfall events (such as in the 2002 high rainfall and subsequent events) which probably washed plant-based detritus into the ocean. Breakdown of these detrital materials by bacteria could serve as a source for increased TON fractions.

What are the possible sources of inorganic nitrogen in Lanai's coastal waters? Sources of inorganic nitrogen in oceans and on land include the fixation of atmospheric nitrogen by bacteria, lightening (which is more important over land), and from the breakdown of organic molecules into ammonia nitrogen, nitrite and nitrate (Milne 1995, see Figure 12.3). Wollast (1993) points out that this breakdown of organic nitrogen to the inorganic forms (NO_3, NO_2 and NH_4) is a major pathway of nitrogen flux in coastal oceans and Smith (1984) notes that fixation of atmospheric nitrogen by bacteria is a dominate source of inorganic nitrogen in marine autotrophic systems (such as on coral reefs). More recently Karl *et al.* (1997) notes that inorganic nitrogen fixation by mid-ocean cyanobacteria may fuel up to half of the new production in those systems. Lastly, despite the increases and oscillations in TN in Lanai's coastal waters in recent years, these increases are small relative to the dissolved nitrogen concentrations measured below the photic (lighted) zone of the mid-Pacific ocean. Karl *et al.* (2001) note nitrate/nitrite measurements in excess of 550 ug/l which is about twice the highest TN concentrations measured here.

e. The April 2009 Change in Phosphorus

As noted above, both total phosphorus and orthophosphorous were elevated at six of the eleven stations sampled in the area fronting the development at Hulopoe in the April 2009 survey. The question arises as to possible sources for these materials. The highest concentrations were found at sites close to the shoreline suggesting that inputs were coming from land. However, there was little evidence of freshwater input which would be the obvious transport mechanism carrying excess phosphorus (from fertilizers) to the ocean either via sheet flow following heavy rainfall or groundwater input. In addition there had been little rainfall since the previous survey when phosphorus concentrations were in their normal range which would have caused surface runoff to occur. Furthermore the highest concentrations of phosphorus were found at the shoreline fronting the Hulopoe Bay Beach Park albeit elevated concentrations were encountered at sample sites located along the foot of the sea cliff fronting the Manele Bay Golf Course. If sewage were the source of the elevated phosphorus, other parameters (nitrate, ammonia, total nitrogen and silica) should have been similarly elevated which they were not and because freshwater is a major component of sewage, salinity should have been strongly depressed which it was not. If the source of the elevated phosphorus was from excessive use of fertilizers, again salinity should have been lower than normal in the samples because freshwater would be the probable carrier of the phosphorus from land to the sea and there is a reasonable probability that nitrogen would have been also elevated, because most fertilizers have nitrogen as a component. Furthermore, studies on the movement of materials through soil horizons has found that nitrate nitrogen with its negative charge is carried via irrigation water to the underlying groundwater (Green 1981). Leaching of applied phosphorus is unlikely because of its low solubility and high reactivity (sorption) in soils (Green 1991, Soicher and Peterson 1997). Thus at this point in time, the source(s) for the elevated phosphorus encountered in the April 2009 field sampling in Hulopoe Bay remain unknown.

Despite the April 2009 spike in phosphorus at six of the eleven stations sampling the marine environment fronting the development at Hulopoe Bay and the golf course to the west, sampling carried out subsequently in July, August and October 2009, May, November 2010 as well as in March, June, November and December 2011 found that the concentrations of phosphorus at these six stations as well as at all others had returned to normal concentrations which are no different from the concentrations measured over the last twenty years at these locations. Thus with the disappearance of the phosphorus spike, we may never determine the source of the high concentrations encountered in April 2009. Despite the transitory spike, there was no evidence of any measurable impact or change to the marine communities resident to the waters where the high phosphorus concentrations were measured.

However in the October 2010 survey, orthophosphorous was in the usual range at both control stations as well as at those fronting the development but total phosphorus was elevated at both station groups (Table 8). The fact that this increase appeared across all stations suggests that it was coast-wide and had nothing to do with the development at Hulopoe. Mean total phosphorus concentrations have declined with recent surveys (November 2010, March, June, November and December 2011) to the middle and lower parts of the range at both stations fronting Hulopoe Bay as well as at control stations (Table 8).

Table 17 presents the amount of nitrogen and phosphorus used as fertilizer for the Manele Bay Golf Course in the 1995 - 2011 period. Inspection of Table 17 shows that the application of fertilizers has been somewhat variable though the years. Initially (in 1995-96), only dry fertilizer was used but in 1997 golf course managers commenced supplementing this with liquid fertilizers. In Table 17 conversion of the liquid fertilizer data has been made using the assumption that a gallon of liquid fertilizer has the same weight as water (i.e., one gallon weighs 8.35 pounds). In 1997, 4% by weight of the total fertilizer used was in liquid form; the contribution of liquid fertilizers has oscillated through the years going as high as 13.3% in 2006 to 1.1% in 2008 of the total used. After April 2011 all fertilizer used is in the liquid form and the weight used is supplied by the Golf Course Superintendent. It should be noted that up through 2007 the fertilizer use data was broken down by amount used in each golf area (i.e., greens, tees, and roughs and fairways) but commencing in 2008 and continuing through the first quarter of

TABLE 17. Fertilizer use at the Manele golf Course for 1995 through 2011 given in terms of grams of material used per square meter per day or over the period of a year. Areas that are the greens (area = 1.29 ha), tees (area = 2.21 ha) and the roughs plus fairways (area=31.51ha) Data courtesy of the Manele Bay Golf Course. Note that the third quarter 2009 is missing and April 2011 data are missing.

Area	Annual Application gm N/m2/yr	gm P/m2/yr	N : P Ratio
1995			
Greens	63.00	15.40	
Tees	52.10	16.60	
Roughs & Fairways	30.90	4.10	
Annual Totals	146.00	36.10	1 to 0.25
1996			
Greens	65.04	18.39	
Tees	50.32	15.96	
Roughs & Fairways	30.62	4.04	
Annual Totals	145.98	38.39	1 to 0.26
1997			
Greens	137.58	78.55	
Tees	18.93	2.44	
Roughs & Fairways	23.39	2.43	
Annual Totals	179.90	83.42	1 to 0.46
1998			
Greens	93.20	57.20	
Tees	23.10	1.70	
Roughs & Fairways	34.80	2.30	
Annual Totals	151.10	61.20	1 to 0.41
1999			
Greens	74.78	16.02	
Tees	21.53	3.14	
Roughs & Fairways	18.62	2.97	
Annual Totals	114.93	22.13	1 to 0.19
2000			
Greens	92.43	41.28	
Tees	13.87	2.77	
Roughs & Fairways	17.26	4.00	
Annual Totals	123.56	48.05	1 to 0.39
2001			
Greens	68.75	69.90	
Tees	13.22	5.45	
Roughs & Fairways	16.51	8.38	
Annual Totals	98.48	83.73	1 to 0.85
2002			
Greens	71.33	26.03	
Tees	12.36	2.73	
Roughs & Fairways	24.32	5.97	
Annual Totals	108.01	34.73	1 to 0.32
2003			
Greens	50.00	12.87	
Tees	1.27	0.00	
Roughs & Fairways	12.61	1.09	
Annual Totals	63.88	13.96	1 to 0.22
2004			
Greens	74.11	19.04	
Tees	6.18	1.09	
Roughs & Fairways	14.59	1.36	
Annual Totals	94.88	21.49	1 to 0.23

TABLE 17. Continued

Area	Annual Application gm N/m2/yr	gm P/m2/yr	N : P Ratio
2005			
Greens	26..82	18.91	
Tees	18.27	4.47	
Roughs & Fairways	6.83	0.85	
Annual Totals	51.92	24.23	1 to 0.47
2006			
Greens	51.63	24.04	
Tees	2.88	0.31	
Roughs & Fairways	4.68	1.08	
Annual Totals	59.19	25.43	1 to 0.43
2007			
Greens	30.39	4.64	
Tees	0	0	
Roughs & Fairways	4.84	1.12	
Annual Totals	35.23	5.76	1 to 0.16
2008 [Note: only a grand total for whole course provided to us]			
Annual Totals	10.07	2.11	1 to 0.21
2009 [Note: No third quarter data and only a grand total for whole course provided to us]			
9-month Totals	2.32	0.29	1 to 0.13
2010 [Note: Only a grand total for whole course provided to us]			
Annual Total	4.38	0.66	1 to 0.15

2011 Date and Area	gm N/m2	gm P/m2	N : P Ratio
January - March (Entire Course)	0.05	--	
April - No Data	--	--	
May - December			
Greens & Approaches (1.98 ha)	6.76	--	
Tees (1.25 ha)	11.30	--	
Fairways (11.33 ha)	1.56	--	
Note 2011 Data are incomplete	19.67	--	

2011, only a total for the entire course has been provided, thus the change in the format as given in Table 17. Also, the 2009 fertilizer data are incomplete due to missing third quarter data and the data for April 2011 is also missing. It should be noted that commencing in May 2011 the data are again provided by golf areas as shown in Table 17. Inspection of the fertilizer use data show an obvious decline in application rates commencing in 2008 (albeit 2009 has missing data) such that use in 2010 is well below that found on many other coastal Hawaiian golf courses which is commendable.

DISCUSSION

A. Geometric Means

In the 13 December 2011 survey, the geometric means for nitrate nitrogen, ammonia nitrogen, total nitrogen, turbidity and chlorophyll-*a* were out of compliance with the state dry standards when considering all stations together. Calculating the geometric means for either experimental sites (fronting development) or control stations (away from the development) for the December survey noted that the geometric means for nitrate nitrogen, ammonia nitrogen and total nitrogen were out of compliance at both the experimental, control as well as at control plus Awehi station groups. Furthermore, the geometric means for turbidity were out of compliance at both the sites fronting the development as well as at control plus Awehi sites and chlorophyll-*a* was out of compliance at the two control station groups. Otherwise the remaining parameters were in compliance with state dry standards at stations fronting the development as well as at the control stations in this most recent survey.

Total nitrogen has been out of compliance on many surveys especially in 2001-2003 period and again since December 2006. Since similar elevation of total nitrogen was found at other survey sites statewide by this author in these same periods, these increases are hypothesized to be related to changes in current patterns around the Hawaiian Islands bringing deep, high nitrogen laden waters into inshore areas. This hypothesis is supported by the findings of Karl *et al.* (2001). Total nitrogen has been out of compliance on 27 dates; three of these occurred at control stations alone, on two dates at stations fronting the development and on twenty-two dates the non-compliance occurred at both station groups. The overwhelming pattern seen in non-compliance at monitoring stations along Lanai's south shoreline has been one where if non-compliance is found at stations fronting the development, it is usually found at control stations on the same date. Thus if a parameter is out of compliance on a particular date, the lack of compliance occurs among both the control and experimental station groups (Table 4). Examples supporting this statement are found with most parameters. In the baseline period, both turbidity and chlorophyll-*a* were out of compliance during two of the five baseline surveys at both control and experimental (i.e., those fronting the development) stations and at one additional period at control stations only. Since the commencement of construction at Hulopoe Bay in January 1993, turbidity has been out of compliance on 27 occasions at stations fronting the development and on 44 occasions at control stations. Examining these during construction data further (Table 4), turbidity was out of compliance on three occasions at stations fronting development only, twenty instances at control stations only and 24 occasions at both the control and Hulopoe Bay stations. These data suggest that if noncompliance in turbidity is going to occur along the south coast of Lana'i Island, it occurs on a coast-wide basis rather than just at stations fronting the development only. Examining turbidity further in the many of the past surveys, higher turbidity occurs during regular wave events as well as following high rainfall events. Impinging surf serves to resuspend particulate materials already in the marine environment. Surf emanating from the WSW through the ESE is not unusual and thus finding noncompliance in turbidity at all or some of the three groups of stations is not unexpected.

The past lack of compliance in turbidity at control stations may be due to the lingering impacts from the runoff events in 2002 coupled with small surf to resuspend materials along the island's eastern shoreline. In many of the surveys the geometric means for turbidity measured at control stations are greater than those measured at stations fronting the Hulopoe development suggesting that the runoff from land, persistence of turbidity and resuspension by surf in the ocean is greater at control sites relative to Hulopoe Bay sites.

As noted above, the 29 January 2002 high rainfall event resulted in significant runoff all around Lanai and West Maui. The high turbid water remained intact along Lanai's south and east coast through the middle of April 2002 and was only partially dispersed at the time of sampling on 22-23 April 2002. Turbidity continued to persist aided by the high rainfall of 12-13 May 2002 and again on 14-17 October 2002 (13.10 inches!) as recorded at the Manele STP gage. Besides these inputs, the local oceanographic conditions did not advect the plumes of high turbidity water out and away from the southern coastline of Lanai until August 2003, 18 months later and turbid conditions continued to persist along the eastern side on the island up to some point just before the June 2005 survey. Under these conditions, the continuing lack of compliance with the parameter, turbidity, is not unexpected especially if there was any surf present at the time of sampling.

In 40 of 78 sampling periods, the geometric mean for ammonia nitrogen has exceeded state DOH standards for "dry" coastlines at either stations adjacent to the development or at control sites or both (Table 4). The baseline grand mean for this parameter also exceeds the "dry" standard (Table 6). Other parameters frequently out of compliance with the "dry" standards include chlorophyll-*a*, turbidity and to a lesser extent, nitrate and total nitrogen. In some cases the lack of compliance is probably related to inputs from land (i.e., natural runoff) prior to sampling. The only sampling periods where the geometric means of all parameters were in compliance were in the December 1994, June 1996, April 1999 and the August 2009 surveys when considering all stations together or separately by station groups (i.e., experimental stations fronting the development, control stations alone and control stations plus the Awehi stations). In the case of the December 1994 survey, the results were probably due to the relatively long period of low rainfall and relatively low surf conditions along this coastline before and at the time of sampling. However, in the June 1996 survey, the Lana'i Airport recorded 2.15 inches (54.60 mm) of rainfall in the 26 days prior to our sampling but only 0.25 mm (0.01 inch on 9 June) was reported for this period at the STP above the golf course. Again, low rainfall in the coastal region coupled with relatively low surf conditions probably were responsible for all parameters being in compliance in June 1996. In April 1999 no rain had been recorded in the coastal area for the 96 days preceding the collection of samples and surf conditions prior to sample collection were down. The surf was down at the time of the August 2009 surveys and rainfall prior to sampling had been very light (Table 5). Again these conditions were probably responsible for all parameters being in compliance.

In general, the concentration of ammonia nitrogen has been elevated during many of the sampling events. In the September 1995 survey, a strong concentration gradient of ammonia nitrogen was particularly evident in the waters fronting the Hulopoe gulch with the highest value seen at the shoreline and decreasing in a seaward direction (station 1 = 25.06 ug/l, station 2 = 17.50 ug/l, station 3 = 12.46 ug/l, station 4 = 7.56 ug/l). High ammonia nitrogen concentrations were also encountered offshore of Awehi gulch (station 20 = 11.06 ug/l) and in Manele Bay Harbor (station 13 = 94.92 ug/l). Ammonia nitrogen concentrations were elevated at both the experimental and control stations in the September 1997 survey but decreased in the December 1997 survey. In the January 1999 survey measured ammonia concentrations were again elevated particularly in the waters fronting the gulch at Hulopoe Bay but were down at the time of the April 1999 survey and have remained relatively low adjacent to shore through until the rainfall events in 2002 when they were again elevated.

Ammonia nitrogen is derived from organism metabolism (excretion), decomposition, certain fertilizers and/or sewage. If sewage is the source of high ammonia nitrogen, silica, nitrate nitrogen and sometimes orthophosphorous are similarly elevated particularly at the point of entry into the ocean (here station 1). Also there should be an obvious depression in salinity due to the freshwater content of the treated sewage effluent. This has not been the case with samples collected in this study. If the source of ammonia is from a fertilizer applied to the golf course (urea), a means of conveying it to the ocean is necessary (assuming that it is not just dumped directly into the ocean). The usual mechanism is via irrigation (fresh) water applied to the course which carries the dissolved material to the sea. Irrigation (ground) water is high in silica and will appreciably lower the salinity at the point of entry to the sea. The salinity depression fronting the Hulopoe gulch has been very small and the silica elevation has been low (but variable) suggesting that there is not much freshwater entering the system that could be carrying ammonia down from the golf course. To our knowledge and until recently, urea was not used on the

Manele Bay Golf Course and the soil samples analyzed thus far show little ammonia present suggesting that the source is not from fertilizer applied to the golf course.

The highest ammonia nitrogen concentration encountered thus far in this study was in the September 1995 survey at the Manele Bay Harbor (station 13). At the time of sampling a run of halalu (juvenile akule or *Selar crumenophthalmus*) was in progress as evidenced by the large number of Lanaians fishing along the seaward breakwater of the harbor for these fish. The school of hahalalu could easily account for the ammonia elevation encountered in the harbor. On 26 September 1997 a run of hahalalu was again in progress in the harbor. The ammonia concentration of this September 1997 sample (no. 13) was 51.52 ug/l which again supports the hypothesis that a source of this material could be from the schooling fishes. In the January 1999 survey we encountered a small school of akule in Hulopoe Bay over the sand fronting the beach. We attempted to obtain water samples for the determination of ammonia but the school was continually scattering and moving about due to predators which probably accounted for the relatively low mean ammonia concentration encountered (6.21 ug/l) albeit this concentration is more than three times greater than the state standard.

In terrestrial ecosystems the flux between organic nitrogen and ammonia is a dominant dynamic process (Rosswall 1981). There are few studies that bear directly on these processes on coral reefs. Naturally occurring local elevation of ammonia on coral reefs has been reported by a number of investigators. This ammonia may be the result of ammonification of organic matter (Wiebe 1985). Myer *et al.* (1983) showed that fish could be responsible for some locally elevated ammonia concentrations. High ammonia concentrations on coral reefs from completely natural sources are poorly understood. This lack of understanding led to the Hawaii State Department of Health to fund a study to explore the source(s) of elevated ammonia nitrogen on coral reefs. Hulopoe Bay was used as one of the study sites. The study concluded that aggregated or schooling fishes may cause significant local increases in ammonium; these increases are most easily seen where water circulation is reduced as in caves (Brock and Kam 2000).

Our work in the brackish water (anchialine) ponds on the Kona coast has shown significant elevation of ammonia nitrogen in those pools containing fish (topminnows). The presence of a large number of fish may cause a local elevation of ammonia, which could explain the increased concentration of this parameter in the area fronting the gulch at Hulopoe. Because of the usually turbid conditions of the water in this area, we have not seen any fish while swimming the 20 m from our work vessel to shore to collect the shoreline sample (the remaining samples in this series are taken from a vessel) but halalu or another schooling species may be in the area.

The relatively high diversity and abundance of marine communities close to shore at many locations around Lana'i coupled with lower circulation may be responsible for the observed ammonia nitrogen values measured at several sampling areas. Ammonia nitrogen concentrations measured on the diverse coral reefs along completely undeveloped sections of the Kona, Hawaii coast are greater than those measured in this study (Brock and Kam 1992).

It is important to note that State standards for open coastal waters are frequently exceeded for many water quality parameters irrespective of the presence of nearby coastal development. Brock and Kam (1989) found that under dry conditions nitrate nitrogen concentrations are equal to "dry" criteria for waters fronting Lahaina, Maui (a developed area) and that chlorophyll-*a* exceeded the "wet" criteria; following a heavy rain (85.8 mm or 3.38 inches over a 24-hour period) nitrate nitrogen, turbidity and chlorophyll-*a* all exceeded state standards (Brock 1990a). At Mahukona, Hawaii an area with little surrounding development, both chlorophyll-*a* and ammonia nitrogen exceeded DOH "dry" standards (Marine Research Consultants 1989, Brock 1990b). An ocean water quality monitoring program has been in place at the Natural Energy Laboratory of Hawaii Authority (NELHA) at Keahole Point, Hawaii since 1982. The waters offshore of Keahole Point are considered to be pristine; the presence of high quality deep ocean water adjacent to shore was an important factor in locating the NELHA facility there. The long-term mean for ammonia nitrogen at Keahole Point is 5.04 ug/L which exceeds state "dry" standards. The fact that pristine Kona waters exceed state standards for ammonia nitrogen suggests that the standard may be unrealistic and too stringent. Other long-term means from NELHA are usually similar to or are greater than the concentrations of nutrient species from the south coast of Lana'i (using 13 December 2011 data), e.g., nitrate NELHA = 2.80 ug/L, Lana'i = 4.98 ug/L; orthophosphate: NELHA = 4.96 ug/L, Lana'i = 3.43 ug/L; ammonia nitrogen: NELHA = 5.04 ug/L, Lana'i = 2.51 ug/l. The NELHA data are courtesy of the University of Hawaii Analytical Services Laboratory.

B. Rainfall and Runoff

There have been eight occasions where substantial rainfall occurred prior to our water quality monitoring. In December 1989 the water quality sampling was carried out 2 days after 81.0 mm or 3.19 inches of rain fell at the Lana'i Airport. Heavy rainfall again occurred about 12 days prior to the October 1991 sample period with the Kaho'olawe recording gage reading 62.2 mm or 2.45 inches on 20-21 September 1991. Heavy rainfall again occurred prior to the 14-15 January 1993 sample effort. On the last four days of December 1992, 153.7 mm (6.05 inches) was recorded at the Lana'i City gage; this same gage had accumulated an additional 60.5 mm (2.38 inches) by 5 January 1993 and in the period from 6 through 13 January 1993, 38.6 mm (1.52 inches) was recorded at the Lana'i City gage. The Lana'i Airport gage recorded 78.7 mm (3.10 inch) for the month of September 1993 with most of this (55.9 mm or 2.20 inch) falling on 12 September; sampling occurred 18 days later (on 1 and 2 October 1993). The Lana'i Airport gage recorded more than 70.6 mm in the five days preceding the 17-18 February 1994 sample effort and this rainfall is reflected the data, particularly for sites adjacent to intermittent stream mouths (stations 1, 6 and 19). Lana'i Airport rainfall data courtesy of the Department of Meteorology, University of Hawaii.

By far the greatest rainfall recorded at Hulopoe Bay (at the Manele Sewage Treatment Plant gage) over the course of this 264-month study has fallen in 2002. Between 27-30 January 2002 8.29 inches (210.57 mm) was recorded. On the 27th, 2.54 mm fell, on the 28th, 16.51 mm fell and on the 29th, 177.80 mm or 7.00 inches was recorded. On the day of sampling (30 January), an additional 13.72 mm was recorded at this gage. Again on 14 through 17 October 2002, 13.10 inches (332.74 mm) was recorded at the Manele STP gage with sampling occurring 20 days later. These high rainfall events resulted in runoff from land carrying terrigeneous materials (silt, vegetation and refuse) into the sea. In the January 2002 event rainfall was also recorded at the Lana'i Airport gage where 6.35 mm fell on the 27th, nothing recorded on the 28th and 52.07 mm was noted on the 29th of January. On the 30th, 48.51 mm fell at the airport thus the airport total in this four-day period was 4.21 inches (106.93 mm). In the October 2002 high rainfall, no rain was recorded at the airport gage. Since 2006-2007 the collection of rainfall data at Lana'i Airport gage has been inconsistent and/or nonexistent.

The Lana'i City gage is situated in an area that usually receives more rainfall than the gage at the Lana'i Airport which in turn usually records greater rainfall than at the STP above Hulopoe Bay. The differences are related to differences in elevation and the fact that most rainfall is due to orographic (mountain-caused) processes in the Hawaiian Islands (Armstrong 1973). However, high intensity (kona) storms may approach and impact the islands from a southerly direction and during these events, higher rainfall may be recorded at coastal rather than inland (higher elevation) sites. During the January 1995 - December 1997 period, the relationship between measured rainfall at the Lana'i Airport gage and the STP gage above the Manele Bay Golf Course at Hulopoe Bay was reasonably strong; regressing airport and STP monthly rainfall totals shows a significant positive correlation ($r=0.88$, $n=46$, $P>0.0005$, significant). Much of this correlation may be related to (1) the direction or sources of rainfall, i.e., orographic or kona, (2) and the relatively higher rainfall totals for 1996 on the golf course (see Table 5 in previous reports).

The January 2002 survey was undertaken during an extremely wet period in the three days prior to sampling which resulted in runoff to the sea. The resulting high turbidity remained over the next two months and only began to dissipate in the week prior to the April 2002 survey. Rainfall in mid-May 2002 and again in mid-October probably added to the runoff reaching the sea at times prior to sampling. In the past when rainfall has been recorded at the STP, there has been little evidence that the rainfall was correlated with increased concentrations of any measured parameters in the ocean directly fronting the golf course suggesting that little if any runoff occurs which may be related to the water retention design of the golf course. However, regression analysis of the 2002 and later survey data noted strong positive correlations between rainfall and nitrate nitrogen, total nitrogen, total phosphorus and turbidity suggesting that these high rainfall events (e.g., 7.00 inches on 29 January 2002 the day prior to the January 2002 sampling) overwhelmed the safeguards to retain runoff on land and allowed materials to enter the ocean. This may have also occurred following the 4.10 inches on 12-13 May 2002 and the 13.10 inches in October, 20 days prior to sampling (These correlations are supported by the highly visible plumes of turbid water that continued to be present on the south (through May 2003) and eastern shores of Lana'i through the February 2005 survey. However, by the June 2005 survey (41 months after the initial high January 2002 rainfall), the turbidity along the eastern shoreline had dissipated). In general however, the golf course area above Hulopoe Bay receives little rainfall. These conditions coupled with relatively low surf have probably been responsible for the geometric means for most parameters being in compliance when considering all stations on many of the past surveys.

High rainfall events in the coastal region may result in runoff to the sea carrying terrigeneous materials and often causing local transitory elevation of certain inorganic nutrients in the near shore marine environment. These inputs create gradients of concentration that decrease in a seaward direction. Gradients in turbidity, nitrate nitrogen, silica, salinity and to a lesser extent, chlorophyll-*a* are probably due to input from land albeit no active surface stream flow has been evident during any sampling period. Because oceanic waters are low in these and other dissolved nutrient species, a concentration gradient is established. Gradients have been most evident at stations fronting the intermittent streams (Hulopoe gulch - station nos. 1-4, Makole gulch - station nos. 6-8, and Awehi gulch - station nos. 19-21). Inspection of the data from those sampling periods following heavy rainfall (e.g., December 1989, October 1991, October 1993, February 1994, January and November 2002 - see previous reports) bear this out. Concentration gradients for the above mentioned parameters are near-absent from the data collected during relatively dry periods.

Near-shore elevation of turbidity with a decreasing offshore gradient may be the result of terrigeneous input following heavy rainfall and runoff or it may occur due to resuspension of material already in the ocean. Resuspension occurs during periods of high surf. In the June 1993 sample effort, turbidity readings were elevated at a number of shoreline stations probably due to the higher than normal surf (2 to 4-foot south swell) occurring at the time despite the fact that there had been little rainfall reported in the 22 days prior to this sample period (3.3 mm or 0.13 inch at the Lana'i Airport gage). In the October 2001 survey, 2 to 4-foot swells from the south and southeast directions occurring for a period of several days prior to sampling decreased near shore water clarity and resulted in higher turbidity readings at control stations. High surf was probably the agent responsible for the parameter turbidity not meeting state standards in November 2005 and many of the other surveys.

The persistence of high turbidity along Lanai's south and eastern shorelines following the 29

January 2002 rainfall and runoff event for 18 months is very unusual. Never during this 264-month period of this study had this occurred previously. It is surmised that the input to the sea from this and subsequent (May and October) storms have been among the largest to date. Surf will cause resuspension of terrigeneous materials that have otherwise settled to the bottom. If the surf is relatively mild and the currents not strong, the areas of turbid water are continually present due to resuspension but they were not advected from the near-shore environment. These conditions persisted until waves and currents flushed the southern coast of the island. However, along the eastern shoreline of the island, plumes of highly turbid water continued until some time just prior to the June 2005 survey (a period of 37 to 41 months in duration).

Turbidity concentrations measured at stations fronting Awehi gulch demonstrate the level of input that may occur with rainfall. There are three stations fronting this intermittent stream: station 19 on the shore, station 20 approximately 100 m offshore and station 21 located about 500 m offshore. In the five days preceding the February 1994 sample effort, 70.6 mm (2.78 inches) of rainfall was recorded at the Lana'i Airport gage. Waters fronting Awehi gulch stream terminus were very turbid; turbidity at station 19 was 158 NTU which exceeds the state dry standard by 790 times (state dry standard = 0.20 NTU). However, turbidity at station 21 (500 m directly offshore) turbidity was measured at 0.08 NTU which is well within the state dry standard and is typical of oceanic settings. It was readily apparent that the intermittent stream at Awehi had been recently flowing because of the obvious cut through the sand beach created by the flow of runoff to the sea. Despite no rainfall recorded at the Lana'i Airport gage in the 27 days preceding sampling in September 1995, the Awehi gulch shoreline station (no. 19) had a turbidity reading equivalent to that encountered at the Hulopoe gulch shoreline station (no. 1, both 0.43 NTU). These examples (as well as many others in this study) demonstrate that high turbidity readings are not necessarily associated with development; undeveloped lands with poor vegetative cover due to normally low rainfall conditions when exposed to high rainfall, can result in runoff and transitory high turbidity in the near shore areas. The photographs presented in Figure 4 of the April 1997 biological report present a qualitative picture of the impact of high rainfall and resulting turbidity in the adjacent ocean. These aerial photographs were taken in early January 1997. In the 25 days preceding the taking of these photographs, more than 165 mm or 6.5 inches of rainfall was recorded. Inspection of these photographs points out high turbidity along both developed and undeveloped sections of the coastline. The greatest extent of the highly turbid water appears along undeveloped sections of the coastline.

High turbidity in the marine environment following heavy rainfall is a natural event. Indeed, the study of Inman *et al.* (1963) noted on Kauai that beaches of the dry leeward coastlines contained significantly greater proportions of land-derived sedimentary constituents than did the beaches of the wet, windward coasts of the island which had a greater proportion of coralline derived sediments. In this case, the wet regions have excellent vegetative cover to hold the soil in place during heavy rainfall whereas on the semi-arid lee coasts, runoff from an equivalent rainfall event carries a greater sediment load to the ocean. This appears to be the situation along the arid coastlines of Lana'i.

The greater turbidity concentrations often encountered at the shoreline stations is related to proximity of terrigeneous input from the nearby intermittent streams, resuspension of materials due to surf and the probable low local circulation resulting in poor flushing characteristics of these near shore waters. Thus when materials are carried to the sea via runoff, they probably remain in the near vicinity for some time, being resuspended by surf resulting in a greater local turbidity. However, when local winds blow in an offshore direction, deeper, more oceanic waters are carried shoreward to replace shoreline surface waters that are carried seaward. Along the south shore of Lana'i, offshore winds occur when the wind direction is from the north as occurred in the period preceding and during the December 1997 survey. In the December 1997 survey, the near shore waters were among the least turbid for any sample period to date. This survey is the only one carried out to date where the winds were blowing from a northerly direction. To bring the point of materials carried to the sea remaining in the near shore region, water quality and biological sampling was attempted again on 13-14 February, 3-4 April and again on 22-23 April 2002. Only on the last date had the water clarity improved to a point (from 30 January 2002) where biological sampling could be carried out at the monitoring stations. Even then, much of the near-shore waters along the eastern and south shore of Lana'i remained very turbid through the May 2003 survey. Conversations with the dive tour operators who visit this coastline on a near-daily basis and the enforcement officers for the Department of Land and Natural Resources confirmed that the near-shore waters had continuously remained very turbid from the January 2002 storm and only in August 2003 that the waters along the southern side of the island had cleared up.

In general, measured turbidities are greater fronting the Hulopoe gulch (bisecting the developed area) than in the waters fronting the Makole gulch (the undeveloped control area) during most sampling periods. The Hulopoe gulch drains an area approximately twice the size of the Makole gulch (Hulopoe drainage basin = 1.32 km^2, Makole drainage basin = 0.65 km^2). Irrespective of human activities, the similar slopes, vegetative cover and probable similar rainfall regimes, more terrigeneous input to Hulopoe Bay than at Makole is to be expected on the basis of drainage basin size alone. However, the Hulopoe gulch is one of several that bisect the Manele Bay Golf Course; any concern that the development is responsible for the differences in turbidity should be viewed in light of data from the waters fronting other gulches that bisect the golf course. Station 9 (Kaluakoi) fronts a small gulch that crosses the golf course and this site has been routinely sampled since December 1989. Turbidity measurements have not exceeded state standards at this site except for the January 2002 data, but otherwise, the highest measured values occurred in the two sample periods following heavier rainfall recorded at the Lana'i Airport gage (December 1989 and October 1991) prior to any development.

A major concern of increased turbidity is the impact it may have on coral reefs. Sedimentation may be the result of turbidity and it has been considered to be a major environmental problem for coral reefs. Increases in turbidity may decrease light levels resulting in a lowering of primary productivity. Perhaps a greater threat would be the simple burial of benthic communities that may occur with high sediment loading. Many benthic species including corals are capable of removing sediment settling on them but there are threshold levels of deposition where cleaning mechanisms may be overwhelmed and the individual becomes buried. However, the impact of sedimentation on Hawaiian reefs may be overstated. Dollar and Grigg (1981) studied the fate of benthic communities at French Frigate Shoals in the Northwest Hawaiian Islands following the accidental spill of 2000 tons of kaolin clay. These authors found that after two weeks there was no damage to the reef corals and associated communities except where the organisms were actually buried by the clay deposits for a period of more than two weeks.

In Hulopoe Bay sediment is derived from natural runoff from land and major input probably occurs with high rainfall; such events are not common in an area that has a mean rainfall of only 30 cm (12 inches) per year (MacDonald 1940). In this low rainfall setting, natural vegetative cover is incomplete and feral animals probably assisted in the ongoing erosion thus any heavy rainfall event could trigger runoff. With the development of the golf course at Hulopoe Bay, the vegetative cover has increased and the course has been constructed and graded to retain water thus lowering the potential input of water and sediment to the sea. The obvious basaltic fraction in the sand offshore of Makole and Hulopoe Bay suggest that sediment input via runoff has been occurring for many years. However, the results of the biological monitoring program (Part B) has shown that the greater coral development in Hulopoe Bay is just offshore and west of the Hulopoe gulch intermittent stream terminus suggesting that these coral communities have persisted with the levels of input from this intermittent stream that have occurred over the last 50 to 100 years. Despite this persistence, transitory high levels turbidity may have impact on corals as recorded in the April 1997 biological report. Mortality occurred to about 2% of the coral cover at stations fronting the development and at slightly lesser amounts at control stations. Such relatively small declines in cover are usually rapidly offset by recruitment and growth such that a year following an event, the impact is not distinguishable in the coral community.

C. Short-Term Changes in Water Quality

Examination of the means of water quality parameters collected at permanent sample sites by quarterly survey date show considerable variability from quarter to quarter irrespective of proximity to the development at Hulopoe Bay. In most instances, the measured concentrations track between sites fronting the development to those measured at control sites for a given date but variability is high between dates (see Table 8). Water quality samples were collected on two separate occasions spaced a day apart in June 2006 and again in January 2008 to address the question of short-term variability. In the June 2006 survey, the means of four of the twelve parameters were significantly different between the two days and in the January 2008 back-to-back surveys, the means of five parameters were significantly greater on the first day relative to the second day collection. Despite these statistical separations, the numeric differences were not large in the June 2006 dataset while in the January 2008 surveys, these differences were greater. The most important fact to emerge from these closely spaced surveys is that variability in these water quality parameters on short temporal scales appears to be the norm. This being the case underscores the fact that despite statistical separation in parameter means from one survey to the next, this separation is not anything caused by development but is due to the natural variability in the chemistry of coastal waters.

D. Statistical Analyses

The statistical analyses of water quality data have been considered from a number of different perspectives in this study. Data used in these analyses are from the first 18 stations eliminating station 13 (Manele Harbor) and station 11 (low-salinity water from a faucet at Manele Harbor). The statistical analyses utilized in this study are primarily non-parametric thus avoiding some of the assumptions (normality, homogeneity of variances, etc.) that must be made or corrected for with the use of parametric statistics.

The first analysis considers all stations in aggregate (i.e., experimental plus controls) and makes the comparison between sample dates prior to any golf course construction (i.e., the baseline period, December 1989 through January 1993 - five sample periods) to the sample periods during and following completion of the golf course (since January 1993 to present - 73 sample periods). This analysis as given in Table 7 found statistically significant differences in the mean concentrations of ammonia nitrogen, total nitrogen, silica, turbidity, salinity, chlorophyll-*a*, percent saturation of dissolved oxygen, and pH. The during- and post-construction means which are significantly greater than the pre-construction means include those for ammonia nitrogen (pre-construction mean = 3.08 ug/l, postconstruction mean = 3.20 ug/l), total nitrogen (pre-construction mean = 75.61 ug/l, post-construction mean = 108.39 ug/l), turbidity (preconstruction mean = 0.26 NTU, postconstruction mean = 0.47 NTU), silica (preconstruction mean = 84.90 ug/l, post-construction mean = 118.49 ug/l) and salinity (pre-construction mean = 34.497 ppt, all later sample dates mean = 34.746 ppt). These differences are well within the normal ranges encountered in Hawaiian waters and have no relationship to the development. The greater mean post-golf course construction turbidity is related to recent rainfall/runoff across all stations and persistence of materials in near shore waters (since 2002) and not to development.

The next analysis examined the question, "are there differences in the means of parameters by date that show a chronology related to the development?" There is no evident statistical separation among the sample period means by date. However, the highest grand means of most parameters from the control sites are greater relative to the grand means from sites fronting the Hulopoe development consistently through all of the nutrient data to date except for the April 2009 survey means for orthophosphorous and total phosphorus only at stations fronting the development which decreased in subsequent surveys (July 2009 to present). Thus the highest grand means for nitrate nitrogen, ammonia nitrogen, total nitrogen, silica, turbidity and chlorophyll-*a* are at control stations. Only the grand means for orthophosphorous, total phosphorus, salinity, temperature and pH have their greatest means at stations fronting the development and many of these differences are small (e.g., greatest mean temperature at Hulopoe Bay stations = 29.3°C versus 29.0°C at control stations, salinity at Hulopoe stations 35.412 ppt versus 35.376 ppt and greatest mean pH at Hulopoe stations is 8.24 versus 8.21 at control stations). The greater grand means of many parameters measured at control sites suggest that the runoff has been greater and the subsequent advection/dilution and uptake of materials has been probably less along the undeveloped portions of Lanai's south coast. Greater runoff along the undeveloped sections of the coastline is related to the intensity and amount of local rainfall as well as the amount of vegetative cover and erosion control occurring in the area. The best management practices in place on the project site are probably serving to contain more of the runoff on site than occurs on the natural terrain under similar rainfall regimes. Finally the elevation of total phosphorus means found in the October 2010 survey appear to be very similar between stations fronting the development (15.47 ug/l) to that found at control stations (16.99 ug/l) suggesting a coast-wide trend. Furthermore, in the subsequent (November 2010, March, June, November and December 2011) surveys, mean total phosphorus concentrations are in the middle and lower end of the range respectively at both control and stations fronting the development.

The next analysis examined the changes in mean concentration of parameters at stations fronting the development (the experimental stations, nos. 1, 2, 3, 4, 5, 9, 10, 15, 16, 17, 18) to those away from the development (the control stations, nos. 6, 7, 8, 12, 14) over the entire period of this study (December 1989 - December 2011, 78 sample periods). The results of this analysis (Table 9) found a statistically significant greater mean concentration of chlorophyll-*a* at control stations (0.152 ug/l) over the experimental stations (0.147 ug/l), significantly greater turbidity at control stations (0.69 NTU versus 0.36 NTU), significantly greater mean dissolved oxygen concentration at experimental stations (100.7%) over control stations (100.4%) as well as significantly greater temperatures at experimental stations (26.0°C) over control stations (25.6°C). As noted above, the changes with turbidity, chlorophyll-*a*, dissolved oxygen concentration and temperature are not related to the development. Finally, mean nitrate nitrogen at stations fronting the development is significantly greater (2.75 ug/l) relative to the mean at control stations (2.32 ug/l). These differences in mean nitrate nitrogen concentrations are small.

The next step in the analysis was to make the same examination as directly above, i.e., compare changes in mean parameter concentrations at experimental stations relative to control stations in the period preceding any golf course construction (i.e., from December 1989 through January 1993). This analysis (Table 10) found that salinity was significantly greater at the experimental stations (i.e., those adjacent to the development, mean = 34.568°/oo) relative to the control stations (mean = 34.432°/oo). Also, the mean percent saturation of dissolved oxygen was significantly greater at the control stations (mean = 102.8%) relative to the experimental stations (mean = 102.1%) in the period preceding golf course construction. These differences are very small relative to the ranges usually encountered in near shore waters. This analysis suggests that there were no changes of any significance in water chemistry parameters that would impact marine biota.

The next statistical analysis carried out in this study compared changes in mean parameter concentrations at control stations relative to the experimental stations in the period subsequent to the commencement of golf course construction in January 1993 to present which includes the operation of the golf course. This analysis (Table 11) found that mean chlorophyll-*a* concentration was significantly greater at control stations (mean = 0.149 ug/l) than at experimental stations adjacent to the golf course (mean = 0.144 ug/l) in the period since construction and operation of the golf course commenced. Again, mean turbidity measured at control stations (0.71 NTU) was significantly greater than at stations fronting Hulopoe (0.37 NTU) being related to the prolonged impact of the high rainfall events in 2002. In addition, mean temperatures were significantly greater at post-construction experimental stations over the control stations with the difference being 0.4°C and mean dissolved oxygen concentrations were significantly greater at experimental stations (100.6%) over control stations (100.4%). Finally, mean nitrate nitrogen concentrations are greater at stations fronting the development relative to the mean found at control stations albeit the actual differences are small (2.72 ug/l versus 2.29 ug/l). The significantly greater mean concentration of nitrate nitrogen at stations fronting the development relative to the control stations is new having first manifested itself with the May 2010 survey and probably has nothing to do with development at Hulopoe Bay. This is especially true if one looks at the greatest survey mean (16.26 ug/l) for nitrate nitrogen occurred at the control stations in January 2002 (Table 8).

The analyses above support the contention that there has been no significant change to measured parameters that may be attributed to the development of the golf course at Hulopoe Bay up through the November 2011 sample period. However, with the April 2009 survey, a singular event where both the means for orthophosphorous and total phosphorus were the highest to date at stations adjacent to shore fronting the development. The distribution of these high measured concentrations of phosphorus suggested that it came from activities on land, but the lack of change in concurrent salinity measurements did not support this hypothesis. Furthermore, the strong sorption affinities of phosphorus to soils as shown in previous local studies, suggested that the source may not be from land. Thus the source(s) for these materials is unknown and with the precipitous decrease in phosphorus since the April 2009 survey to normal concentrations, the source may never be known.

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