ANNUAL REPORT OF THE WATER QUALITY MONITORING PROGRAM FOR THE WAIKOLOA RESORTS – 2025 ANNUAL

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WWS Report No. 2025

May 2026

EXECUTIVE SUMMARY

This report summarizes the findings of the quarterly water quality monitoring program designed to monitor the water quality characteristics of the groundwater and marine waters at the Waikoloa Resorts from the program's beginning in 1986 through 2025. In 2025, water quality monitoring surveys were carried out on 3 March, 10 July, 1 October, and 30 December. This document focuses on the results of the 2025 field surveys and presents a comparative analysis with earlier environmental water quality data. The Makalawena-Awake'e control site survey was performed on 23 December 2025.

This monitoring program complies with the methodology outlined in the Coastal Resource Monitoring Protocols for West Hawai'i (West Hawaii Water Coastal Monitoring Task Force 1992). The University of Hawai'i's Waikoloa Anchialine Pond Preservation Area (WAPPA) and its monitoring program was active from 1986 through mid-2007 and the present quarterly monitoring program not only utilizes data from the WAPPA program in addition to data collected by Waimea Water Services and Environmental Assessment. Collectively, these two data sets span a period from 1977 to the present including more than three thousand samples collected, thus Waikoloa has one of the most comprehensive water quality monitoring programs in existence in Hawaii.

This quarterly monitoring program reports on samples from 18 to 25 permanent stations primarily collected in the 1991-2025 period. These stations sample a broad cross-section of water; from wells inland of the coastal development, through anchialine pools, wells, and fishponds adjacent to development as well as marine waters fronting the Waikoloa Resorts in three areas. The program also monitors an undeveloped location at Makalawena-Awake'e Bay and has, until 2000, collected samples from a second site on the Kona coast to serve as control sites. Samples in this program focus on measuring water quality parameters identified by the Department of Health (Hawai'i Administrative Rules, Chapter 11-54 (d)).

This work shows typical concentration gradients of nutrients that have greater concentrations inland which decrease due to dilution and uptake as groundwater moves towards the shoreline; once in the ocean, these concentrations fall to ambient oceanic levels within several hundred meters of the shoreline due to dilution by the overwhelming volume of the ocean water.

Imposed on this dynamic are anthropogenic inputs related to golf courses, resorts, and residential development. These inputs are generally within the range of concentrations that we find at other locations on the West Hawaiʻi coast that have no surrounding development. Past observations of these anthropogenic inputs, particularly nitrate-nitrogen and orthophosphorus, show that nitrate nitrogen and total nitrogen in the anchialine pools have declined somewhat, while orthophosphate and total phosphorus appear to have increased in recent years. This increase is especially pronounced in Site 3, the golf course anchialine pool, although this pond still has healthy flora and fauna and does not appear to be adversely affected by the high phosphorus concentrations.

Despite the variability in nitrogen and phosphorus measured in the groundwater at the Waikoloa Resorts, measurement of these parameters at other non-developed sites on the West Hawaiʻi coastline finds mean concentrations greater than those encountered at Waikoloa. Thus, the observed concentrations remain in the range of these materials measured elsewhere. Furthermore, the elevation and variability of the nutrients measured in groundwater are not reflected in the adjacent marine environment.

Nitrate nitrogen and total nitrogen concentrations in the groundwater beneath the Waikoloa Resorts project site data show evidence of a decreasing input of nitrogen from anthropogenic activities to the underlying groundwater after 2002. In this case, the concentration of nitrogen in the undisturbed groundwater prior to its passage beneath the project site, as measured in the inland wells, is greater than that measured in an anchialine pool located adjacent to the ocean.

Phosphorus concentrations in groundwater and the anchialine pools at the Waikoloa Resorts appear to be moderating after an apparent peak in the period of 2015-2018. The Waikoloa Resorts management team has substantially decreased the use of phosphorus in the maintenance of golf and landscaped areas in recent years.

Three marine transects were monitored on four occasions in 2025 including transects fronting the WAPPA pond preserve, Waiulua Bay, and ʻAnaehoʻomalu Bay. Seven water quality parameters are subject to State regional standards and monitored at each marine site. Thus, there are 3 transects x 4 surveys x 7 parameters resulting in 84 opportunities for compliance/non-compliance to occur with a parameter in 2025. In total, 61 of the 84 opportunities were non-compliant with State regional standards which is a rate of 72.6% non-compliance. The Makalawena-Awakeʻe control site is sampled once in 2025 for seven parameters on a single transect site. Three out of the seven opportunities did not meet compliance with the State regional standards in 2025 resulting in a non-compliance rate of 42.9% at the Makalawena-Awake‘e control site. In this case, the rate of non-compliance is somewhat comparable to the control site situated along a completely undeveloped section of shoreline. Over the long-term, non-compliance of water quality parameters from 2000 through 2025 is similar between the Makalawena-Awake‘e control site at 67.7% and the Waikoloa Resorts at 70.2%. These data support the contention that the regional water quality standards do not reflect the natural variability in water quality parameters in West Hawai‘i.

The question, “Has the water quality at the Waikoloa Resorts changed through time?” can be addressed by separating the data into two groups, the anchialine pools and the marine sites and statistically examining each of these groups. In previous years, we evaluated the statistical significance of water quality parameter changes by utilizing the non-parametric One-Way ANOVA Test. Given the relatively small number of comparisons, multiple true statistical difference analyses (t-tests) are preferred in this context, as they offer greater statistical power and simplicity without the added assumptions of more complex methods. While ANOVA followed by a Tukey post-hoc test is useful for handling a large number of comparisons and controlling Type I error, it introduces stricter assumptions, such as homogeneity of variances, which may not always be met. For focused analyses with limited comparisons, the t-test remains a more robust and interpretable option, making it the more appropriate choice here.

Statistically significant changes have occurred over the period of observation for the annual means of most parameters at marine sample sites as well as in the anchialine pools. In the anchialine pools, all parameters except for salinity and chlorophyll-a demonstrate significant changes. Certain parameters show trends with time and are discussed in depth in the report text. Notable is the nitrate nitrogen concentration in the anchialine pools, which has shown a decrease since a peak in the period of 2003 to 2007. Total nitrogen also shows similar behavior, with a peak in the period of 2001 to 2010 and subsequent decline. Orthophosphorus and total phosphorus appear to be in decline recently, although this is not a statistically significant trend, although it may prove to be in the future. Additionally, there are no water quality criteria for anchialine pools, so the question of compliance with water quality standards is not applicable to this context, and we can only evaluate and compare observed water quality parameters with other sites observed.

Observed macronutrient increases in the anchialine pools suggested a continuing and greater input of materials from the coastal development at Waikoloa in the years prior to about 2000. In 2006 personnel responded by decreasing the application of fertilizers and the use of fertilizers at the Waikoloa golf courses remains reduced up to the present time such that the 2025 annual use of nitrogen fertilizer was 3.29 metric tons (mt), well below the mean annual use of 17.26 mt, and for phosphorus fertilizers was 0.22 mt, also well below the mean annual use of 4.01 mt. The use of both nitrogen and phosphorus fertilizers has been greatly reduced in recent years.

Examination of the mean values by date for marine sites noted no statistically significant differences among the mean values by date for total nitrogen, orthophosphorus, and total phosphorus, meaning that they appear to have not changed significantly. Furthermore, there is no evidence of statistically significant increasing concentrations with time in marine waters offshore of the Waikoloa Resorts. Despite the water quality parameter annual mean values being much greater in groundwater, the mean values of these parameters from adjacent ocean sample sites are much lower, as dilution is the dominant factor reducing the concentrations of these parameters in the marine environment.

The measured concentrations of nutrients in anchialine pools situated in areas with no surrounding development, such as at Makalawena-Awakeʻe, indicate that the nutrient chemistry of West Hawaiʻi groundwater is highly variable both spatially and temporally, and concentrations are frequently in excess of biological needs. Because nitrogen moves easily with irrigation water to the underlying groundwater, the loading of nitrogen is more easily managed by the hydrologic system relative to phosphorus. Although the Waikoloa Resorts have significantly reduced their use of phosphorus fertilizer, phosphorus concentrations in groundwater remain elevated. It is surmised that this increase is related partially to the previous high use of phosphorus, which may have saturated the soil horizons due to its high capacity to bind with soils, resulting in slow subsequent movement to the groundwater below, in addition to the use of treated wastewater in irrigation. Over some loading limit, the hydrologic system will not be able to flush phosphorus from the system, and it will accumulate. It should be pointed out, however, that the anchialine pool with the highest orthophosphorus concentration is Site 3, which appears to be a very healthy anchialine pool with healthy native flora and fauna. Therefore, it appears that the presence or absence of non-native species, principally fish, in the anchialine pools is a greater determinant of anchialine pool health than water quality. In the case of nitrogen, the changes demonstrate the positive steps that the Waikoloa Resorts management team has made to improve the quality of the groundwater passing beneath the project site as well as the marine waters fronting Waikoloa. The Waikoloa Resorts have shown a continuing interest in managing groundwater quality, and strategies to reduce continued and potential additional inputs to groundwater are being pursued. Several recommendations to reduce nutrient loading of groundwater are presented at the end of this document for consideration.

The Waikoloa Resorts has the longest continuous water quality monitoring program on the West Hawai‘i coast. The changes noted in this annual report may be related to both long-term natural environmental fluctuations and the use of treated wastewater in irrigation and have no direct connection to the management and maintenance of the golf and landscaping at the Waikoloa Resorts. The Waikoloa Resorts management team has always been responsive to addressing environmental problems and the actions taken by the golf course managers in the past to reduce inputs, as well as lower operational costs have been commendable, and have served to protect the ground and marine water quality at Waikoloa. We expect that these positive actions will continue as they are needed in the future.

Annual sampling for pesticides was carried out on 30 December 2025. The most-used pesticides on the King’s and Beach golf courses with the highest eco-toxicities were identified for monitoring. Pesticide sampling is carried out annually at two anchialine pool sites at Waikoloa and in an anchialine pool at the Makalawena-Awake‘e control site. Results of the 30 December 2025 survey revealed no pesticide products present in groundwater above the laboratory method reporting limits.

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1.0 INTRODUCTION

Land use may impact marine and surface water ecosystems through changes in water quality, which may be due to direct impacts, such as those that occur during construction, or they may be more indirect resulting from gradual, long-term disturbances as may occur with non-point source discharges to groundwater causing gradual but chronic impacts to the aquatic communities.

Regulatory agencies, recognizing the potential for long-term negative impacts to aquatic communities resulting from coastal development, directed developers including the Waikoloa Land Company to prepare and initiate environmental monitoring and mitigation programs aimed at averting these potential environmental changes. This water quality monitoring program aims to identify changes to water quality in groundwater, surface waters, and marine waters that may impact biological communities.

The development of the coastal region at Waikoloa began in 1976. Development of the Hilton Waikoloa Village Hotel resulted in the creation of the Waikoloa Anchialine Pond Preservation Area (WAPPA) in 1985 and the initiation of a program carried out by the University of Hawaiʻi to manage and monitor the ponds in the WAPPA preserve. The WAPPA program focused on monitoring the biota and water quality characteristics of the ponds and groundwater in the vicinity of the 12-acre preserve and continued these efforts until funds were exhausted in 2007. In 1987, water quality monitoring commenced as a requirement of the use permit for the King's Golf Course. Data collected through 1990 have been assimilated into the annual WAPPA report. On the recommendation of permit agencies, Waikoloa Development Company created a separate but overlapping sampling and reporting effort. The present document reports on the findings of this effort for the year 2025.

Monitoring at Waikoloa is conducted quarterly. However, due to the transition of this work from Environmental Assessment LLC (EA) to Waimea Water Services LLC (WWS), monitoring was not performed in the first quarter of 2019. In 2020, due to COVID-19 restrictions, the first-quarter monitoring event was delayed until the second quarter. Since then, monitoring has been performed regularly on a quarterly basis. This document focuses on the results of the 2025 field surveys and presents a comparative and cumulative analysis with earlier water quality observations.

Potential environmental and ecological degradation caused by changes in water chemistry may be minimized or mitigated if water quality observations are correctly interpreted early on in any coastal development. Environmental data can serve to identify areas that may be susceptible to anthropogenic impacts, or conversely, particularly resistant to such perturbations. The first step in the protection of environmental quality is to carry out a quantitative baseline assessment against which later measurements of change can be made. An objective of any environmental baseline assessment is to establish quantitative information to accurately depict the community structure of the extant aquatic communities as well as describe the physio-chemical environment. The quantitative description of the physio-chemical environment provides the baseline upon which subsequent monitoring can be compared; significant deviation from the baseline may serve as an early warning and indicator of impacts to the aquatic community and may be used to guide management practices and enact corrective operational actions.

Changes to the physio-chemical environment may cause changes in aquatic communities. If changes in physio-chemical inputs are not too great, a potential for chronic low-level disturbance may result in adjacent aquatic communities. In the operation of a coastal development such as at the Waikoloa Resorts, long-term water quality changes may come from the irrigation and upkeep of golf courses and associated grounds, from stormwater runoff, and subsequent changes to groundwater characteristics. In West Hawai‘i, golf courses are often irrigated by a combination of brackish groundwater and wastewater treatment plant effluent, as is the case with the Waikoloa Resorts, which utilizes Waikoloa Wastewater Treatment Plant R-1 treated wastewater discharge for irrigation. With golf course development and use, a nutrient subsidy from fertilizers and reclaimed water, as well as inputs from pesticides, are likely to reach groundwater and move towards the ocean in brackish basal groundwater. Because of their inland location, anchialine pools would probably be the most immediate sites in which changes in groundwater chemistry, and subsequent impacts to aquatic biota, would be detected. Ongoing studies at the Waikoloa Resorts suggest that in monitoring chemical parameters, changes are first and most evident in anchialine pools; changes in water chemistry are less obvious in the marine environment due to dilution (Brock et al. 1988c). Through 2025, despite changes in water chemistry, no quantifiable changes have been noted in the anchialine communities at the Waikoloa Resorts solely attributable to water chemistry changes (Brock and Norris 1988a, Brock and Kam 1990, 1992, 1994, Brock 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013a, 2014, 2015, 2016, 2017b, 2018, WWS 2020, WWS 2021, WWS 2022, WWS 2023, and WWS 2024). The quantitative baseline for the marine communities was completed in 1988 (Brock and Norris 1988b) and the anchialine resources present at Waikoloa have been routinely monitored since the inception of the WAPPA program in January 1986 (Brock and Norris 1988a, Brock and Kam 1990, 1992, 1994, Brock 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013a, 2013b, 2014, 2015, 2016, 2017a, 2018, WWS 2019, WWS 2021, WWS 2022, WWS 2023 and WWS 2024). Thus, an appropriate strategy in monitoring indications of chronic, low-level impact in aquatic communities following baseline assessments is to focus first on changes in chemical parameters in-ground and near-shore marine waters. If statistically significant changes are noted, a search for quantitative change in adjacent anchialine and marine communities should be made. If discernible impacts are evident, a mitigation plan should be put into effect to alleviate impacts.

Physical Setting

The Waikoloa Resorts are located in the ahupuaʻa of ʻAnaehoʻomalu, centered on a promontory formed by a Kau basalt series lava flow from Mauna Kea of approximately 3,000 to 5,000 years old (Wolfe and Morris 1996). Along the shoreline, the area spans from ʻAnaehoʻomalu Bay on the south to Honokaʻope Bay on the north side. In the center, this shoreline is cut by Waiulua Bay, parts of which form the Waikoloa Hilton lagoon. The shoreline can be described very generally as a sloping lava shelf with significant coral coverage in many areas. Hydrogeologically, these lavas support characteristically high hydraulic permeability in basal aquifers, with the hydraulic conductivity of the Kaloko 2 well reported at a value of more than 20,000 feet/day by Bauer (2003), with certain assumptions about the thickness of the basal layer. Thus, we can state that inputs of soluble and mobile compounds to groundwater will reach marine waters on timescales of days to weeks or months, the uncertainty being due to a lack of knowledge of the basal groundwater hydraulic gradient.

2.0 METHODOLOGY AND QUALITY ASSURANCE

Water quality parameters were monitored at 24 sites through 2025 at the Waikoloa Resorts. The locations of monitoring sites are given in Figure 1. Three samples are collected from wells on the property, five from anchialine pools, 14 samples from the marine environment, and two from Kuʻualiʻi and Kahapapa Fishponds. Other than marine bottom samples or wells, all samples are collected just under the surface (i.e., within the upper 20 cm of the water column).

The wells that are routinely sampled include Irrigation Well No. 1 (Site 1, State Well No. 5452-03), Irrigation Well No. 2 (Site 2, State Well No. 5552-01), and the open “dug well” Dust Control Well located mauka of the maintenance facility (Site 18). Anchialine pools that are sampled under this program include the "Best Efforts" Pond (Site no. 3) which is situated on the Beach Golf Course about 915 m inland from the shoreline and inland of the Pond Preserve, Pond No. 48 in the Waikoloa Anchialine Pond Preserve (Site 21), Pond No. 155 also in the pond preserve (Site 11), Pond No. 188 in the pond preserve (Site 22), and an unnumbered anchialine pool that is situated about 30 m inland of Kahapapa Fishpond (Site 20). During 1992-93, Site 3 was occasionally sampled; from 1994 to the present, this site, along with Pond 188 (Site 22) in the Pond Preserve, were routinely monitored. Two stations have been established around the two fishponds at ʻAnaehoʻomalu Bay; these are Site 15 located at the inner edge of the makaha (i.e., entrance-exit channel) for Kahapapa Fishpond and a station along the inland (mauka) side of Kuʻualiʻi Fishpond (Site no. 17). Site 27 (not shown in Figure 1) is an irrigation water reservoir located on the Beach Golf Course near the maintenance facility and was sampled from 1986 through 1993. Monitoring of this location has been reinstated and commenced with the December 2013 survey and continues to present. In the ocean, three transects with an onshore-offshore orientation were established for water quality sampling; the first of these is in Waiulua Bay fronting the Hilton Waikoloa Village Hotel. This transect begins near the lagoon bridge and extends outside of Waiulua Bay. At this location a station sampling surface waters has been established on the shoreline on the seaward side of the channel connecting the Hilton Lagoon with the ocean (Site 4) which is at the head of Waiulua Bay, a second surface station has been established about 75 m offshore in Waiulua Bay (Site 5), a third station situated about 150 m offshore sampling surface waters (Site 6) as well as the water near the bottom (7 m deep, Site 7), and a fourth site (Site 23) sampling surface waters is situated about 300 m offshore of Waiulua Bay. A second transect is situated offshore of the Waikoloa Anchialine Pond Preservation Area where four stations sampling anchialine pools were established; these are shoreline (Site 9), Site 10 is approximately 75 m offshore, Site 24 is at 150 m, and Site 26 at 300 m offshore. ʻAnaehoʻomalu Bay contains a third transect; Site 12 is a shoreline station about midway along the sand beach, Site 13 is approximately 75 m offshore, Site 14 is about 150 m offshore, Site 19 is collected at depth beneath sample 14, and Site 25 is located 300 m offshore.

To provide control and comparative data from systems similar to but physically separate from the ponds and near shore marine ocean fronting Waikoloa, this study is continuing the small sampling program at the undeveloped Awakeʻe-Makalawena area in North Kona. This monitoring effort encompasses both anchialine pools as well as the near shore marine waters adjacent to the pools. The series of pools at Awakeʻe-Makalawena is located approximately 20 km south of Waikoloa and probably represents the most comparable group of closely situated anchialine pools on Hawaiʻi Island not subject to surrounding development. Until February 2000, water quality studies were also carried out at Kūkiʻo which is about 4 km north of Awakeʻe-Makalawena. Until February 2000, the Kūkiʻo ponds and surrounding lands remained undeveloped and representative of undisturbed conditions; since development has commenced, water quality data from this site is no longer used as a control site but the earlier preconstruction data spanning a ten-year period are used below for comparative purposes. Monitoring of the Awakeʻe-Makalawena control site is usually carried out late in the year; thus, these control data are obtained on an annual basis. The 2025 survey at Awakeʻe-Makalawena control sites was performed on 30 December 2025 during the same effort as the annual pesticide survey.

Three ponds sampled at Awakeʻe-Makalawena are situated roughly in a straight line from the shore; the most inland (mauka) pool sampled is approximately 250 m from the shoreline, the middle pond is about 150 m in from the shore, and the makai pool is 75 m from the shoreline. Three ocean sites at Awakeʻe-Makalawena are also monitored: one at the shoreline, a second site 100 m offshore, and the third approximately 200 m offshore. Sample sites at the control area were selected to duplicate as best as possible the distances of sampled sites at Waikoloa. Since the ponds at Waikoloa extend inland more than 300 m from shore, the Awakeʻe-Makalawena pools are most directly comparable to the middle and makai WAPPA ponds.

Monitoring generally follows a quarterly schedule for the 25 Waikoloa sites. Besides the usual collection of control water quality samples at Awakeʻe-Makalawena, usually in the third or fourth quarter, we also collect control pesticide samples from Awakeʻe-Makalawena for the annual pesticide sampling program. In each quarterly sampling effort, the designated anchialine pools are sampled for all water quality parameters. Native biological components are monitored in the anchialine ponds, but not in the wells or fishponds. This monitoring involves counts of native species in 0.1 m^2 quadrats placed in the anchialine pools. In the field, water samples for several of the water quality parameters are collected for laboratory analyses and some measurements are made in situ (i.e., dissolved oxygen and temperature). Instruments used for measuring water quality parameters in the field are as follows: dissolved oxygen, Hach Model LDO101 Dissolved Oxygen Meter; temperature with a laboratory grade thermometer reading to 0.1°C, for pH an Extech pH100, and a Hach 2100Q Turbidimeter.

Water quality constituents that are evaluated include the specific criteria as designated for open coastal waters in Chapter 11-54, Section 06(d) (Area Specific criteria for the west coast of the island of Hawaiʻi) of the State of Hawaiʻi, Department of Health Water Quality Standards. These criteria include ammonia nitrogen (NH_4), nitrate + nitrite nitrogen (NO_3 + NO_2, hereafter referred to as nitrate nitrogen or NO_3), orthophosphorus (PO_4), total nitrogen (TN), total phosphorus (TP), chlorophyll-a (chl-a), turbidity, as well as the nonspecific criteria of temperature, pH, oxygen, and salinity. In addition, dissolved silica (Si) is measured due to its usefulness as a groundwater tracer. Total organic nitrogen (TON) is calculated as the difference between total nitrogen and inorganic nitrogen (i.e., nitrate + ammonia nitrogen), and total organic phosphorus (TOP) is calculated as the difference between total phosphorus and orthophosphorus.

The US EPA detection limit utilizes US EPA Procedure Part 136 Appendix B. To determine the limits of detection, the standard deviation for ten replicate measurements of a sample three to five times the expected detection limit is used, divided by the t-test factor for ten replicate samples. To calculate accuracy, a coefficient of variation (CV) which is also known as the relative standard deviation was multiplied by the mean concentration of values used to determine the EPA detection limits. The CV value is the standard deviation of a series of measurements divided by the mean expressed as a percentage. The value used is the pooled CV over all low-level detection ranges for each analyte. Utilizing these methods, the limit of detection (precision) and accuracy of nutrient determinations are as follows: total nitrogen accuracy = 0.42 uM or 5.88 ug/L, limit of detection = 0.14 uM or 1.96 ug/L; total phosphorus accuracy = 0.07 uM or 2.11 ug/L, the limit of detection = 0.04 uM or 1.24 ug/L; orthophosphorus accuracy = 0.02 uM or 0.62 ug/L, limit of detection = 0.01 uM or 0.31 ug/L; nitrate+nitrite accuracy = 0.06 uM or 0.84 ug/L, limit of detection = 0.01 uM or 0.14 ug/L; ammonia nitrogen accuracy = 0.02 uM or 0.28 ug/L, limit of detection = 0.02 uM or 0.28 ug/L; and silica accuracy = 0.25 uM or 7.02 ug/L, limit of detection = 0.03uM or 0.84 ug/L.

Water samples are collected by opening 250 ml acid-washed polyethylene bottles at the desired depth. These bottles are pre-washed with liquinox and deionized water and are also triple-rinsed with sample water prior to sample collection. In the laboratory subsamples for nutrient analyses are filtered through glass fiber filters and immediately placed in 125 ml acid-washed, triple-rinsed polyethylene bottles refrigerated until analysis. Analyses for ammonia nitrogen, orthophosphate, and nitrate are performed using a Technicon autoanalyzer following standard methods for seawater analysis (Strickland and Parsons 1968, Grasshoff 1983). Total nitrogen and total phosphorus are similarly analyzed following digestion but are made on non-filtered samples.

Turbidity and pH samples are collected as unfiltered water in 60 ml polyethylene bottles until measurements are made as soon as possible after sample collection. Turbidity is measured on a Hach 2100Q Turbidimeter following procedures as described in Standard Methods (2017). Chlorophyll-a samples are collected by filtering known volumes of sample water through glass microfiber filters; filters are stored frozen in dark containers until analysis. Pigments are extracted in 90 percent acetone in the dark for 12 to 24 hours and fluorescence before and after acidification is measured on a Turner Designs fluorometer. Salinity samples are collected in triple-rinsed 250 ml polyethylene bottles and are analyzed on a laboratory conductivity meter with a limit of detection of 0.001 ppt and an accuracy of 0.003 ppt.

Quality assurance/quality control is maintained by the collection of duplicate samples; field measurements are also handled in the same manner. Laboratory analyses are carried out through approved laboratories. Before sampling activities, instruments are calibrated. Secondary checks are performed during and after sampling.

On an annual basis, sampling for possible pesticide contamination in groundwater and anchialine pools is carried out at the Waikoloa Resorts. Since pesticide sample processing is expensive, this program focuses on those compounds that have either been used for a considerable period of time, have been used in relatively large quantities, and are considered to be highly toxic for aquatic organisms. The list of products used in greatest amounts is evaluated from the previous year to determine analytes, based on the total weight of active ingredients and ecological toxicity.

In previous years, the decision as to what pesticides to sample was usually made in the third quarter of the year when the actual sampling often takes place. These decisions were based on the reported use of chemicals for the year up to that point in time and the history of use. Analyses of water and sediment from anchialine pools focused on products that had high and long-duration use up through 2008. Because of problems in carrying out the chemical analyses with sediment samples due to their usual biological origin leading to unacceptably high limits of detection, from 2009 forward only water samples are collected and analyzed in this program. These samples are collected in pre- cleaned glass containers with Teflon-lined caps, held on ice, and processed by an EPA-approved laboratory on the mainland using standard methods.

Pesticide sampling is carried out in an anchialine pool at Awake‘e-Makalawena serving as a control (site 3) and at the Waikoloa Resorts in the “Best Efforts” pond (site 3), as well as at Pond 155 (site 11). The “Best Efforts” pond is located near the makai side of the Beach Golf Course and Site 11 (Pond 155) is in the middle of the pond preserve. Analytes were chosen based on the high-use pesticides on the King’s and Beach golf courses and the product's relative eco-toxicity.

All methods used in the Waikoloa Resorts quarterly monitoring program comply with and follow most of those as outlined in the West Hawaiʻi Coastal Monitoring Task Force guidelines (1992) specified practices for water quality studies. These same methods have been utilized in the WAPPA program, which ran from 1986 through 2007. To avoid problems with the lack of normality of data, non-parametric statistical procedures are used to evaluate whether changes in measured water quality parameters are statistically significant. Analyses include the true statistical differences test, and procedures used in other data analyses are given where met within the text. Because the WAPPA program was funded through the University of Hawaiʻi Foundation (1986 - 2007) and the results of that program are made public, this study has incorporated some of those data since the pond preserve is situated in the present study area.

3.0 RESULTS AND DISCUSSION

Water quality monitoring under this program began in 1986 and has been generally carried out on a quarterly basis. In 2025, water quality monitoring activities were performed quarterly on 20 March, 10 July, 1 October, and 30 December. In total 3,410 water samples have been collected. The 2025 data are presented in Appendices 1 through 12. Table 1 presents a summary of the geometric means calculated for each parameter in marine samples for each of the quarterly surveys since 1991. Data from the previous years' surveys are given in the earlier annual reports. The locations of all sampling sites are shown in Figures 1 and 2.

3.1 Water Quality Parameter Concentration Gradients

Samples from the well sites, anchialine pools, and the fishponds provide information on the chemistry of groundwater as it moves under the site towards discharge into marine waters. The marine samples provide information on the fate of groundwater and its constituents as it enters the ocean. Groundwater is usually relatively high in the concentration of silica, nitrogen, and phosphorus relative to marine waters (Table 1). The freshwater basal lens of groundwater generally has low salinity in mauka areas, however, with decreasing distance to the shoreline tidal forcing mixes the basal lens with higher salinity water and salinity in the basal lens increases with proximity to the ocean. The salinity gradient observed in basal groundwater should generally be the opposite of that of silica, which is diluted by marine waters, although this rule is broken by mixing with basal groundwater that is both high salinity and high silica. Other water quality parameters including the nitrogen and phosphorus species monitored, as well as chlorophyll-a, generally decrease with increasing proximity to the ocean as they are diluted by marine waters; however, macronutrients (i.e., nitrogen and phosphorus species) also have anthropogenic and biological sources and may also be reduced by biological uptake.

Plotting each measurement of nitrate nitrogen (Figure 3) and orthophosphorus (Figure 4) against distance from the shoreline shows relatively low nitrate and orthophosphorus concentrations in the mauka groundwater are represented by Sites 1 and 2 (i.e., mauka Wells 1 and 2). Individual observations are shown in this plot to illustrate the intrinsic variability of the water quality parameters. These mauka wells have mean combined nitrate nitrogen and orthophosphorus concentrations of 570.68 ug/L and 46.84 ug/L, respectively, but these values vary by about 50%. As this water moves towards the ocean under the site, the input of macronutrients is apparent because higher concentrations are encountered at sample sites close to and makai of the development, rising to a maximum in anchialine pool Site 21, although a high degree of variation is apparent. As this high-nutrient water continues towards the shoreline, these concentrations rapidly decrease due to dilution and uptake such that the marine samples show relatively low concentrations of nutrient species. Even the shoreline samples, Site 9, show quite low concentrations relative to those measured in the anchialine pools. Figure 4 shows an increase in orthophosphorus inputs farther makai than the nitrate nitrogen inputs as seen in Figure 3, with maximum orthophosphorus concentrations seen in Site 3, the golf course anchialine pool.

3.2 Nutrient Inputs

Possible anthropogenic sources for macronutrients observed in the study are likely to be from the WWTP R-1 discharge used for irrigation or discharge into the injection wells, use of fertilizers, accidental spills/leaks, stormwater runoff, and unknown off-site anthropogenic sources. Figures 5 and 6 show time series of the concentrations of nitrate nitrogen and total nitrogen, in Sites 18, 21, and 22, respectively. Curiously, Site 18 shows relatively slight variations in nitrate nitrogen (Figure 5) while total nitrogen (Figure 6) shows a pronounced rise and subsequent decrease during the period of about 2002-2016. Site 21 shows similar changes, albeit much more pronounced.

There are three or four primary peaks in the observed concentration of nitrate nitrogen and total nitrogen at Site 21. The first occurred in the 1989-90 period and has been attributed to the "grow-in" period for the Kings' Golf Course (Brock and Kam 1992). During the grow-in period, fertilization and irrigation schedules are increased until the turf becomes well-established. A second peak occurred in 1992 which EA (Brock 1993) determined was related to an accidental spill of liquid nitrate fertilizer due to a failed valve (Brock 1993, Brock and Kam 1994), although this peak may be conflated with that of 1989-1990. Liquid nitrate nitrogen is no longer used as a fertilizer at Waikoloa. Figures 5 and 6 also show a broad second peak, or third if the 1989-1990 peak is considered, in nitrate nitrogen and total nitrogen concentrations in Site 21 around 2002-2007. Finally, a third (or fourth) broad and lower peak in the period of 2014-2018 is apparent. Since this time, the mean concentration of nitrate nitrogen as measured at Site 21 (Pond 48) in the pond preserve has declined and has varied in the range of 700 ug/L to 1,200 ug/L, similar to concentrations encountered elsewhere in anchialine habitats along undeveloped sections of the West Hawai‘i coastline.

Nitrate nitrogen and total nitrogen observed in Site 18, the maintenance "dug" well, are also plotted in Figures 5 and 6. This well is located inland of the golf course and most resort landscaping. Due to its location upgradient of most land uses respective of the direction of groundwater flow; nitrogen concentrations have not been significantly affected by activities occurring on the golf courses. There is some similarity between the behavior of Site 18 and Site 21 nitrate nitrogen concentrations, but the variation of Site 18 is much less than that of Site 21. The fitted regression lines, or trend lines, for both Site 18 and 21 nitrate nitrogen data are also given in Figures 5 and 6. A flat regression line suggests little or no change and a line with a significant positive slope suggests an increase in concentration over time. Similarly, a fitted regression line with a significant negative slope suggests a parameter that is decreasing in concentration through time. The slope of the regression line to nitrate nitrogen for Site 21 ($r^2 = 0.19575517$, slope = -0.076463268) shows that while quite variable, nitrate nitrogen in these sites has increased slightly over time. In contrast, at the more inland Site 18 and Site 22, the slope of these fits are nearly flat and do not differ significantly from zero, suggesting any long- term change in the measured concentration of nitrate nitrogen at Site 18 and Site 22 over the 37-year period of observation. The two sites show at least some correlation, with discernable peaks around 1990 and the broader rise in the period of 2006 to 2009. Some of these changes appear to be related to changes in Wells 1 and 2, which show spikes in phosphorus concentrations from 2002 to 2007, roughly corresponding to behavior in Site 18.

The nearly flat slope of the fitted regression lines for nitrate nitrogen and total nitrogen measured at Sites 18 and 22, which are inland of most of the development, show no significant change in nitrate nitrogen concentration over time. Site 18 is a former "dug well" excavated for dust control purposes and is located inland of most development. At this location nitrate nitrogen and total nitrogen concentrations are consistently lower and show little fluctuation through time relative to Site 21. We would expect Site 22 to show somewhat higher values than Site 18, but Site 22 appears to be more affected by dilution. On the other hand, it is important to note that nitrate nitrogen concentrations at Site 18 have a mean value of approximately 740 ug/L over the entire study. The measured concentrations of nitrate nitrogen and total nitrogen at Site 18 are very similar to those found at other inland well sites in West Hawaiʻi and are probably representative of the nitrate concentrations in undisturbed groundwater as it first enters the coastal development at Waikoloa.

Figure 7 and Figure 8 show time series for orthophosphorus and total phosphorus in Sites 18, 21, and 22, respectively. Both orthophosphorus and total phosphorus in Site 21 show several pronounced maxima including those centered around 2003 to 2005 and 2017 to 2018, while Site 18 shows much lower and more stable concentrations. Site 22 appears to track the Site 21 changes at lower values, indicating that these sites are likely expressing the same groundwater with site 22 being more diluted by brackish groundwater. After 2018 some reduction is seen towards values more representative of the mean, but linear regressions to orthophosphorus and total phosphorus show an overall increase, with r^2 values of 0.345 and 0.182, respectively. Although not shown on these plots for the sake of presentability, Site 3, the golf course anchialine pool behaves very much like Site 21, suggesting that the nutrient inputs are occurring between Site 3 and 21, and are likely to be due to golf course irrigation and possibly the two lakes located on the golf course.

Sites 18, 21 and 22 show very different behavior in orthophosphorus and total phosphorus than seen in that of nitrate nitrogen and total nitrogen. Like the nitrate nitrogen data for Site 21, mean phosphorus concentrations, both orthophosphorus and total phosphorus, were elevated during the period of "grow-in" of the Kings' Golf Course in the late 1990s. In fact, several distinct peaks in phosphorus concentrations are seen in Site 21 around 1994-1995, 1997-1998, 2003-2007, and most recently a broad peak from 2014-2018, followed by an apparent decrease in 2019-2021. The source of this phosphorus is likely from coastal development because orthophosphorus concentrations did not change significantly at Site 18, located inland of most of the development, since the commencement of sampling in 1986. In the 2010-2013 period, orthophosphorus concentrations were not much different than they were in 1986-89 at Site 21. The sources and possible causes of nitrogen and phosphorus in the coastal groundwater at the Waikoloa Resorts are examined in more detail below.

In servicing the golf courses Waikoloa Resorts personnel apply nitrogen, phosphorus and potassium-containing fertilizers. Because of size and proximity, fertilizers and irrigation applied to the Beach Golf Course, which is situated inland or mauka of the Waikoloa Pond Preserve, has the greatest probability of being a source for the nutrient compounds detected in the anchialine pools of the preserve. However, we should keep in mind that other sources are likely, including irrigation and fertilizers applied to areas not managed by Waikoloa Land Co., such as The Shores. Fertilizers used on the golf courses are primarily comprised of nitrogen, phosphorus, and potassium. Of these constituents, nitrogen applied in the ammonium form will rapidly convert to the nitrate form (i.e., NO_3 - the form readily utilized by plants), which does not bind to the soil and readily moves down through the soil horizons with water, when transported by water from surplus irrigation or rainwater. The total annual quantities of nitrogen and phosphorus applied on the two Waikoloa Resorts golf courses is given in Table 2. Fertilizer use has varied over the 34 years of record but declined continuously and substantially after about 2008 and has remained well below previous levels ever since. Relative to the overall mean values, nitrogen use in 2025 was about 19% of the 34-year mean use of 17.26 metric tons (mt), and for phosphorus the 2025 use of 0.22 mt is just about 5% of the 34-year mean value of 4.01 mt. The large decrease in golf course fertilizer use in recent years is commendable and demonstrates the commitment that the Waikoloa Resorts has towards environmental protection. The variations in measured phosphorus concentrations at Site 21 in the course of this study may be related to the temporary increases in phosphorus fertilizer use in 1992-1993, 1995-1996, 2000-2001, and again in 2004-2005 and phosphorus present in treated wastewater used for irrigation, as well as other sources. After 2009 phosphorus fertilizer was reduced significantly, therefore, the increase in phosphorus seen in Site 21 after 2010 must be related to other activities or inputs including treated wastewater in irrigation or discharge in injection wells, leaks in the irrigation ponds, as well as inputs from other off-site sources in the area that are not part of Waikoloa Resorts. The latter includes portions of the Waikoloa resort area that are not under the control of Waikoloa Land Co., such as The Shores development.

In summary, the concentration of nitrate nitrogen measured at Site 21 has fluctuated since the time of the nitrate nitrogen spill in 1992, but since about 2019 has remained stable and relatively low. The decreasing use of both nitrogen and phosphorus on the golf courses in the last several years, as well as possible biological adaptation to nutrient loading, appears to have resulted in a decrease in nitrate nitrogen at Site 21, especially in 2010-2014 where the nitrate nitrogen values are close to their values when monitoring program began in 1986. The picture for phosphorus is different; large variations in orthophosphorus have occurred at Site 21 over the last 34 years, along with a long-term increase and particularly high values from 2014 to about 2019. However, the most recent phosphorus concentrations in Site 21 show a marked decline in orthophosphorus and total phosphorus concentrations, probably at least due in part to the COVID-19 related reduction in tourism and the consequent dearth of WWTP discharge. This may have had a short-lived impact on the overall phosphorus loading of the Waikoloa Resort hydrologic system.

In response to the increase in measured orthophosphorus, particularly at Site 21, golf course personnel stopped applying dry phosphorus fertilizer on the Beach Golf Course. Similarly, no nitrogen fertilizer was placed on the Beach Course until 1999 when 33 kg of phosphorus was used, and 4,860 kg of nitrogen was applied to the course. The decrease in the application of fertilizers starting in 1997 appears to be evident in the graphical data for 1999. These data suggest that a lag occurs with these materials as they are transported relatively slowly to groundwater, however the increase in phosphorus use in 2000 and 2001 (Table 2) became evident in the last two quarters of 2000 at Site 21. In 2002-03, relatively little phosphorus was used, but in 2004-05 use increased. In response, as seen at Site 21, phosphorus concentrations remained elevated through the 2002-late 2006 period and subsequently decreased, which may be related to the decrease in its use in 2007 to present. Although orthophosphorus concentrations in Site 18 remain largely unchanged, Site 21 phosphorus concentrations showed a rise in mean values to greater than 400 ug/L in the period of 2014 to 2018, including some of the highest phosphorus mean values of the historical range of the monitoring program. This is followed by an apparent decrease after 2019, with the mean orthophosphorus concentrations of the 2021 surveys of 243.63 ug/L, in 2022 of 332.62 ug/L, in 2023 of 245.65 ug/L, 2024 of 281.94 ug/L, and in 2025 of 275.59 ug/L.

Adjacent marine water is relatively low in concentrations of these nutrients due to dilution by marine water (Figure 2 and 3). In addition, both in and around the WAPPA anchialine pools, biological uptake/sequestration by vegetation accounts for some unknown fraction of this reduction. Because of a continuing upward trend of nitrogen and phosphorus in groundwater observed from about 2000 to 2007, the Waikoloa Resorts golf courses responded in 2007 by decreasing the application of fertilizers. Reduction in fertilizer use has continued up to the present time such that the 2025 annual use of nitrogen fertilizer was 3.29 metric tons (mt) and phosphorus fertilizer use was 0.22 mt. The overall 35-year annual mean use of nitrogen fertilizers is 17.26 mt and for phosphorus is 4.01 mt and their use has been greatly reduced in recent years.

Figures 9 and 10 show the time series of total nitrogen and total phosphorus for Wells 1 and 2, respectively. Total nitrogen and total phosphorus show similar behavior, although total phosphorus shows a strong peak in the period of 2001 to 2004, which may have been due to grading of the area, which tends to release phosphorus from enhanced weathering. Both plots show a broad rise from about 2001 to 2015, then a return to lower and stable values. The curves in total nitrogen and total phosphorus may be responding to the same event, possibly wildfires, or they may be responding to different events. In any case, the fact that the rise and fall of total nitrogen and total phosphorus are seen, while there is no similar behavior in the species of orthophosphorus and nitrate nitrogen show that these inputs are of species in the inorganic forms and are not likely to be due to human activity. Wildfires are likely to be a source of infiltrated nutrients, and WWS has requested wildfire history data from the Hawaii Wildfire Management Organization. An inspection of historical aerial photographs of the area shows that the West Hawaii Concrete quarry located south of Waikoloa Road went through rapid growth from 2001 to 2005. This grading and excavation would have likely released phosphorus during rainfall events.

Observation of the mauka wells time series also shows, intriguingly, that the Well 1 – Well 2 pairs of values are often very close. The relative percent difference (RPD) for total nitrogen is 31.80% and for total phosphorus of 36.83% for the entire dataset. This shows that water quality parameters of the two mauka wells vary together and respond to the same changes in groundwater chemistry, and they are not responding to inputs that originate locally. The changes occurring are large-scale changes in the entire aquifer.

Visual interpretation of time series is problematic and prone to over-interpretation. Also, groundwater is often seen as steady state, but Wells 1 and 2 apparently show real groundwater chemistry changes. Wells 1 and 2 show variation of total nitrogen and total phosphorus of at least 100% over timescales of several years, although the time resolution of our data set will blur, or not detect, events that occur on a timescale of less than several months, on average. Thus, we caution the reader against relying on trendlines alone for interpretation. As the dataset is largely composed of non-random variables, only multivariate statistical analyses can confidently give us an understanding if changes are statistically real. The variables are of natural parameters, which means that they are showing characteristics of different systems (i.e., basal groundwater, anchialine pools, marine environments, and the entire bio-hydrological system of the study area). These systems are all the result of dynamics, most importantly being hydrologic/hydrogeologic flow (i.e., basal and infiltration from irrigation), as well as primary productivity and other biological productivity.

Groundwater, with dissolved and sometimes suspended chemical constituents, moves downhill with the hydraulic gradient. Infiltration of rainfall, irrigation, injection or dry wells, or other sources, may input macronutrients. Surface exposures of groundwater allow photosynthesis and uptake of nutrients into biomass sinks, which also will release nutrients to the ecosystem. The buildup of organic matter, or biomass, in the anchialine pools enhances rates of nutrient uptake, nitrification, and photosynthesis. This is a positive feedback cycle that results in sedimentation and senescence of the anchialine pools.

All groundwater progresses towards the ocean and is mixed via tidal forcing, primarily with high-salinity, low-silica marine water, but is also mixed in the vertical dimension with high-salinity, high-silica groundwater. This latter phenomenon has been observed by WWS in a number of locations, but this data is not publicly available and has not been published.

3.2.1 Use of Treated Wastewater in Irrigation at Waikoloa

The Waikoloa Resorts continues the practice of diluting R-1 treated wastewater with low salinity groundwater to about 20% by volume for irrigation of golf and landscaping at Waikoloa. The fraction of treated effluent in the irrigation water has remained consistently in the range of 20% to 25%, with the exception of 2019 and 2020 due to the COVID-19 resort shutdown. The year 2021 showed increased WWTP effluent of 190.54 MG and 18.7% of total groundwater pumped, but still below the mean for the past several years. In 2022 and 2023 the fraction of R-1 water used in irrigation is about 20% to 21%. Figure 11 shows a time series plot of treated wastewater used in irrigation and the volume of R-1 water used, with a long-term increase of treated wastewater, rising to a peak in 2018. This trend was interrupted by discharge to the injection wells in 2007 and 2008, as well as the recent dip due to COVID-19. The analysis presented in past reports showed that rainfall amounts had little impact on the total irrigation volume, likely because of the small amount of rainfall, usually about 10 inches annually, and close to that average in 2025, in which only a total of 11.26 inches of rainfall were recorded. At the end of May 2008, the use of treated wastewater diluted with low-salinity groundwater for use in the irrigation for turf and landscaping was temporarily stopped at the Waikoloa Resorts to upgrade the wastewater treatment plant (WWTP) to R-1 standards. During the period of the WWTP plant upgrades, treated wastewater was disposed via two temporary percolation pits located on the treatment plant site. This upgrade was completed on 17 September 2012 but use of the temporary pits for discharging the R-1 treated water continued through 2012. Through this period, 2008 to 2012, these nutrients were not detected at the routinely monitored sites, although it is possible that because the injection well inputs find a different route to marine waters than that from irrigation. Commencing in early 2013, the R-1 water was once again recycled (blended) with low salinity irrigation water for turf and landscaping at Waikoloa, fairly coincident with the rise of orthophosphorus concentrations in Site 21. It is likely that the long-term trend of rising phosphorus since 2013 is due to the increasing use of treated wastewater for irrigation, but possibly also due to phosphorus loading being greater than the ability of the hydrologic system to remove it.

Treated wastewater typically has high concentrations of both nitrogen and phosphorus, usually found in a ratio of nitrogen: phosphorus in the range of 5:1 to 10:1, with nitrate nitrogen often in excess of 10 mg/L (Hawaii Water Service, 2023). The N:P ratio observed in the Waikoloa anchialine pool Site 21 shows increasing phosphorus relative to nitrogen. Figure 12 shows a time series of the total nitrogen to total phosphorus ratio, or N:P ratio, for Site 18, Site 21, and the mauka irrigation wells 1 and 2, along with least-squares fit lines. The N:P ratios of Wells 1 and 2 show a slight change over the historical range of the data set, while the N:P ratios for the two anchialine sites appear to show increasing phosphorus loading relative to nitrogen loading. As phosphorus possesses significantly reduced mobility relative to that of nitrogen species, which are generally highly water soluble, this appears to show the reduced ability of phosphorus to be flushed from the Waikoloa Resorts hydrologic system. Nutrient uptake is also certainly occurring in the anchialine pools, and if nitrogen is the limiting nutrient for photosynthesis, this dynamic may also reduce the N:P ratio.

We interpret these data to suggest that groundwater in the Waikoloa Resort hydrologic system shows evidence of a limited ability to remove phosphorus, compared to the relatively soluble and mobile nitrogen species. In a previous report (WWS 2022) we speculated that we would see a rise in phosphorus concentrations in the Waikoloa Resorts anchialine pool hydrologic system after the COVID-related decrease, particularly if most of the phosphorus loading is due to irrigation with R-1 treated wastewater, and this appears to be occurring. Wells 1 and 2 show a slight decrease in N:P ratio while Site 21 shows a much greater decrease in this ratio, indicating the increasing concentration of phosphorus relative to that of nitrogen. This is evidence of phosphorus loading in the Waikoloa Resorts hydrologic system at a rate greater than the system's ability to remove phosphorus.

Ku'uali'i and Kahapapa Fishponds are nutrient sinks where nutrients are stored in sediments and biomass. Some nutrients are sequestered in the bottom of these ponds in sediments. This type of uptake and storage results in the temporary reduction of macronutrients. Uptake also moves up the food chain, as herbivores including fish, zooplankton, and invertebrates utilize nutrients, while decomposition releases nutrients. Cycling of nutrients between organisms and trophic levels (i.e., between primary producers, herbivores, and predators) may free nutrients, resulting in some points being above the mixing line suggesting additional input; most of these data are from Site 4 at the mouth of the Hilton Waikoloa Lagoon where lower salinity lagoon waters meet marine waters. The point should be made that in the anchialine ponds at Kūkiʻo, North Kona, an area sampled for more than ten years prior to any surrounding development, nitrate concentrations were routinely measured in the range of 1,750 ug/L to 2,520 ug/L. Other anchialine pools sampled under other programs at Kūkiʻo show nitrate nitrogen concentrations in the 2,520 ug/L to 3,360 ug/L range. Thus, high nitrate nitrogen concentrations may be a completely natural phenomenon in some West Hawaiʻi anchialine systems and the native biota appear to be completely insensitive to these apparently higher nitrate concentrations.

Phosphorus is a major component of fertilizers, but its use has been greatly reduced in recent years at the Waikoloa Resort golf courses (Table 2). The use of treated wastewater in the irrigation water has probably resulted in soil deposition of phosphorus and subsequent leaching to the underlying groundwater, particularly during rainfall events. Phosphorus is produced naturally by the weathering of rocks, which is likely to be the origin of the phosphorus observed in the mauka wells but is also present in treated wastewater. The plot of orthophosphorus concentration with salinity shows many points above the conservative mixing line (Figure 13), which suggests input from autochthonous (i.e., locally derived) sources at lower salinities. It should be noted that, in general, the majority of the points in Figure 13 fall below a concentration of 200 ug/L, which is the upper concentration measured in anchialine pools at Makalawena-Awakeʻe where there is no surrounding development (Table 4, also see Brock and Kam 1994). The high nitrate and orthophosphorus values found at some Waikoloa Resorts are possibly related to the leaching of these materials to the groundwater as well as to the naturally high nutrient loading typically found in West Hawaiʻi groundwater. Brock and Kam (1992, 1994) noted that the groundwater chemistry of West Hawaiʻi is highly variable with respect to inorganic nutrients, and this program has observed such behavior at the Waikoloa Resorts, notably in Sites 1 and 2, the mauka wells (Well 1 and Well 2). The measurement of inorganic nutrients from anchialine pools that are situated in localities with no surrounding development has shown values greater than those recorded at Waikoloa. These data suggest that nutrients are frequently in excess and are not limiting primary productivity in these systems. In many other aquatic habitats, inorganic nutrients are limiting and when supplied in excess result in major shifts in those aquatic communities. Such biotic changes have not been documented at Waikoloa (Brock and Kam 1992, 1994 and see below). Figure 14 shows the relationship between nitrate nitrogen and salinity with the conservative mixing line shown. Curiously, many anchialine pools plotted show nitrate nitrogen concentrations below the conservative mixing line, demonstrating either uptake by biological activity, or mixing with high-salinity and low-nutrient groundwater, or both. Figure 15 shows the relationship between silica and salinity in all sites, with the mixing line shown and the intercept value determined by the mean Site 1 and Site 2 concentration. Silica generally shows predictable behavior given groundwater inputs and dilution in the mixing zone by lower-silica water. Generally speaking, points above this line show inputs of nutrients while points below the line show uptake of nutrients. Input of silica may occur from irrigation water, while nitrogen and phosphorus species may find inputs from the decomposition of vegetation, as well as irrigation water. Alternatively, silica may be enhanced through mixing with high-silica brackish groundwater.

3.3 Compliance with Department of Health Criteria

The Hawai‘i State Department of Health (DOH) has developed specific criteria for different classes of State waters (e.g., as for harbors, streams and marine waters) to be used in the determination of compliance. Up to July 2000, the waters fronting Waikoloa were classed as “Open Coastal Waters” said to remain “...in their natural pristine state with an absolute minimum of pollution or alteration of water quality from any human-caused source or action” (Hawai‘i Administrative Rules, Chapter 11-54-01). The most stringent standards have been set for open coastal waters and these standards are presented in Table 5. New standards were imposed for the West Hawai‘i coastline in the year 2000 that utilize a regression approach for marine sample sites where salinity is 32 parts per thousand (ppt) or less. This regression approach is used in determining the standard for nitrate + nitrite nitrogen, total nitrogen, orthophosphorus, and total phosphorus. Standards for other parameters are based on the 95% confidence interval derived from regression calculations performed by DOH personnel using water quality data collected from “undisturbed sites” along the West Hawai‘i coast. There are no standards set for anchialine pools or coastal brackish wells used for irrigation purposes, thus the water collected at Waikoloa may be considered in two groups: marine samples where the regional West Hawai‘i standards apply and other sites located away from the ocean in this study. Table 5 presents the old open coastal water quality standards that apply for marine samples collected prior to July 2000. The applicable standards for marine samples collected from 2000 and later are summarized in Table 6.

3.3.1 Pre-2000 Samples and Criteria

The old open coastal water quality standards are established on the basis of the volume of local freshwater input, either as surface runoff or as groundwater entering the ocean and are given in Table 5. "Dry" conditions in the standards are defined as those coastal waters that receive less than three million gallons of freshwater discharge per day per shoreline mile and "wet" coastlines are those with greater input. Previous work on the West Hawai'i coast suggested that the groundwater discharge in the vicinity of Waikoloa was in the range of 0.97 to 3.97 million gallons of groundwater discharge per day per shoreline mile (Kanehiro and Peterson 1977). Recent estimates are higher; presently, the groundwater discharge in the Waikoloa area is estimated to be in the range of eight million gallons per shoreline mile per day (Nance 2003).

At Waikoloa, the Department of Health "wet" standards were exceeded on every survey prior to July 2000 for nitrate nitrogen except for the March 1996, September 1996, and August 1997 surveys (Tables 1 and 5). The geometric mean values for nitrate nitrogen exceeded the "not to exceed 10 percent of the time" value on 29 of the 38 quarterly surveys (Table 1) in this early period. Similarly, the "absolute not to exceed" value for nitrate (25.00 ug/L) was exceeded in eleven of these early surveys. Ammonia nitrogen was similarly high; the geometric means exceeded the State standards for all except five of the 38 surveys (i.e., April 1992, September 1993, June and October 1994 as well as in October 1999). However, the absolute "not to exceed" standard for ammonia nitrogen (15.00 ug/L) was not violated except in the July 1998 and June 1999 surveys. Total nitrogen geometric means were above the state standards in the December 1992, September and December 1993, March 1994, July 1995, August 1997, March, October, November 1998, April and June 1999, as well as in the April and June 2000 surveys but did not violate the "10%" or "absolute not to exceed" standards. Chlorophyll-a is a measure of photosynthesis; the wet standard was exceeded on three occasions in this data set (July 1991, July and October 1995). The geometric mean values for all other parameters and sample periods were in compliance, except for total phosphorus in May 1993, March 1994, July 1995, January and September 1996, August 1997, March, July, October 1998, June 1999, as well as in April and June 2000.

In general, the highest nitrate nitrogen and total nitrogen values for marine stations are found at locations with greatest salinity depressions, meaning where groundwater is diluted the least (i.e., sites 4, 5, 9 and 12) at monitoring stations located near the shoreline. As groundwater is naturally high in nitrate nitrogen relative to marine waters; simple mixing of high nitrate groundwater with seawater can account for much of the lack of compliance with criteria in these observations. Extrapolation of these data suggests that at salinities less than about 33.5 ppt, the measured concentration of nitrate nitrogen would exceed the standards. Forty-five percent of the surface marine samples collected prior to July in the 2000 sample set had salinities at or below 33.5 ppt and 32.8% of the marine samples collected at all surface marine stations since 1991 have had salinities below 33.5 ppt. Using only those station numbers that were sampled prior to July 2000, and examining the data from July 2000 to the present, 39.8% of the marine samples had salinities less than 33.5 ppt, thus about forty percent of the samples would be expected to not meet state water quality standards due to the large influence of groundwater.

3.3.2 Post-July 2000 Samples and Criteria

The DOH West Hawai'i regional standards break the criteria down into three tiers (Table 6). The standards for parameters that do not display distinct onshore-offshore gradients of concentration utilize a geometric mean "not to exceed" single value. These parameters are ammonia nitrogen, chlorophyll-a, and turbidity. For the remaining parameters, the following two situations apply: if there is no substantial groundwater flow as evidenced by a salinity depression near the shore, a geometric mean "not to exceed" value also applies. Where groundwater flow is evident and depressing salinity to 32.0 parts per thousand or less, a straight-line mixing relationship is specified, and the water quality criterion is the 95% upper confidence limits of the slope of this regression line. Application of these criteria to marine samples requires that sample sites be located in a "transect" commencing at the shoreline and sampling at various distances offshore. The standards as given in the DOH document suggest that sample sites be located at the shoreline, and at distances from the shoreline of 10 m, 50 m, 100 m, 500 m, and 1000 m from shore and that only samples from the surface layer (i.e., within a meter of the surface) be used in making the analysis. Thus, marine sample sites that do not conform to this sampling configuration (i.e., as those collected at depth) cannot be included in this analysis.

At Waikoloa, three marine transects with surface-collected samples have been routinely monitored since the mid-1980s. In Waiulua Bay, Site 4 is located at the shoreline, Site 5 at the surface about 75 m offshore, Site 6 again at the surface 150 m offshore, Site 7 collected at depth one meter above the bottom directly beneath Site 6, and Site 23 which is 300 m offshore. A second "transect" is situated offshore of the Waikoloa Anchialine Pond Preservation Area where four stations sampling surface waters have been established; Site 9 is at the shoreline, Site 10 is approximately 75 m offshore, Site 24 is 150 m offshore, and Site 26 is 300 m offshore. In 'Anaeho'omalu Bay is another transect of stations to sample surface waters. Site 12 is collected at the shoreline about midway along the sand beach, Site 13 is 75 m offshore, Site 14 is 150 m offshore, Site 19 is collected at a depth of 6 m just beneath Site 14, and Site 25 is taken 300 m from the shoreline. Since the application of the regional standards, four of the above stations are new; these are Site 23 (Waiulua Bay - 300 m offshore), fronting the WAPPA Site 24 at 150 m out and Site 26 at 300 m offshore, and a final station offshore of the Anaehoʻomalu Bay transect, Site 25 which is 300 m from the shoreline. The results of compliance with the regional standards are given for each of the 2025 surveys in Appendix 2 (20 March 2025 survey), Appendix 5 (10 July 2025 survey), Appendix 8 (1 October 2025 survey), and Appendix 11 (30 December 2025) for the marine surface stations fronting Waikoloa and Appendix 13 presents the 2025 data collected at the Makalawena-Awakeʻe control site. The results of compliance at the three Waikoloa marine transects, as well as at Makalawena-Awakeʻe control station for all years (2000 through 2025) are summarized in Appendix 15.

Salinity was depressed (i.e., 32 ppt or less) on at least one Makalawena-Awakeʻe transect during 2025. Where a salinity gradient was present (i.e., less than 32 ppt at the shoreline), the regression method utilizing data from surface samples was applied for determining compliance with the standards. The other criteria as given in Table 6 apply to those marine sites for the determination of compliance with State regional standards.

Compliance data for the four 2025surveys are given in Appendices 2, 5, 8, and 11, and are summarized in Appendix 15. Ammonia nitrogen and turbidity exceeded all criteria over all transect for both the project area and the control site in 2025. For the project area, four sampling days over three locations and seven parameters equates to 84 opportunities for exceedance, of which 61 were above the threshold for an exceedance rate of 73%. All seven sampling points (anchialine pools and marine transect) at the Makalawena-Awakeʻe control site were non-compliant on 23 December 2025. Based on recent historical data there has been total rate of exceedance that is higher than typical (about 85%, or 6/7 sampling points), considered against their long-term exceedance rate of 70% and 68% for Waikoloa and Makalawena, respectively.

Examination of parameter compliance at Kūkiʻo, a former control site currently undergoing development, we find that during the 10-year pre-development period, nitrate nitrogen, ammonia nitrogen, and total nitrogen were never in compliance (Table 4) but most other parameters were within the compliance threshold. This long-term lack of compliance at different sites, both developed and undeveloped, suggests that the 2025 Waikoloa results are not unusual, and the regional standards may be somewhat too stringent and not reflective of the natural physical and biological characteristics of the coastline. For instance, the turbidity criterion of 0.1 NTU is, in fact, lower than the turbidity criterion for drinking water under the Safe Drinking Water Act (EPA 2023). Furthermore, while one may have speculated that we would have observed reduced rates of non-compliance given the reduced intensity of use of the Waikoloa Resorts in 2020-2021 due to the COVID-19 travel restrictions, this is not observed, suggesting that non-compliance is a result of natural processes. In summary, the reader should not be alarmed by the apparent high rate of non-compliance with water quality criteria as this is a normal situation because the criteria do not reflect normal, natural ambient water quality conditions.

Appendix 15 and Table 7 summarize non-compliance among the seven parameters at the three Waikoloa transect sites as well as for the Makalawena-Awake‘e control site since the designation of the West Hawai‘i regional standards in the year 2000. The annual rate of non-compliance may be determined by the following: there are three transect sites at Waikoloa which were sampled on four occasions in 2025 and seven parameters that are subject to State regional standards. This results in 4 x 3 x 7 = 84 opportunities for non-compliance to occur. In total, there were 61 instances of non-compliance in 2025 at Waikoloa Resorts marine sampling sites, resulting in a 73% overall rate of non-compliance. Rates of non-compliance have varied through the years; fronting Waikoloa they have ranged from a high of 83.3% in 2011 to a low of 46.4% in 2016. The high rate of non-compliance in 2011 may be partially related to the tsunami which removed much of the seaward side of Ku‘uali'i Fishpond, opening it up directly to the sea, and releasing sediments and stored nutrients into ‘Anaeho‘omalu Bay. The fishpond was open to the ocean for a 141-day period until the sand berm was replaced in late July 2011. The tsunami resulted in a large amount of sand and debris being moved about ‘Anaeho‘omalu Bay, as well as an unrestricted flow of relatively high nutrient brackish water from the fishpond which could have contributed to the greater non-compliance in the 2011 marine data.

Fronting the Makalawena-Awake‘e control site, rates of non-compliance have ranged from 42.8% over several years to 100% in 2021. Overall mean non-compliance fronting Waikoloa is 69.8% and offshore of Makalawena it is 66.7% again, suggesting that non-compliance is a normal occurrence along these two sections of the coastline. These data show that non-compliance occurs with virtually the same frequency at both Waikoloa as well as at the Makalawena control site having no surrounding development. These data suggest that non-compliance among water quality parameters occurs on a regional basis and, again, the determination of compliance using the regional standards may be too stringent and not reflective of actual ambient conditions.

Examination of marine water samples from many coastal areas with little or no development inland (South Kohala, North Kona, South Kona, Lānaʻi, etc.) reveals that often the waters do not meet the State water quality standards for open coastal waters. As noted above, groundwater inputs may account for much of the lack of compliance. Brock and Kam (1990) 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 of 858 mm over a 24-hour period, and nitrate nitrogen, turbidity, and chlorophyll-a all exceeded state standards (Brock 1990a). At Māhukona, Kohala, Hawaiʻi, 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 Hawaiʻi Authority (NELHA) at Keāhole Point, Hawaiʻi since 1982. The waters offshore of Keāhole 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 Keāhole Point is 5.04 µg/L, which exceeds the old state "wet" standards. The mean for nitrate nitrogen at Keāhole is 2.80 µg/L and for orthophosphate is 4.96 µg/L, which is less than the old State standards, although under the old standards, orthophosphorus had no standard.

The water quality standards are human criteria imposed on a natural system and, as such, may not represent the variability of natural conditions. The frequent lack of compliance of near- shore marine waters in areas well removed from any coastal development indicates that the criteria for these standards may be too stringent. This suggests that some revision of the state standards should be considered. Knee et al. (2010) reported nitrate nitrogen and ammonia nitrogen concentrations at Kealakekua Bay ranging from 11.2 ug/L to 37.8 ug/L, and 1.4 ug/L to 2.8 ug/L, respectively. Groundwater concentrations of these macronutrient species are much higher, with Johannes (1980) reported groundwater nitrate levels between 1,610 ug/L to 5,320 ug/L from Perth, Australia, and Marsh (1977) noted groundwater nitrate concentrations in Agana, Guam of 2,492 ug/L, which are above any values found in the present study. These values are consistent with Waimea Water Services' observations of nitrate nitrogen in groundwater at numerous sites in West Hawaiʻi, where the approximate range of 0.5 mg/L to 4.0 mg/L are observed. Thus, despite not meeting state standards for many parameters and sample sites, the waters fronting the Waikoloa Resorts site are typical of West Hawaiʻi coastal settings with groundwater discharge, with the exception of areas with limited mixing such as bays, harbors, and fishponds.

3.3.3 Annual Change in Water Quality

The groundwater, anchialine pool, fishpond and near-shore marine waters at Waikoloa have been subjected to potential impacts over the duration of this monitoring program. The development of resorts, housing, golf courses, commercial areas, and associated infrastructure are all sources for potential impacts to water quality in this coastal area. The accidental leakage of sewage enriched irrigation water, as well as the spill of nitrate fertilizer in 1992, provided additional sources. Brock et al. (1998), as well as Brock and Kam (1992, 1994), reviewed the status of impacts to groundwater and aquatic biota at Waikoloa and found that changes occurred in some groundwater parameters with golf course development, but as noted above, these changes were within the range of values measured in undeveloped sites along the West Hawai‘i coast. Additionally, no statistically significant changes in water quality can be attributed to the abundance of important anchialine species in the Waikoloa Resorts anchialine pool system. These changes are attributed to the introduction of non-native fish species, which obviate the presence of native shrimp species and ultimately result in increased anchialine pool sedimentation and senescence.

The question may be asked, "Have there been any statistically significant changes in water quality in the anchialine pools?” The true statistical differences test (t-test) is used to answer this question by determining if statistically significant differences exist among the different mean values of each of the twelve parameters. The results of this test are given in Table 8 for the anchialine pool monitoring sites. For this analysis we have binned the data by year, which helps to minimize short-term variability and emphasize long-term changes. In previous years, different analysis platforms, the one-way ANOVA test with Tukey comparisons and the Kruskal-Wallis ANOVA with SNK comparisons were used. However, we now use the t-test due to the relatively small number of comparisons, multiple true statistical difference analyses (t-tests) are preferred in this context, as they offer greater statistical power and simplicity without the added assumptions of more complex methods. These tests are nearly identical and no change in interpretation is required.

Table 8 presents results of the True Statistical Differences Test for the anchialine pool monitoring sites. These results show that all water quality parameters except for salinity and chlorophyll-a noted significant changes. The remainder of the 2025 mean values are generally in the middle or slightly in the bottom half of the historical ranges of the data set, but do not differ from the remainder of the dataset. Although not statistically significant, total nitrogen may show a decrease after the statistically significant broad peak, group A, in the period of 2001-2010. Since 2019 the annual mean values of total nitrogen have been near the bottom of the historical range. Ammonia nitrogen appears to show a long-term increase until 2017 after which there appears to be a sudden and substantial decrease, this does not appear to be a statistically significant trend due to the high variability of the data set. Although orthophosphorus and total phosphorus show similar behavior, with long-term increases and a subsequent decline since 2017-2018, these trends are not statistically significant according to the Tukey comparisons. But if these trends are real, they may be shown to be statistically significant in subsequent analysis and reports.

We apply the t-test to the marine portion of the data set to answer the question, "Have there been any statistically significant changes in water quality at the Waikoloa Resorts marine monitoring sites or at marine sites fronting the development?" Examination of the mean values by date for marine sites noted no statistically significant differences among the mean values by year according to the t-test results for total nitrogen, orthophosphorus, and total phosphorus (Table 9). Ammonia nitrogen shows some of the highest values in 1995 through 1999, and these values are statistically separable from the remainder. Therefore, the peak in ammonia nitrogen observed in this period is statistically significant. Silica shows no apparent trend with time, nor does salinity. The highest value for turbidity of the data set was observed in 2021 and this value is significant according to the t-test. Similarly, chlorophyll-a values for the years 2020, 2021, 2010 and 1995 are statistically higher than the remainder of the dataset and are considered outliers. In general, the variations seen in this analysis of the anchialine pools and well water quality parameters are not observed in the marine waters, suggesting that dilution by marine waters is dominating significant changes in groundwater characteristics.

The four 2025 surveys (Appendices 1, 4, 7, and 10) illustrate the changing total phosphorus and orthophosphorus values, which show apparent declines after a strong peak in the period of 2016-2018. This trend is seen most visibly in sites 3 and 21 and is likely related to their locations relative to golf and landscaping activities. Site 3 (Figure 1) is located directly seaward (about 20 m away) from the Beach Golf Course and Site 21 is the closest sample site seaward of Site 3. Both the Vista and Shores at Waikoloa developments are situated between these two sample sites, so the proximity to areas possibly receiving nutrients from treated wastewater used in irrigation, groundwater used in irrigation containing nutrients, as well as fertilizers applied to landscaping, produces a greater sensitivity to these inputs. There is also the possibility of leaks in the distribution and reservoir system, and it should be noted that off-site sources may also be significant. Additionally, the relevance of the t-test for orthophosphorus and total phosphorus in light of the apparent trend in Figure 5 should be addressed.

All other marine water quality parameters, binned by year, showed statistical separation among the annual means with the Tukey Comparisons, although all had overlap between most years, including nitrate nitrogen, ammonia nitrogen, chlorophyll-a, salinity, turbidity, temperature, percent saturation of dissolved oxygen, and pH. Herein lies a limitation of the Tukey comparisons; if natural variability produces a high degree of noise within particular surveys, comparison of individual years to other years will be dominated by this noise. Hence the analysis includes binning of the data by year.

Chlorophyll-a concentrations have been elevated through much of this study in the ocean and 2019 through 2025 are all near the upper end of the range (Table 9), although the 2025 values are nearer the middle of the historical range. The annual mean values of chlorophyll-a for 9 of the 34 dates exceed state regional standards (i.e., 0.30 µg/L), but the values shown are averages and not geometric means and this comparison underestimates the number of exceedances. The high chlorophyll-a mean values may be related to the connection of Kuʻualiʻi and Kahapapa Fishponds to marine waters, which occurs directly and through flow through the sand beach berm. In the fishponds, chlorophyll-a concentrations are very high (Appendices 1, 4, 7, and 10, sample sites 15 and 17). These fishponds are located along the shoreline of ʻAnaehoʻomalu Bay where, during decreasing tides, water from the fishponds flows into the sea via the mākāhā. As noted above, chlorophyll-a is a measure of phytoplankton biomass and the chlorophyll-a concentrations are very high in these ponds (mean = 13.14 µg/L, n=271), thus the source for high chlorophyll-a values may be simply due to sampling the marine waters in ʻAnaehoʻomalu Bay during periods of decreasing or ebb tides when phytoplankton would be carried into the ocean from the fishponds via the mākāhā. The phytoplankton population is also similarly elevated in the Hilton Lagoon which flows out into Waiulua Bay where our sampling also occurs. Phytoplankton transported out of the fishponds and into the ocean, as would occur during falling tides, may survive for some period in the higher salinity waters of the ocean so despite not having always sampled during the ebb tide, phytoplankton from the fishponds would probably be present in the inshore areas of ʻAnaehoʻomalu Bay through all phases of the tide cycle.

In addition to elevated chlorophyll-a concentrations, high mean turbidities in marine samples at Waikoloa appear to be the norm; it should be noted that the annual means for turbidity have all exceeded the West Hawaiʻi regional standard (0.10 NTU), except for 1998 where mean turbidity was 0.06 NTU, otherwise the annual mean range runs from 0.15 to 0.74 NTU (see Table 9). The relatively elevated mean concentration for turbidity in 2021 (0.84 NTU) is probably related to high surf occurring during the 2021 period surveys. Generally speaking, visibility is quite poor in ‘Anaeho‘omalu Bay. Surf resuspends fine particulate matter already present in coastal waters and, when impinging on sand, moves loose stones and coral fragments across the bottom which causes abrasion leading to in situ generation of particulate materials that will serve to reduce water clarity. Along sandy beaches, such as at ‘Anaeho‘omalu Bay, rapidly rising and higher than normal tides wash fine particulate materials from the sand at higher reaches along the shoreline causing higher turbidity. However, WWS has identified phytoplankton, including diatoms that utilize the silica-rich groundwater, in ‘Anaeho‘omalu Bay, and these are likely to be responsible for the persistent and characteristically milky-white turbidity at ‘Anaeho‘omalu Bay. These higher wave conditions were probably responsible for the higher mean turbidity in 2003 as well as in many of the other quarterly surveys carried out through this study. 2022 and 2023 both had several periods of high surf, but WWS has been investigating the possibility that the high turbidity typically observed in ‘Anaeho‘omalu Bay is related to a diatom population which utilizes silica-rich groundwater discharging from the fishponds.

3.4 Pesticide Analysis

The most recent annual sampling for pesticides was carried out on 30 December 2025. Because pesticide sampling is expensive, products used in greatest amounts or over long periods are typically selected for sampling. Pesticides with low eco-toxicity are generally de-selected from the survey, and compounds with high eco-toxicity, as reported by the US EPA’s ECOTOX database (EPA 2023), among other sources, are given greater weight. Here the term pesticide means herbicide, insecticide, or fungicidal compounds.

Pesticide monitoring is undertaken annually at Waikoloa; up until 1994, this sampling was carried out under the WAPPA program. Since 1994, pesticide sampling has been usually carried out in the August-September period under the present privately funded monitoring program. Because of the near-continuous high surf along the West Hawai‘i coast in the October 2009-March 2010 period, the pesticide analyses that had been slated for collection in late 2009 did not occur. In 2010, pesticide sampling was carried out in October 2010 and included an examination of pesticides used in both 2009 and 2010. The pesticide sampling for 2011 was carried out in March 2012 and the 2012 sampling was completed in August 2013. In recent years, the list of products used in greatest quantities has not changed dramatically. Because of this, we combined the 2013 and 2014 pesticide sampling effort carrying out the collection of samples in October 2014. The sampling for pesticides based on the high-use products used in 2015 was carried out on 2 August 2016 and high use products used in 2016 were sampled on 31 October 2017. Sampling for 2017 high-use products was undertaken on 10 December 2018, thus includes some analyses of products used in both 2017 and 2018. The products sampled and analyzed in 2025 were high-use products, as reported by the Waikoloa Resorts as used at the King's and Beach Golf Course.

Pesticide samples are collected and processed by an EPA-approved laboratory on the mainland. In earlier years of the program (i.e., through 2008), both water and sediment samples were collected and processed. Sediment samples were examined for various products because many pesticides will adsorb or adhere to particulate materials and soil particles which settle, sequester, and accumulate in the bottom of ponds. Sampling these sediments affords an opportunity to examine the materials present that have accumulated over time, thus potentially providing a historical overview of products used in the past. However, the sediments found in West Hawaiʻi anchialine ponds are primarily biogenic (biological) in origin and often have a large number of chemical constituents that are the result of biological processes. These components often result in chemical interference which reduces the accuracy and detection limits for many of the active ingredients of products used that the laboratories are targeting. Furthermore, there have been instances in the laboratory where acidification of the sediment samples, a necessary step in determining the presence and concentration of certain active ingredients of pesticides used, resulted in explosions in the laboratory breaking glassware and endangering chemists. Thus, the results of examining sediment were less than satisfactory. In contrast, water samples provide low detection limits for many products but if the product is not present in the water column at the time of sampling, it could be missed. Due to these problems, commencing with the 2009 WAPPA sampling program, pesticide sampling has focused on those high use products in water only.

Since pesticide sample processing is expensive, the program focuses on those compounds that have either been used for a considerable period of time, have been used in relatively large quantities, and are of particular concern, including those of high eco-toxicity. Table 10 presents the list of materials used along with the amount used on the two golf courses at Waikoloa in 2025 with earlier annual use given in previous annual reports. Table 11 presents a summary of high-use products by year for the two golf courses from 2009 through 2025. Referring to Table 11, many of the high-use products used in the 2009-2025 period have been consistent. Notably, however, glyphosate-containing products including Roundup have been phased out. In some cases, there have been changes in the names of the commercial product used but the active ingredients have remained the same and the active ingredients are what the laboratories look for in determining the presence and amount of a given pesticide. An example is a herbicide with four different commercial herbicide names; these products are Ranger Pro, Roundup Max, Roundup Pro, and Touchdown which all have glyphosate and its daughter product, AMPA, as the active ingredients and as noted above, it is the active ingredient that is targeted by the laboratory for detection. In 2018, Hawai‘i banned the insecticide chlorpyrifos, beginning in 2022, but the Waikoloa Resorts has not used this product since 2018.

3.4.1 2025 Pesticide Results

As noted above, once the list of high-use products is known, laboratories carrying out the analyses are contacted to ascertain that they can carry out the analyses for the target products and provide acceptable minimum detection limits. Field sampling includes the use of appropriately pre-cleaned one-liter glass bottles with Teflon-lined caps. Once collected, samples are chilled and shipped to US EPA-approved laboratories on the mainland. This effort utilized the Matrix Sciences Pacific Agricultural Laboratory in Sherwood, Oregon. All field sampling and subsequent handling (including chain-of-custody forms) follow US EPA guidelines and methods. Laboratory methods used include Modified EPA 8270D (GC-MS/MS) and Modified EPA 8321B (LC-MS/MS).

Appendix 16 presents the lab results of the analysis of water samples from two anchialine pool sites at Waikoloa (Site 03, Best Efforts Pool and Site 11, Pond 155 in the WAPPA) and one control site location, an anchialine pool at Makalawena, sampled on 23 December 2025. None of the analytes was detected at or above the Method Reporting Limits.

As noted above, many of these same high-use products have been used in previous years on the two Waikoloa golf courses. Table 11 presents those high-use products targeted for analysis for the 2009 through 2025 periods. In no case during the 2009 through 2025 period were any of the active ingredients from high-use products targeted for analysis present at or above the Method Reporting Limits, although some products have been heavily used through the entire period. These data suggest that the careful use of pesticides in recent years has not resulted in their detection, which is evidence of the careful best management practices followed by the Waikoloa Resorts golf and landscaping personnel.

3.4.2 Past Pesticide Results

Sampling for pesticides commenced in June 1987 and the results of the earlier pesticide surveys are given in earlier reports and are not repeated here. As time has progressed, the pesticides used at the Waikoloa Resorts have changed; these changes, mandated by the general policies of the U.S. Environmental Protection Agency, have been towards compounds that continue to be effective upon application but have reduced product half-lives once the material is released into the environment. Changes in the use of products also reflect State of Hawai'i legislation, as in the case of the Chlorpyrifos ban. There has also been a trend to avoid use of glyphosate products, as health problems associated with exposure to them are now well-documented (e.g., Costas-Ferrira et al. 2022). The result has been an ever-changing list of materials used. In recent years many of the same products continue to be used; examination of Table 11 shows products used in the greatest quantities since 2009. In no case have any of these products been encountered at the method reporting limits as given in the previous annual reports. Although pesticides have not been detected at the Waikoloa Resorts and other coastal sites with golf courses along the West Hawai'i coast, public concern continues over the possibility of pollution from this source. Another way to approach the question of whether contamination is occurring is to sample long-lived aquatic species that inhabit potentially contaminated waters and thus could serve as bioaccumulators of these compounds. The use of long-lived species enhances the possibility of detection; presumably, such species would have been subjected to any contamination, if present, for a greater period of time.

In 2021 WWS tried an alternative pesticide analysis strategy. The analytical laboratory used for this analysis, Pacific Agricultural Laboratories, offered a multi-residue analysis of more than 300 compounds, including many common pesticides, for an affordable fee. None of these products were detected at or above the Method Reporting Limits. Sampling is carried out annually at the two anchialine pool sites Site 3 and Site 11 at the Waikoloa Resorts and in an anchialine pool at the Makalawena control site. Past pesticide sampling has also not found any of the products used. Given that the annual pesticide survey is a targeted survey, except in 2021, the fact that no high-use pesticides have been detected strongly suggests that the application of pesticides on the Waikoloa Resorts King's and Beach golf courses is being done appropriately and safely.

The Clean Water Branch of the Hawai‘i State Department of Health has a program established to test organisms for bioaccumulation of toxic materials. WAPPA program personnel worked with the Department of Health in collecting samples of the red shrimp, *Halocaridina rubra* from anchialine pools in three localities: adjacent to the golf course at Mauna Lani Resort, from Pond No. 155 at Waikoloa (site 11), and from a pool at Kūki‘o with no surrounding development at that time (the control site). These samples were collected on 9 May 1991. *Halocaridina rubra* has a lifespan in excess of ten years and if materials are leaching from golf courses into the water table, the biota of anchialine pools would probably have the greatest exposure due to proximity to points of application. The samples were treated as "whole body tissue samples" and examined for the presence of 44 different contaminants (see Table 9, Brock and Kam 1994). In no cases were any compounds detected.

3.5 Biological Monitoring

In its recommendations, the West Hawai‘i Coastal Monitoring Task Force (1992) suggested that the ubiquitous red shrimp or ‘ōpae‘ula (*Halocaridina rubra*) be considered as a prime "indicator" anchialine species for numeric monitoring of populations because of (1) its dominance in the anchialine community, (2) the usual abundance of this native species in many anchialine systems, and (3) the usually non-cryptic nature of this species while feeding in pools, thus lending itself to population estimates. Counts of this species are accomplished by placement of quadrats with area of 0.1 m^2. The results of these counts are given in Table 12.

The studies suggest that the nutrients are not limiting in natural anchialine systems on the West Hawai‘i coast. However, on the spectrum from oligotrophic (i.e., non-productive) to eutrophic (i.e., high biological productivity, increasing nutrient loading generally hastens the senescence process of anchialine pools. In wetland terms, the older anchialine pools have characteristic wetland plant and animal species, and wetlands soils. The native ‘ōpae‘ula (*Halocaridina rubra*) are excellent foragers and appear to reduce the sediment and biomass accumulation rate relative to that of a fish population (Dalton 2012) as shrimp are about twice as effective at foraging than fish. Ecologically, shrimp are very important for trophic flux, which means that they are also important for nutrient cycling and will facilitate transport of nutrients. Although some fish have been placed intentionally into anchialine pools, possibly to reduce mosquito populations, this practice also hastens anchialine pool senescence as the fish prey upon the ‘ōpae. The long-term maintenance costs also need to be considered as ponds containing fish require more maintenance to prevent their sedimentation.

The Waikoloa Resorts data set shows statistically significant increases in the abundance of the most characteristic anchialine species, *H. rubra*, in 2005-2006 over previous years, and a leveling off of abundance in 2007 in ponds that lack alien fishes. These increases occurred at a period when nutrient concentrations were on the rise at Waikoloa. Alien fish were intentionally released into the Waikoloa anchialine pond preserve sometime in early 2004. Where fish are present, many native anchialine species are absent during daylight hours when sampling occurs (Carey et al. 2009). By 2008, these fish spread and have colonized almost every pond in the WAPPA preserve. Waikoloa management, in consultation with the US Army Corps of Engineers and the University of Hawaiʻi WAPPA program, determined, among other things, that control of the alien fish problem requires an on-site resident pond manager. Mr. Tim Cooke was hired as the on-site pond manager and implemented a program to achieve the following: (1) better protect the WAPPA ponds by the planting of hedges comprised of native vegetation around portions of the pond preserve to keep visitors out of the ponds, (2) obtained the necessary permits from the regulatory community to release native predatory fish in some of the biologically degraded pools, (3) develop and place additional signage to better educate visitors of the unique resources in Waikoloa's anchialine system, and (4) remove unwanted encroaching vegetation from parts of the pond preserve.

In many aquatic habitats other than anchialine pools, nutrients limit productivity and, when supplied in greater concentrations, the result is major shifts to in the aquatic communities. Since nutrients often naturally occur in excess in Hawaiian anchialine systems and the biota appear to be completely insensitive to changes in the range of concentrations observed thus far, it is concluded that the increases in concentrations that have occurred at Waikoloa likewise have no apparent negative impact. This insensitivity is probably due to these species having evolved in a system where inorganic nutrients are not limiting and thus changes in concentrations in the ranges that we have measured on the Kona coast have no impact. The anchialine pool Site 3, named the "Best Efforts" pool, illustrates this, with high numbers of shrimp and healthy mats of the blue-green algae Schizomythas spp., while, at the same time, showing high concentrations of macronutrients.

Referring to Table 12, it is evident that the abundance of these ubiquitous red shrimp has changed over time. Initially, shrimp were present in three sampled pools (Sites 11, 21 and 22) in the WAPPA pond preserve where mean abundances in the April 1999-December 2003 period for Site 11 (Pond 155) was 106 shrimp/0.1m^2, subsequently decreasing to zero in the in the next March 2004 survey. By the May 2004 survey, the mean shrimp count at Site 22 (Pond 188) had gone from a mean of 88 shrimp/0.1 m^2 in the December 1990-March 2004 period to zero in the May 2004 survey.

Sometime between the 9 December 2003 and 9 March 2004 field surveys, someone intentionally released tilapia into the anchialine pools of the WAPPA on the makai side of the road. The largest and oldest fish were in pond numbers 31 and 32 directly adjacent to the roadway and at the time of their discovery, these fish were actively reproducing. About 20 pools or roughly one-third of the system was infested with the problem on 9 March 2004, which included sampled Pond 155. By the next survey in May 2004, fish had spread to Pond 188 resulting in the disappearance of shrimp at that location. No native shrimp were present in any of the pools containing tilapia. It was surmised that the release of fish had been done in late December 2003 or early January 2004, which would account for the extent of the spread. Waikoloa management was immediately notified of the problem and they, along with representatives from the U.S. Army Corps of Engineers, instituted a management program and strategies to control the spread of these alien fish species.

In summary, at the time of the first quarter 2004 survey, tilapia were present in Pond 155 (Site 11) but had not colonized Site 22 (Pond 188); but by the second quarterly (6 May 2004) survey, tilapia were present in all but one small isolated pool on the makai side of the roadway. Because the tilapia are predators of the native shrimp, these shrimp disappear and the diurnal census for these species shows them to be absent, although they may be present at night. Their absence results in statistically significant changes (decreases) in their abundance as noted above.

However, tilapia had not colonized the anchialine pools located on the mauka (inland) side of the access road that bisects the WAPPA up through the 8 January 2008 survey. Thus, one of the routine sample sites located in the mauka portion of the preserve (Pond 48 or Site 21) continued to have high counts of native shrimp present. Mr. Tim Cooke, resident pond manager, tracked the spread of tilapia in the mauka WAPPA system noting that it was in January 2008 that he first saw a tilapia "...in the mauka anchialine pond system. It was limited to just one pond in the northwest corner. Within two months, the population had grown exponentially to several hundred and the pond showed signs of degradation, slight buildup of silt and the algal mat was shrinking in size. Within four months, in April 2008, the silt build-up had increased to at least 4 to 6 inches in the deeper portions of the pond, the algal mat was virtually gone, and the tilapia population continued to increase. Six months later, in July 2008, the silt depth was 12 or more inches, the algal mat was completely gone, and the tilapia population seemed to have leveled off to several hundred." The second quarter 2008 water quality and anchialine pool survey was carried out on 11 July 2008, at which time nine anchialine pools along the north boundary of the WAPPA were colonized by tilapia including Site 21 (Pool 48).

As a result, the counts of native shrimp were zero and have remained so since that time because all of the routinely monitored pools in the WAPPA have tilapia. Subsequently, tilapia have spread throughout the pools in the WAPPA such that today we are aware of no more than two small, isolated pools in the WAPPA that remain free of tilapia.

There are two routinely monitored anchialine pools with native anchialine shrimp present and no alien fish species at Waikoloa; these are the open pit maintenance well (Site 18) and the "Best Efforts" pond (Site 3; see Table 12). Since the introduction of alien fish, the counts of shrimp in these two ponds increased significantly in 2007, probably because of the food resources present and the loss of foraging habitat (due to alien fish) at other routinely monitored locations. If the counts of native shrimp are any indication of habitat quality in those ponds that lack alien fish, the data suggests that the habitat without alien fish continues to remain favorable, and native shrimp are using this habitat in large numbers. This suggests that other than alien fish introduction in 2003/04, there have been few if any, negative impacts on this important anchialine species caused by changes in water quality with the continuing development at Waikoloa.

The maintenance "dug" well Site 18 is located inland of a holding/disposal area for green waste. The well was used for dust control purposes in the past but is not used today. Inspection of the ʻōpaeʻula shrimp counts made at this well show initially with our routine census of shrimp, which commenced with the January 2008 survey, relatively high counts (mean 151 shrimp/0.1 m^2) over the first ten surveys (from January 2008 through November 2010). However, counts have subsequently decreased to a mean of 57 shrimp/0.1 m^2 in the April 2011-September 2017 period. This decline is significant ($P<0.0001$) and suggests that there has been a fundamental change in the population structure at this location. Although shrimp census work at this location did not commence until January 2008, one could not help noticing the high abundance of shrimp present during the collection of water samples in this earlier August 1987 to November 2010 period. The water chemistry of Site 18 has not materially changed over time, suggesting that the significant decrease in the abundance is due to another factor. Because access to Site 18 is relatively easy and is in an area that does not have people present all of the time, we suspect that these shrimp may have been gathered for use as bait or chum prior to some surveys. When present in relatively high numbers, it only takes a few minutes to catch several hundred to several thousand shrimp, so it is not a labor-intensive process. More recently, however, Site 18 has become quite overgrown with sour bush (*Pluchea carolinensis*), which reduces the growth of the shrimp's primary food source, the blue-green algae *Schizothrix* spp. We suggest that Waikoloa management consider fencing off Site 18 to keep the public out of the area and that the vegetation surrounding this anchialine pool be removed routinely.

Prior to its termination in July 2007, the WAPPA program funded through the University of Hawai'i Foundation had directed the research and education components of the pond preserve program. With the introduction of tilapia to the makai WAPPA ponds in 2004, the need for a revised management program became apparent. No longer could the WAPPA program be carried out from an off-island location as it had for 19 years and the funds remaining in the University of Hawai'i Foundation account were nearly exhausted. This account had been established in 1985 with funding ($321,000) coming from the developer. Waikoloa Development Company, in consultation with the US Army Corps of Engineers and the University of Hawai'i WAPPA program, decided that an on-site manager was essential to the management and protection of the WAPPA pond area. Mr. Tim Cooke was hired by Waikoloa Development Company to carry out the mission of the WAPPA. Mr. Cooke's preliminary efforts included the establishment of hedges using native plants to keep the public out of the pond preserve, increased signage to better inform the public of the pond preserve's mission, completion of permits from the regulatory community to allow the release of native predatory fish to control unwanted tilapia in infected pools, and the removal of encroaching vegetation in the parts of the preserve.

Concern regarding impacts to the aquatic biota from the operation of golf courses often focuses on nitrate nitrogen which can readily leach to the groundwater under the right conditions. Inorganic fertilizers usually supply nitrogen in other forms that rapidly convert to the nitrate form (NO_3) which does not bind to the soil and readily moves down through the soil horizons with water. This lability makes nitrate nitrogen of particular interest insofar as potential impacts on aquatic biota are concerned. No impact to the biota has been observed at Waikoloa with the levels of nitrate nitrogen recorded here. Most notably this is seen in Site 3, the anchialine pool located on the Beach Golf Course, in which macronutrient concentrations are high, but the pool appears healthy with abundant 'ōpae'ula and other native flora and fauna. However, in other pools the combination of high nutrient concentrations and non-native species, most importantly fish species, undoubtedly causes enhanced sedimentation senescence of the anchialine pools.

WWS encourages the Waikoloa Resorts to consider the removal of fish species from WAPPA and understands that the main barrier to such actions is regulatory. More specifically, use of rotenone for fish control in brackish surface waters is not a permitted use, although Kaloko-Honokōhau

National Historical Park has apparently used rotenone in limited applications (Annadale 2022). However, WWS supports the Waikoloa Resorts in its efforts to maintain the health of the anchialine pools present and will provide permitting support for the use of rotenone and other pond management activities, some of which may require a Conservation District Use Permit.

Nitrate nitrogen has been noted as the least toxic of the inorganic nitrogen compounds to aquatic species, and the toxicity of nitrate is due to its effect on osmoregulation and possibly on oxygen transport (Colt and Armstrong 1981). There have been several studies determining the acute toxicity (96-hour LC50) of aquatic organisms to nitrate. Of the species tested, the most sensitive are guppies (*Poecilia reticulata*) with a 96-hour LC50 at 180 to 200 mg/L (Rubin and Elmaraghy 1977). Relative to the nitrate concentrations measured thus far in this program, these values are high. Some aquatic species are relatively resistant to nitrate nitrogen; included in this group is the bluegill (Lepomis macrochirus) with a 96-hour LC50 up to 2000 mg/L or 2,000,000 ug/L (Trama 1954). Other studies (e.g., Westin 1974, Colt and Tchobanoglous 1976, Rand and Petrocelli 1985) suggest that nitrate nitrogen is relatively innocuous as an aquatic toxicant. Long-term studies are few; channel catfish (*Ictalurus punctatus*) and largemouth bass (*Micropterus salmoides*) show a gradual nitrate accumulation in the tissues with a nitrate concentration in the habitat of 96 mg/L (i.e., 96,000 ug/L) being tolerated for 164 days with no apparent impact on growth or feeding (Knepp and Arkin 1973). For comparative purposes, the highest natural nitrate nitrogen concentration measured in anchialine pools on the West Hawaiʻi coast is at Kūkiʻo (2,632 ug/L) in an area with no surrounding development at the time observations were made (Brock and Kam 1992). This concentration is equivalent to 2.63 mg/L of nitrate, which is well below the toxic levels discussed above.

Gradba et al. (1974) showed significant histological damage to rainbow trout when held in water with nitrate in concentrations between 5-6 mg/L or 5,000 to 6000 ug/L. Colt and Armstrong (1981) note that additional research is needed to confirm these results. Marine aquaculture has used 88.6 mg/L or 88,600 ug/L as an acceptable upper limit for nitrate (Kinne 1976, Spotte 1979). Muir, Sutton, and Owens (1991) found significant mortality to protozoa of the penaeid shrimp (Penaeus monodon) held in water with nitrate at a concentration of 994 ug/L. These results are in contrast to studies on later life stages in this species; the 48-hour LC50 for juvenile *Penaeus monodon* is 14.9 mg of nitrate/L or 14,900 ug/L (Wickens 1976). *Penaeus monodon* larvae occur well offshore (Motoh 1985) where nitrate concentrations are typically very low (Spencer 1975). It is probable that *P. monodon* larvae are adapted to low nitrate conditions and are relatively intolerant of elevated nitrate.

On the other hand, the aquatic species found in West Hawai‘i anchialine systems are at the other extreme; nitrate concentrations are naturally quite variable and are frequently very high in these systems, and species that complete their life- cycles in the pools are probably adapted to these conditions. If this hypothesis is correct, it is this trait that has minimized the potential for negative impact with the transitory oscillations of nitrate at Waikoloa that occurred in the past.

3.6 Calculated Magnitude of Nutrient Loading

Since 1993 we have attempted to estimate the input of nutrients via dry fertilizers and the use of treated wastewater in the irrigation system. This was done because the water quality data, statistical analyses, graphical presentations, and mixing model analyses suggest an autochthonous input of nitrogen and phosphorus occurs resulting in inputs to the coastal groundwater at the Waikoloa Resorts. Possible sources of these nutrients are from fertilizers and/or the use of treated wastewater from the Waikoloa Wastewater Treatment Plant (WWTP). This practice was temporarily halted in May 2008 and then commenced again in early 2013. During this period, WWTP discharge of R-1 wastewater was discharged into two open pits located near the WWTP. In 2025 all treated wastewater was used in irrigation, after blending with pumped groundwater.

This section presents estimates on the transport of nitrogen and phosphorus to marine waters and the possible contribution of these nutrients from fertilizers and treated wastewater-enriched irrigation water at the Waikoloa Resorts. However, these nutrients occur naturally in relatively high concentrations in West Hawai‘i groundwater so inputs due to human activities may not be the primary source of changes measured. Moreover, observation of nutrient concentrations from marine shoreline stations shows that small concentrations of nitrogen and phosphorus potentially from anthropogenic sources appear in the adjacent ocean.

3.6.1 Shoreline Groundwater Discharge

A rough estimate of the amount of autochthonous nitrogen can be calculated for 2025 as has been performed in past reports. However, beginning in 2023, we used nutrient concentrations at site 21 instead of site 22, which is more affected by dilution with brackish water. We assume that the Waikoloa coastline is about 2,800 m in length and that about 8 million gallons of groundwater discharges per shoreline mile per day in this area. The total natural groundwater discharge is estimated at 52,342 m^3 per day for this 2,800 m section of shoreline. The mean concentration of total nitrogen as observed in 2025 wells 1 and 2 (Sites 1 and 2) in the groundwater is 624.39 ug/L.

The daily input of nitrogen from groundwater arriving from off-site is about:

52,342 m^3/day x 0.65029 mg TN/L = 34.04 kg N/day for the entire coastline and on an annual basis this amounts to: 34.04 kg N/day x 365 days = 12,423.7 kg TN/yr.

The mean total nitrogen concentration in Site 3 over the entire data set (N=115), located about 360 m inland of the WAPPA shoreline, is 1894.53 ug/L.

Thus, the total nitrogen flux in groundwater through a theoretical line through Site 3 and parallel to the shoreline is:

52,342 m^3/day x 1,894.53 ug N/L = 99.16 kg TN/day

99.16 kg TN/day x 365 days = 36,194.61 kg TN/yr. The difference in these two values, i.e.,

36,194.61 kg TN/yr – 12,423.69 kg TN/yr = 23,770.91 kg TN/yr or 65.13 kg TN/day

Repeating the above calculation for total nitrogen input between the mauka wells and Site 3 yields in the year 2025 yields 23,770.91 kg TN per year, or 65.13 kg TN/day input into the hydrogeologic system. This value represents a rough estimate of total nitrogen added annually between the inland wells and Site 3 which is located about 360 m of the shoreline.

Over the 2010-2016 period, there was a decrease of nitrogen between the inland wells and Pond 188 adjacent to the sea which has been interpreted as being due to decreased use of nitrogen fertilizers meaning that landscaping and golf turf needs were met but nitrogen was not supplied in excess thus little nitrogen was escaping to the seaward flowing groundwater, and some was likely taken up by nitrifying microorganisms. Speaking generally, most anchialine pools saw an increase in nitrate nitrogen and total nitrogen, with a very noisy long-term decrease. Observations of orthophosphorus in the anchialine pools show the opposite trend, however. We do not have a measure of the use of nitrogen fertilizer use on the non-golf course areas of the Waikoloa Resorts and therefore cannot estimate the significance of this component. We do, however, understand the relative significance of nitrogen inputs from golf course fertilizer applications and WWTP R-1 used in irrigation.

Summarizing the annual changes that have occurred with nitrogen near the shoreline (here Site 22, Pond 188), we find that in 2010, the calculated annual total was 2,307 kg less at the shoreline relative to the inland wells, in 2011 it was 4,234 kg less, in 2012 it was 770 kg less, in 2013 it was 3,464 kg less, in 2014 it was 1,923 kg less, in 2015 it was 387 kg less and in 2016, it was 2,113 kg less. Thus, in the 2010-2016 analyses, despite some transport of nitrogen to the groundwater, the nitrogen in the mauka wells continued to be greater than found at the shoreline which is usually seen at undisturbed coastal sites due to dilution by marine waters. Presumably, the judicious use of dry fertilizers on Waikoloa's landscaping and golf courses, as well as the temporary suspension (mid-2008 to January 2013) of the use of treated sewage effluent, had reduced these sources of excess nitrogen. However, this changed in 2017 where total nitrogen was in excess by about 3,464 kg per year. In 2018, the excess was calculated to be 2,500 kg per year, in 2019 1,116 kg total nitrogen, in 2020, 1,807 kg total nitrogen, in 2021, 2,058 kg total nitrogen, and in 2022 1,640 kg total nitrogen.

The same calculations can be made for phosphorus. The mean for total phosphorus from the assumed undisturbed groundwater (inland wells nos. 1 and 2) in 2024 is 65.94 ug/L. Running the same calculation as above yields a value of 3.45 kg P/day or 1,259.78 kg TP/yr. The mean of total phosphorus measured in Site 3 during 2024 is 375.41ug/L or 19.65 kg TP/day and 1,259.78 kg P/yr passing through the theoretical line parallel to the shoreline at Site 3 on an annual basis. The difference, i.e., 7,172.18 kg/yr – 1,259.78 kg/yr = 5,912.40 kg P/yr or 16.20 kg P/day is the amount of phosphorus added to the system between the inland wells and Site 3 near the shoreline in 2024. This added phosphorus is presumably from anthropogenic sources, including treated wastewater used in irrigation and nitrogen fertilizers. In the case of phosphorous, there has been an excess present at the shoreline relative to the inland wells probably due to inputs occurring on the project site, although the use of phosphorus fertilizers has been dramatically reduced in the last decade. Recent phosphorus fertilizer use has been as follows: 2010 = 8 kg, 2011 = 740 kg, 2012 = 550 kg, 2013 = 160 kg, 2014 = 70 kg, 2015 = 340 kg, 2016 = 140 kg, 2017=30 kg, 2018=250 kg, 2019 = 8 kg, 9.5 kg phosphorus in 2020, 192 kg in 2021, 138 kg in 2022, 300 kg in 2023, 110 kg in 2024 and 220 kg in 2025. The mean phosphorus fertilizer use for the entire record was 4,010 kg/yr (Table 2).

Most nutrients in groundwater, whatever their specific source, find their way to marine waters, although the relative motility of the nitrogen and phosphorus species must be considered, as they are widely different. It is evident in the 2010-2016 period that sources of past excess nitrogen had been reduced and/or eliminated but there has been a continuing input of phosphorus despite greatly reduced fertilizer application rates in the last decade or so. In addition, treated wastewater continues to be generated at the Waikoloa Resorts, which formerly went to two open pit discharges from mid-2008 through 2012 but in 2013 the treated effluent was once again blended with pumped groundwater for golf course irrigation. Since that time all treated wastewater, now R-1 water, is blended with pumped groundwater for golf course irrigation. Since 2013 total treated wastewater discharge has been above an annual total of 200 million gallons, except during the COVID-19 years of 2020 and 2021.

If phosphorus is the limiting nutrient for biological activity in groundwater and surface waters, including the anchialine pools, we expect that nitrogen would be taken up and reduced in concentration with the addition of phosphorus. The microbial population including photosynthetic algae may adapt to increasing phosphorus loading by taking up more nitrogen. Further, WWS has observed a common pattern in West Hawai‘i groundwater, in which nitrogen loading of groundwater produces a spike of nitrogen species lasting 2-3 years, after which there is recovery and reduction. In past reports, this was explained as resulting from the turf grow-in period and subsequent reduction of application of nitrogen fertilizers. However, there may be a second dynamic occurring in which the microbial population adapts to increased loading, thereby increasing uptake, resulting in a long-term recovery of nitrogen species concentration in groundwater. This latter dynamic requires that phosphorus is the limiting nutrient to biological productivity. WWS expects to resolve this issue in the future through a comparison of different monitoring sites.

3.6.2 Nutrient Inputs From R-1 Irrigation Water

In past years, the calculations below were made based on data (i.e., total annual volumes of irrigation water and treated sewage effluent used) for the entire year. However as noted above, commencing in May 2008 the Department of Health stopped the practice of using treated wastewater from the WWTP diluted with low salinity irrigation water for meeting the irrigation needs at Waikoloa until the WWTP discharge could be brought up to R-1 standards. Consequently, all treated effluent from the WWTP was temporarily discharged into two discharge pits located adjacent to the WWTP until the improvements to the plant could be completed. As noted above, the upgrades to the WWTP were completed on 17 September 2012 at which time all R-1 treated effluent continued to be discharged to the two temporary pits until 17 January 2013 at which time use of the R-1 effluent commenced use in the golf course irrigation system. In 2013, because treated effluent was once again being applied to the golf courses, we began monitoring the irrigation holding pond (Site 27). As previously noted in 2008 through 2012, the water quality monitoring program had not detected an increasing concentration of nutrients which could be indicative of the presence of this discharged treated effluent coming from the two discharge pits at the routinely monitored sample sites. Thus, through this period (i.e., 2008-2012), the assumption was made that the effluent discharged into the open pits was not present in the groundwater at the routine sample sites. However, with the resumption of placing treated wastes on the golf courses in January 2013, below we examine the nutrient loading via irrigation and R-1 treated wastewater volumes from March 2013 through the end of 2025. Similar calculations were made using data from the 1 January through 27 May 2008 period and were presented in earlier annual reports (Brock 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, WWS 2019, 2020, 2021, 2022, 2023, and 2024). These calculations demonstrate the range in the calculated nutrient budget for Waikoloa.

The following calculations are based on 2025 data. If 34.04 kg N/day is from offsite sources and 99.16 kg N/day is found at site 3, the input of nitrogen from anthropogenic sources is:
99.16 kg N/day – 34.04 kg N/day = 65.12 kg N/day

Thus, there is a net gain of 65.12 kg N/day or (1,639.81 kg N/year) of nitrogen between the undisturbed natural concentration in the groundwater measured in the irrigation wells and Site 3, where macronutrient concentrations are highest. Contributing to this gain is an input of nitrogen from WWTP effluent-enriched irrigation water; this input is calculated to be:
The 2025 treated wastewater volume = 198.01 x 10^6 gallons or 749,750 m^3 (from Table 3) or 2,054.11 m^3/day.

The mean total nitrogen in irrigation water = 2,935.6 ug/L (2025 mean from the quarterly irrigation holding pond samples; Site 27) therefore,
2,054.11 m^3/day x 2,935.6 mg TN/L = **7.0 kg TN/day**

Thus, the WWTP effluent-enriched irrigation water cannot account for all of the surplus total nitrogen. This line of thinking should be taken as an order of magnitude estimate. Nitrogen will be taken up by vegetation, and only some unknown fraction of nitrogen contained in irrigation water will reach groundwater. However, this argument does provide some evidence that irrigation water is one of a number of majors source of nitrogen in groundwater, as observed in the anchialine pools at the Waikoloa Resorts.

The mean total phosphorus in irrigation water (Site 27, the irrigation holding pond) = 844.21 ug/L (2024 annual mean value for Site 27), therefore, 2,054.11 m^3 /day x 0.84421 mg TP/L = 1.73 kg TP/day, compared to the estimated input of total phosphorus between the mauka wells and the shoreline of 16.2 kg P/day. In this case, this method suggests that treated wastewater input of total phosphorus is only a fraction of the total phosphorus input to groundwater. In this case, the total phosphorus in the treated wastewater-enriched irrigation water is not sufficient to explain the anthropogenic total phosphorus component observed at Site 3. However, as phosphorus is very much less mobile than nitrogen species, this is not at all unexpected. We expect that there is a large lag time on the timescale of months to years for phosphorus to be transported through surficial soil, into groundwater, and toward marine waters.

Additionally, phosphorus, like nitrogen, is being taken up and possibly sequestered by biological activity on the project site. Therefore, the measured concentrations of total phosphorus and nitrogen in the anchialine pools may be affected by decomposition releasing these stored nutrients into groundwater. However, these calculations are again gross estimates predicated on assumptions that are not realistic (i.e., that all nutrients from the R-1-enriched irrigation water passes through to the groundwater and into the sea, etc.) so these are "worst-case" scenarios. These scenarios serve to point out the magnitude of the inputs of nutrients occurring at the Waikoloa Resorts from anthropogenic sources.

3.6.3 Nitrogen and Phosphorus

The calculations above provide insight into the magnitude of groundwater nutrient inputs occurring at Waikoloa and suggest that the uptake and sequestration of nutrients from anthropogenic sources may be occurring. Despite the calculated mass loading of both phosphorus and nitrogen due to anthropogenic activities in the coastal groundwater at Waikoloa, the tremendous decrease in measured concentrations in the adjacent ocean demonstrates the impact of dilution with seawater has on the system. In the case of total phosphorus, this dilution amounts to 94% while for total nitrogen it is 74% in shoreline samples.

In 2010, there was a 71% increase in mean total phosphorus as measured in the makai anchialine pool (Site 22) relative to the mean concentration present in the inland wells (Sites 1 and 2). In 2011, this increase was 81% between the anchialine pool and wells; in 2012, it was 70%; in 2013, it was a 57% increase; in 2014, it was 41%; and in 2015, a 46% increase; in 2016, it was a 3.7 times greater increase; in 2017, it was 3 times greater increase; in 2018, it was 3.6 times greater increase; in 2019, was 3.8 times greater; in 2020, 3.1 times greater, in 2021, 2.74 times greater, in 2022 3.4 times greater, 2023 2.8 times greater, 2024 1.9 times greater, and in 2025 1.4 times greater. These data suggest that the input of phosphorus is occurring at a rate above the hydrologic system's ability to uptake and flush or transport phosphorus.

In contrast to the observed behavior of phosphorus, total nitrogen measured between the inland wells and the makai anchialine pool shows a declining trend, namely, in 2010 the difference was 10% less at the makai anchialine pool; in 2011, it was 21% less; in 2012, it was 3% less; in 2013, it was

14% less; in 2014, it was 7% less; in 2015, it was a 2% decrease; in 2016, it decreased by 16%; but in 2017, it increased by 15%; in 2018, it increased by 19%; in 2019, was about 8% less; and in 2020, 15% less. This behavior switched in 2021 with total nitrogen is higher in Site 22 than in the mauka wells by 20% and in 2022 by 12%. The 2024 the mean total nitrogen concentration in Site 22 was 42% higher than in the mauka wells, but in 2025 Site 22 was 22% higher. Since both phosphorus and nitrogen occur in relatively higher concentrations in the WWTP R-1 discharge than in groundwater, both would be expected to increase if treated wastewater was the sole source for the changes seen here, unless uptake and transport of nitrogen species is enough to compensate. On the face of it, we might interpret this to mean that the treated R-1 wastewater-enriched irrigation water is not the sole source of the nitrogen and phosphorus measured here but rather some of it is from some other sources such as fertilizers. However, we have hypothesized that microbial uptake of nitrogen in groundwater takes time to adapt to loading, and over time, we will see a natural decline as the microbial population adapts to nutrient loading and the concentration of nitrogen species in groundwater declines. This is likely to be true in situations where phosphorus is the limiting nutrient for primary productivity, which would allow more complete denitrification.

Although the R-1 discharge used in irrigation may be a significant source of both nitrogen and phosphorus in the Waikoloa Resorts hydrologic system, it is not the only significant source, as shown by the time series of total nitrogen and total phosphorus in the mauka wells. Total nitrogen in the mauka wells has varied from about 500 ug/L to more than 1,500 ug/L in some surveys (Figure 9). In recent years values have returned to 500 ug/L to 700 ug/L. Total phosphorus has behaved similarly, with no long-term increase but with an interim peak over 200 ug/L between 2000 to 2005, and a recent return to a baseline of about 50 ug/L to 80 ug/L (Figure 10). It should also be pointed out that these changes are typically the same for the two wells, with Well 1 and Well 2 an average of about 10% relative difference from each other. Visually, this means that in Figures 10 and 11 many of the data points can be seen as pairs. In any case, nutrient concentrations in this range are not unusual in Hawai‘i groundwater, although the variability is curious because of the apparent absence of land uses uphill of the Waikoloa Resorts site. The only apparent active use is the West Hawai‘i Concrete quarry, located about 2.6 miles uphill and only slightly cross-gradient with regard to the expected direction of groundwater flow. The quarry may be a contributing source of phosphorus, and other sources may include wildfires, subsequent rainfall, and leaching, as well as changes in rainfall patterns.

Vitousek et al. (2003) discuss the availability of macronutrients in Hawaiian geologies. After about 20,000 years of weathering, base rock will be depleted of phosphorus. Soils, however, including alluvial and colluvial soils, are more long-term sources of phosphorus. In the vicinity of the Waikoloa Resorts, however, there is very little soil development, owing to the youthful terrains and low annual precipitation. Vitousek et al. (2003) note that soil disturbance can liberate phosphorus, which points to a possible source of Well 1 and 2 phosphorus in quarrying activities at the West Hawaiʻi Concrete quarry on Waikoloa Road. This hypothesis, however, does not account for the variability in nitrogen species seen in these wells, in addition to the fact that the nitrogen observed is mostly the organic form. Other possible sources of these nutrients are from leaching due to high rainfall events and possibly leaching from the remnants of wildfires.

In conclusion, nitrogen species appear to be on the decline in the ponds and mauka wells on the site. Ammonia shows declines in 2018 – 2021, although not quite at the level yet of statistical significance. However, throughout this study, total phosphorus and orthophosphorus have continued to increase in the groundwater at Waikoloa as a long-term trend, although both species appear to have declined from 2019 to 2025. Still, it remains to be seen if this trend is real. Despite these trends, which remain in the range of variability as measured at other undeveloped West Hawaiʻi locations, the abundance of important anchialine species increased at Waikoloa (in ponds where alien fish were absent) through 2006, peaking in 2007 suggesting that concurrent changes (i.e., increases) in nutrients were not having a negative impact to these aquatic systems. Waikoloa management responded to the observed increases in nitrogen and phosphorus by reducing the use of dry fertilizers in 2007. These changes in inputs have resulted in a reduction of our estimated discharge of nitrogen to marine waters. Commencing in 2010 and continuing through 2016 there was little evidence of nitrogen input from the Waikoloa Resorts site occurring but as noted above, the input of phosphorus continues to enter the groundwater up to the present time. Because nitrogen moves easily with irrigation water to the underlying groundwater and there has been a relatively small subsidy of this nutrient applied in recent years, most of it is probably being utilized in situ by landscaping and turf, thus its decline in the groundwater in the 2010-2016 period. In contrast, despite a drastic decrease in the use of phosphorus as fertilizer, this nutrient continues to increase in concentration in groundwater under the project site. We suggest that the increased influx of phosphorus to groundwater from WWTP R-1 discharge use for irrigation is but one contribution to greater groundwater concentrations, largely because phosphorus is relatively insoluble and therefore relatively immobile compared to more soluble and mobile forms of nitrogen. Inputs of phosphorus on the site are likely to be near the loading capacity of the Waikoloa Resorts hydrologic system. In the case of nitrogen, the changes demonstrate the positive steps that the Waikoloa management team has made to improve the quality of the groundwater passing beneath the project site as well as the marine waters fronting Waikoloa. Despite these positive steps and results to date, as a cautionary measure and working with the premise that the Waikoloa Resorts will continue to grow and the WWTP discharge will increase in the future, strategies to reduce continued and potential additional inputs to the groundwater should be pursued. Some ideas are presented at the end of this document for consideration but perhaps the most expedient would be to dispose of a greater proportion of the treated wastes via the on-site injection well or an STP. Optimization of the distribution system and reservoirs for efficiency would also be of benefit, as would optimization of irrigation, to minimize the amount of irrigation water that infiltrates to groundwater. Removal of invasive vegetation from anchialine pools will reduce the amount of bio- available nutrients are in the hydrologic system and will reduce the aging process of the anchialine pools. Finally, our nutrient flux calculations suggest that irrigation on the Waikoloa golf courses is just one source for macronutrients in groundwater, and there are undoubtedly other sources, including irrigation and fertilizer use outside of Waikoloa Land Co. management. We encourage the Waikoloa Land Co. to engage with these other entities in order to more efficiently manage irrigation and fertilizer use.

Waikoloa has the longest continuous water quality monitoring program on the West Hawaiʻi coast. Many of the changes noted in this annual report may be related to long-term natural environmental fluctuations and have no connection to the management and maintenance of the golf and landscaping at Waikoloa. If so, only continued monitoring through time will elucidate this. The Waikoloa management team has always been responsive to addressing environmental problems and the actions taken by the golf course managers in the past to reduce inputs have been commendable. These efforts both lower operational costs and serve to protect the ground-and marine water quality at Waikoloa. We expect that these positive actions will continue as they are needed in the future.

This long-term study has demonstrated that development of the Waikoloa coastal plain has caused increases in nitrogen and phosphorus in groundwater passing through anchialine pools, but these increases are not necessarily reflected in the water chemistry data from the adjacent ocean where concentrations remain low, nor do macronutrient changes necessarily translate into ecological changes. Recent data show that there is no evidence of rising nitrogen inputs from anthropogenic activities to the underlying groundwater, as would be evidenced by rising nitrogen species concentrations in groundwater, but there has been a continuing input of phosphorus to groundwater beneath the project site.

The continuing input of phosphorus is likely to be due to the following factors: (1) a long lag time of application and appearance of it in the groundwater since little phosphorus has been applied to the golf courses in recent years; (2) possible leaks in the irrigation storage and transmission system; and (3) inputs from WWTP treated wastewater-enriched irrigation water. The lag time mentioned above is probably related to the known affinity of phosphorus to bind with soils, slowing its movement down to the seaward flowing groundwater. Given the low mobility of phosphorus species, relative to nitrogen species, the Waikoloa Resorts hydrologic system may be able to "flush" only a certain loading rate of phosphorus, and above this rate phosphorus may accumulate in the system.

Phosphorus inputs to groundwater has continued despite the efforts of the Waikoloa management team to substantially decrease the use of phosphorus in the maintenance of golf and landscaped areas in recent years. As noted above, total nitrogen prior to 2010 had consistently showed elevated concentrations at the makai anchialine pond (site 22) relative to the inland wells (sites 1 and 2) due to the input of nitrogen from the project site. Commencing in 2010 and continuing through 2016, this trend reversed where total nitrogen concentrations were greater in the undisturbed groundwater (i.e., the inland wells) relative to the makai anchialine pond.

With the decrease in measured nitrogen concentrations in the 2010-2016 period, discharge of nitrogen species to the ocean has been reduced. Brock and Kam (1992 & 1994) provide data showing the concentration of inorganic nutrients at a number of other locations on the West Hawai'i coast, including areas with no surrounding development. The mean values for important nutrients such as nitrate nitrogen, orthophosphorus, total nitrogen, total phosphorus, and ammonia nitrogen at Waikoloa as measured under the WAPPA program fall within the range of concentrations observed in anchialine ponds in areas with no surrounding development. Thus, despite some past and continuing level of nutrient subsidy to the WAPPA ponds, the water quality in the WAPPA system continues to be within the range of variability encountered in anchialine pools and coastal marine waters at other locations with no surrounding development. Additionally, elevation of nutrient concentrations at the shoreline fronting the Waikoloa development appears to be small and within 100m of the shore are indistinguishable from low oceanic background levels.

Since the early 2000s, the annual mean concentrations of orthophosphorus and total phosphorus have increased gradually at sample sites located on the project site (i.e., anchialine pools and wells) until 2018, after which we see a decrease. This decrease is small, and not yet statistically significant, and requires that all data points for the year be "binned" together to be able to be distinguished. However, wide variations in concentrations for all of water quality parameters monitored appear to be the norm.

Both nitrate nitrogen, as well as total nitrogen, have shown a recent decreasing trend in ponds and wells where mean annual concentrations reached a broad peak in 2007. The nitrate nitrogen data (Table 8) show a downward trend which continued through 2025, with a smaller rise interrupting this trend temporarily in 2014-2015. Use of a higher percentage of WWTP R-1 treated wastewater discharge appears to produce a manageable nitrogen loading in the Waikoloa Resorts hydrologic system. This trend is certainly at least partially due to reduction in fertilizer use. However, this trend is contrary to that seen with phosphorus species. The difference in behavior in the wells and anchialine pools on the site are likely due mostly to the significant differences in chemistry.

Despite past increases, the elevated concentrations of total nitrogen, nitrate, orthophosphorus, and total phosphorus are not high at the Waikoloa Resorts; the greatest mean concentration of orthophosphorus in anchialine pools at the Waikoloa Resorts was 358.71 ug/L measured in 2017 (Table 8); in anchialine pools at the Makalawena-Awake‘e control site with no surrounding development, the 34-year mean for orthophosphorus is 171.88 ug/L. Mean total phosphorus is similar with the Makalawena-Awake‘e anchialine pools 35-year mean being 217.44 ug/L and the Waikoloa Resorts 2025 anchialine pools mean value of 296.95 ug/L. Furthermore, the total phosphorus mean value for the mauka wells (Wells 1 & 2) is 32.09 ug/L, with a high mean value in 266.84 ug/L in 2003, a significant concentration relative to those measured in the anchialine pools, showing that off-site inputs of phosphorus are significant.

Nitrogen species may also be compared. At the Waikoloa Resorts, the 2025 mean concentration of nitrate nitrogen in the anchialine pools was 1172.33 ug/L with the single greatest annual mean value for the anchialine pools was 2046.65 ug/L measured 1992 while at Kūki‘o the 11-year preconstruction mean in ponds and wells was 2,275.99 ug/L. The 11-year preconstruction mean total nitrogen concentration at Kūki‘o was 2,533.39 ug/L while the greatest mean total nitrogen was 2,070.00 ug/L at Waikoloa in 2007.

Considerable groundwater enters the ocean at the Waikoloa Resorts where the average salinity of the marine samples over the last 34 years has been 32.813 ppt while the Makalawena-Awake‘e control marine sites have a mean salinity of 33.775 ppt and at Kūki‘o of 33.043 ppt. Because of the significant groundwater input to the marine environment at the Waikoloa Resorts, a greater nutrient loading in the marine samples would be expected; in 2025, mean orthophosphorus concentration in marine samples from Waikoloa was 31.23 ug/L, total phosphorus 39.41 ug/L, nitrate nitrogen 142.98 ug/L and total nitrogen 220.59 ug/L. In contrast, at the Makalawena-Awake‘e control marine site the 35-year mean orthophosphorus concentration is 8.79 ug/L and for total phosphorus it is 16.35 ug/L. At Kūki‘o control sites, the 11-year means are nitrate nitrogen 59.92 ug/L and for total nitrogen 156.57 ug/L.

Because of earlier concerns over phosphorus, golf course personnel drastically cut use of phosphorus on both the Kings and Beach Golf Courses in 2002. These changes should first result in a decrease in measured phosphorous in the groundwater and anchialine pools followed by an increase and then a subsequent decrease. The increased application rates in 2004 and 2005 could have masked earlier decreases in the use of phosphorus in the sampled ground and anchialine pool water because of phase lags occurring between the time of application to the time of detection in the ground and anchialine pool water.

Examination of the phosphorus content in the soils from samples collected on the Beach and Kings Golf Courses by soil specialists in December 2003 noted that the water-soluble phosphorus was close to 1 ppm on the Kings Course, which is near the recommended minimum, and 6 ppm on the Beach Course which is about double the recommended 3 ppm maximum (3 ppm = 3,000 ug/L). The excess water-soluble phosphorus on the Beach Course may have been leaching to the groundwater below. In 2008, about one month prior to the removal of treated wastewater as a constituent of the irrigation water, soil tested on the Kings Course noted phosphorus (i.e., $NaHCO_3$-P) at 142 ppm which is extremely high and may be a source of phosphorus measured in the groundwater (data courtesy of Waikoloa). During the hiatus of treated wastewater in irrigation water, treated wastewater was injected through injection wells located near the Waikoloa WWTP. It is likely that the flow of this injected wastewater from the injection wells is more directly towards ‘Anaeho‘omalu Bay, and does not flow under the majority of the Waikoloa Resorts site, and therefore nutrients therein are not detected at WAPPA or the other sites (e.g., Site 3, Site 18 and the anchialine pools).

The measured concentrations of inorganic nutrients in anchialine pools situated in areas with no surrounding development indicate that the nutrient chemistry of West Hawai‘i groundwater is highly variable, and concentrations are frequently in excess of biological needs (Brock and Kam 1992, 1994). Thus, the data suggest that inorganic nutrients are not limiting in natural anchialine systems on the West Hawai'i coast. Further support for this hypothesis is evident in the WAPPA data where there have been statistically significant increases in the abundance of the most characteristic anchialine species, *Halocaridina rubra* at the time when the measured concentrations of some nutrients were increasing. The mean counts of these important shrimp species showed significant increases in three of four survey sites at Waikoloa in 2003. In the two routinely censused anchialine pools not colonized by alien fish in 2004-2006, counts of shrimp continued to significantly increase but a statistical comparison of earlier (1990-2006) shrimp count data to the 2007 data have found no continuing significant increase (1990-2006 mean = 111 individuals, 2007 mean = 107 individuals). Finally, because of the continuing spread of alien fish (tilapia) in the WAPPA pools in 2008, native shrimp species have disappeared from these pools during daylight hours when these counts are made. It is hypothesized that the counts of native shrimp would continue to increase in ponds lacking the predatory alien fish despite the fluctuations in the nutrient chemistry of the water passing through them. In many other aquatic habitats, inorganic nutrients are limiting and when supplied in excess result in major shifts occurring in aquatic communities. Since inorganic nutrients often naturally occur in excess in anchialine systems and the native biota appear to be completely insensitive to changes in the ranges observed in our studies, we conclude that the increases in concentrations in the ranges of nutrients encountered on the West Hawai'i coast have had no apparent negative impact to the native shrimp.

The method for the determination of water quality standards for marine waters changed in mid- 2000 for West Hawai'i. Before the year 2000, the standards were numeric "not to exceed" values based on geometric means. With the revisions, if significant groundwater flow is evident a linear regression approach is used to determine the appropriate standard. Prior to July 2000, which encompassed 38 quarterly surveys, the geometric means for nitrate nitrogen were out of compliance on 95% of the surveys, ammonia nitrogen on 87% of them, total nitrogen as well as total phosphorus on 34% of them and chlorophyll-a on 8% of the surveys.

The surveys carried out after July 2000 utilize the West Hawai'i regional standards. Through 2025, there have been 98 quarterly surveys completed. Appendix 15 provides a summary of the compliance/non-compliance for each parameter on each of the three marine transects at Waikoloa and the same information for the annually sampled Makalawena-Awake'e control site. Table 7 further summarizes these data with annual rates of non-compliance with regional water quality standards. Since July 2000 at the Waikoloa Resorts the rates of non-compliance for the different parameters are

(Appendix 15): nitrate nitrogen = 50.9%, ammonia nitrogen = 87.1%, total nitrogen = 56.6%, orthophosphorus = 67.4%, total phosphorus = 65.6%, turbidity = 97.8% and chlorophyll-a = 63.4%. Over the same period at the Makalawena-Awake‘e control site, the rate of non-compliance has been: nitrate nitrogen = 41.7%, ammonia nitrogen = 79.2%, total nitrogen 70.8%, orthophosphorus = 62.5%, total phosphorus = 62.5%, turbidity = 91.7% and chlorophyll-a = 58.3%. These data suggest that non-compliance occurs with a similar frequency whether one is examining these parameters along a developed or non-developed region. A higher rate of non-compliance would be expected at the Waikoloa Resorts because of the greater discharge of groundwater (mean marine salinity = 32.813 ppt) relative to Makalawena-Awake‘e (mean marine salinity = 33.775 ppt).

Three marine transect sites at Waikoloa were sampled on four occasions in 2025 for measurement of seven parameters subject to State regional standards. Thus, there are 3 transects x 4 surveys x 7 parameters resulting in 84 opportunities for compliance/non-compliance to occur with a parameter. In total, 61 of the 84 opportunities were non-compliant with state regional standards which is a rate of 72.6% non-compliance in 2025 at the marine transects offshore of the Waikoloa Resorts. The Makalawena-Awake‘e control site is sampled once during the year for seven parameters on a single transect site. In the most recent 2025 survey for Makalawena-Awake‘e, all seven typically surveyed parameters measured were out of compliance with the regional standards (Table 7 and Appendix 15). In this case, the rate of non-compliance is at 100% at the control site at a completely undeveloped section of coastline. However, mean non-compliance of parameters over the 2000 through 2025 period are similar between the Makalawena-Awake‘e control site at 68% and Waikoloa at 70%. These data support the contention that the regional standards probably do not reflect the natural variability in water quality parameters as occurs in West Hawai‘i.

Despite this lack of compliance, the concentrations measured at the Waikoloa Resorts are not particularly high when compared to other undeveloped areas along the West Hawai‘i coast. It is well-known that near-shore waters on the West Hawai‘i coast frequently do not meet the standards for nitrate nitrogen, ammonia nitrogen, total nitrogen, turbidity and chlorophyll-a. The standards represent an arbitrary selection of criteria; the porous nature of the West Hawai‘i coastline allows considerable percolation of groundwater to occur and as noted above, this groundwater is often naturally high in nitrogen and other materials. Thus, the lack of compliance at the Waikoloa Resorts near-shore waters with present state standards should not be of concern. With the implementation of the regional standards in 2000, the standard for turbidity changed from 0.20 NTU (the old open coastal standard which still applies to all open coastal waters elsewhere in the state) to 0.10 NTU. The new standard is sufficiently low that most near-shore West Hawai‘i waters are not in compliance under normal conditions, the case at both Waikoloa and the Makalawena-Awake‘e control site.

The 2017 mean value orthophosphorus in the anchialine pools was the highest to date and total phosphorus was the third from the top of its respective range in anchialine pools. However, the t-test does not find that this represents part of a statistically significant trend at present. Examining the means by date for marine sites noted no statistically significant differences among the mean values by date for total nitrogen, orthophosphorus, and total phosphorus, meaning that the annual mean values for the entire dataset are all statistically consistent with each other. The 2004- 2007 period measured increases in ponds and wells suggested a continuing and greater input of materials from the coastal development at Waikoloa to which Waikoloa personnel responded in 2006 by decreasing the application of fertilizers. This decline has continued up to the present time such that the 2025 annual use of nitrogen fertilizer was 3.29 metric tons (mt), a low value relative to most of the record, and for phosphorus fertilizers in 2025 use was 0.22 mt, also very low compared to the record of use. The overall 34-year annual mean use of nitrogen fertilizers is 17.26 mt and for phosphorus is 4.01 mt. Use of both nitrogen and phosphorus fertilizers has been greatly reduced in recent years.

In the case of nitrogen in groundwater, concentrations in the undisturbed groundwater before its passage beneath the project site as measured in the mauka wells (Sites 1 and 2) are greater than that measured in an anchialine pool located adjacent to the ocean in the 2010-2016 period. Prior to 2010, the concentrations were greater in the makai anchialine pools as they were in 2017 and 2018 thus demonstrating the input from project activities occurring to the groundwater as it flows to the sea. Concentrations of nitrate nitrogen and total nitrogen in Site 21 have since moderated, as they also have in the mauka wells, although macronutrient concentrations in Site 21 remain above those of the mauka wells.

In contrast to the changes seen in nitrate nitrogen and total nitrogen, there is a continuing input of phosphorus to groundwater beneath the project site. The phosphorus input from the project site as measured between inland wells and in the anchialine pool adjacent to the ocean has continuously found greater concentrations of phosphorus in the makai pool relative to the mauka undisturbed groundwater thus demonstrating input coming from activities on the project site. In 2010, the concentration of phosphorus measured in the makai anchialine pool (Site 21) was 128.58% greater than that measured in the mauka wells, thus presumably from inputs due to anthropogenic activities.

In 2011, this input continued unabated at 109.49% greater in the makai pool; in 2012 it was 110.7% greater; 2013, 131.78% greater; 2014, 146.61% greater; and in 2015, 141.4% greater; and in 2016, it was 159.31% greater; in 2017, it was 1363.4% greater; in 2018, it was 161.91% greater; in 2019, 151.23% greater; in 2020, 132.45% greater, in 2021 it was 113.81% greater, in 2022 it was 140.04% greater, in 2023 it was 139.35% greater, in 2024 was 521.2% greater, and in 2025 was 587% greater in the makai pond relative to the undisturbed groundwater in the mauka wells demonstrating that the input of phosphorus continues.

WWTP discharges have high concentrations of both nitrogen and phosphorus thus both nutrients would be expected in water samples if the source was from treated wastewater. However, this does not consider the relative motility between nitrogen and orthophosphorus and their several forms. The question, "What are the source(s) of phosphorus input?" should be addressed. Phosphorus has a well-known affinity to bind with soils and nitrogen moves freely through soil horizons with water, which suggests that the many years of combined input of treated wastewater as an irrigation source, as well as the previous high use of fertilizers allowed a slow accumulation and saturation of the soil horizons by the se nutrients to occur. Under these conditions, nitrogen continues to pass through the system relatively quickly but because phosphorus binds to soil, its passage takes a much longer time. Removal of the R-1 WWTP discharge for irrigation and a reduction of fertilizer use decreased the input of these nutrients in the mid-2008 through 2012 period resulting in a reduction of nitrogen measured at the makai pool but a continued input and increase in phosphorus at that site. If this scenario is correct, we expect to see an increase in phosphorus in groundwater as use of WWTP effluent in irrigation will probably result in a slow continued increase in phosphorus. We see a more recent decline in phosphorus in the anchialine pools, but it remains to be seen whether this trend will continue.

3.7 Recommendations

The changing concentrations of nitrogen and phosphorous remain within the range of variability as measured at other undeveloped locations along the West Hawai‘i coast. Furthermore, the abundance of important anchialine shrimp species continued to increase in those ponds at Waikoloa where alien fish were absent through 2006 and leveling off in 2007 despite the changes in water chemistry. However, with the near-complete colonization of all anchialine pools in the WAPPA in 2008 by alien fish, the native shrimp are no longer diurnally present in the pools. These data suggest that the changes in water chemistry are not having an impact to these aquatic systems. However, as a cautionary measure and working with the premise that the Waikoloa Resorts will continue to grow and will produce more treated wastewater in the future, strategies to reduce continued and potential additional inputs to the groundwater should be pursued. Among these are the following suggestions, most of which have been put forward previously and some of which have been acted upon by the Waikoloa Resorts management. These suggestions continue to be important as appropriate Best Management Practices (BMP's) and implementation demonstrates the good stewardship the management team has for the natural resources at Waikoloa. These comments and suggestions are as follows:

1. Continue using R-1 treated wastewater in irrigation but optimize irrigation efficiency and reduce system loss through performance of leak tests.
2. Identify sources of phosphorus in the wastewater arriving at the Waikoloa WWTP and investigate strategies to reduce this source.
3. Continue to reduce the use of dry fertilizers replacing them with treated effluent irrigation water as is feasible; such replacement would also decrease operational/maintenance costs.
4. Lower the application of treated wastewater, as feasible, to landscaped and golf course areas at the Waikoloa Resorts. These suggestions are intended to reduce the loading of phosphorus on the Waikoloa Resorts hydrologic system.
    i. Dilute the concentration of WWTP-effluent enrichment in the irrigation water by the addition of more low salinity groundwater, thereby reducing phosphorus loading.
    ii. Optimize the quantity and timing of turf and landscaping irrigation to reduce the amount of irrigation water that infiltrates to groundwater.
    iii. Increase the area irrigated with the enriched water (such as through the development of ancillary businesses, e.g., sod farm, nursery, additional golf courses, etc.) which would assist in handling the additional volume of irrigation water generated in part "i" above (i.e., development of a biofilter). This would result in the nutrients being taken up over a greater area, reducing the impact to groundwater, and would result in a lower percentage of treated wastewater being used in the irrigation water.
    iv. Evaluate the treated wastewater and irrigation systems for leaks, which allow nutrients to reach groundwater without uptake by plants.

5. Renew use of the injection well system to handle a portion of the treated wastewater. As this water is likely to have a different movement more directly towards ‘Anaeho‘omalu Bay, and is injected at depth, it represents use of the treated wastewater over a greater area.
6. Due to the demonstrated steep decline in the abundance of ‘ōpae‘ula (*Halocaridina rubra*) at the open-pit maintenance well (Site 18) in recent years and the high value these shrimp have in the international aquarium trade, we suggest that the maintenance well be fenced off to keep collectors away from this pool. Rubbish should also be removed from this area and the pool itself.
7. Continue Pond Management actions including removal of unwanted encroaching non-native vegetation and alien fish, develop better measures to further protect the WAPPA ponds and to foster raising public awareness to the vulnerability of the Hawaiian anchialine resource. WWS is committed to assisting the Waikoloa Resorts in this endeavor, including assistance with permitting pond management activities that would require a Conservation District Use Permit and other permits.
8. Accumulation of organic matter in the anchialine pools represents a storage bank of nutrients available to organisms. Thus, as organic matter accumulates, we expect eutrophication of the pools, meaning that biological productivity is enhanced, particularly after events that raise sediments, including high winds and maintenance activities. This results in greater consumption of oxygen, overall ecosystem change, and accelerates aging of the anchialine pools. Therefore, as part of a long-term program of pool management, the Waikoloa Resorts should consider removal and off-site disposal of non-native vegetation from anchialine pools.

The Waikoloa Resorts has the longest continuous water quality monitoring program in West Hawai‘i. The Waikoloa management team has always been responsive to addressing environmental problems and the actions taken by the golf course managers in the past as well as at present to reduce inputs have been commendable and have served to protect the ground and marine water quality at Waikoloa.

4.0 REFERENCES

Annadale, K. 2022. Personal Communication at the 5th International Symposium on Anchialine Pool Ecosystems, November 4, 2022.

Bauer. G. R. 2003. A Study of the Ground-Water Conditions in North and South Kona and South Kohala Districts, Island of Hawaii, 1991-2002. State of Hawaii Department of Land and Natural Resources, Commission on Water Resource Management. Report PR-2003-01.

Brock, R.E. 1990a. Report addendum. Predevelopment water quality conditions fronting the Lahaina Master Planned Project, Lahaina, Maui following heavy rainfall. Prepared for PBR, Inc., 1042 Fort Street Mall, Suite 300, Honolulu, Hawai‘i 96813. 17p.

Brock, R.E. 1990b. Predevelopment reconnaissance of the marine macrobiota and water quality conditions fronting the proposed development at Mahukona, North Kohala, Hawai‘i. Prepared for Chalon International of Hawaii, Inc., P.O. Box 249, Hawi, Hawaii 96719. 49p.

Brock, R.E. 1993. Impact of nitrate in anchialine systems at Waikoloa, Hawai‘i. Prepared for Waikoloa Development Co., HC02 Box 5050, Waikoloa, Hawaii 96743. Environmental Assessment Co. Rept no. 93-03. 23p.

Brock, R.E. 1995. Annual review of the water quality monitoring program for Waikoloa - 1994. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kameula, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 95-02. 81p.

Brock, R.E. 1996. Annual review of the water quality monitoring program for Waikoloa - 1995. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 96-09. 64p.

Brock, R.E. 1997. Annual review of the water quality monitoring program for Waikoloa - 1996. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 97-04. 66p.

Brock, R.E. 1998. Annual review of the water quality monitoring program for Waikoloa - 1997. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 98-05. 66p.

Brock, R.E. 1999. Annual review of the water quality monitoring program for Waikoloa - 1998. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 99-01. 78p.

Brock, R.E. 2000. Annual review of the water quality monitoring program for Waikoloa - 1999. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2001-08. 71p.

Brock, R.E. 2001. Annual review of the water quality monitoring program for Waikoloa - 2000. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2000-06. 78p.

Brock, R.E. 2002. Annual review of the water quality monitoring program for Waikoloa - 2001. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2002-13. 82p.

Brock, R.E. 2003. Annual review of the water quality monitoring program for Waikoloa - 2002. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2003-16. 74p.

Brock, R.E. 2004. Annual review of the water quality monitoring program for Waikoloa - 2003. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2004-14. 81p.

Brock, R.E. 2005. Annual review of the water quality monitoring program for Waikoloa - 2004. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2005-09. 83p.

Brock, R.E. 2006. Annual review of the water quality monitoring program for Waikoloa - 2005. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2006-09. 84p.

Brock, R.E. 2007. Annual review of the water quality monitoring program for Waikoloa - 2006. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2006-14. 86p.

Brock, R.E. 2008. Annual review of the water quality monitoring program for Waikoloa - 2007. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2008-13. 91p.

Brock, R.E. 2009. Annual review of the water quality monitoring program for Waikoloa - 2008. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2009-13. 95p.

Brock, R.E. 2010. Annual review of the water quality monitoring program for Waikoloa - 2009. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2010-15. 95p.

Brock, R.E. 2011. Annual review of the water quality monitoring program for Waikoloa - 2010. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2011-14. 103p.

Brock, R.E. 2012. Annual review of the water quality monitoring program for Waikoloa - 2011. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2012-16. 108p.

Brock, R.E. 2013a. Annual review of the water quality monitoring program for Waikoloa - 2012. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2013-13. 109p.

Brock, R.E. 2013b. Report addendum: water quality and anchialine pool monitoring in support of the development at Waikoloa, South Kohala, Hawai‘i - 2012 annual report. Report addendum covering pesticide studies and control site water quality for 2012. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2013-22. 13p.

Brock, R.E. 2014. Annual review of the water quality monitoring program for Waikoloa - 2013. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2014-13. 107p.

Brock, R.E. 2015. Annual review of the water quality monitoring program for Waikoloa - 2014. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2015-11. 114p.

Brock, R.E. 2016. Annual review of the water quality monitoring program for Waikoloa - 2015. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawai‘i 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2016-10. 113p.

Brock, R.E. 2017a. Water quality and anchialine pool monitoring in support of the development at Kukio, North Kona - 2016 annual report. Prepared for WB Kukio Resorts, LLC., Kailua-Kona, Hawai‘i. Environmental Assessment, LLC, Honolulu Hawai‘i, Report No. 2017-04. 104p.

Brock, R.E. 2017b. Annual review of the water quality monitoring program for Waikoloa - 2016. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawaiʻi 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2017-08. 115p.

Brock, R.E. 2018. Annual review of the water quality monitoring program for Waikoloa - 2017. Prepared for Waikoloa Development Company, 150 Waikoloa Beach Drive, Kamuela, Hawaiʻi 96743. Environmental Assessment Co., Honolulu. EAC Rept. No. 2018-07. 112p.

Brock, R.E. and A.K.H. Kam. 1990. The Waikoloa pond program third annual report. Prepared for the U.S. Army Corps of Engineers, Honolulu. Hawaiʻi Institute of Marine Biology unpublished tech. rept., Univ. Hawaiʻi, Honolulu. 64p + appendices.

Brock, R.E. and A.K.H. Kam. 1992. The Waikoloa pond program annual report for 1991. Prepared for the U.S. Army Corps of Engineers, Honolulu. Hawaiʻi Institute of Marine Biology unpublished tech. rept., Univ. Hawaiʻi, Honolulu

Brock, R.E. and A.K.H. Kam. 1994. The Waikoloa anchialine pond program fifth status report. Prepared for the U.S. Army Corps of Engineers, Honolulu. Sea Grant College Program unpublished tech. rept., University of Hawaiʻi, Honolulu. vii+71p.

Brock, R.E. and J.E. Norris. 1988a. The Waikoloa anchialine pond program second status report. Prepared for the U.S. Army Corps of Engineers, Honolulu. Hawaiʻi Institute of Marine Biology unpublished tech. rept., Univ. Hawaiʻi, Honolulu. 65p.

Brock, R.E. and J.E. Norris. 1988b. Quantitative baseline survey of the marine communities at Waikoloa, Hawaiʻi. Prepared for Transcontinental Development Co., Inc., P.O. Box 3028, Waikoloa Village Station, Waikoloa, Hawaiʻi 96743. 53p.

Brock, R.E., J.E. Norris, D.A. Ziemann and M.T. Lee. 1988c. Characteristics of water quality in anchialine ponds of the Kona, Hawaiʻi coast. Pacif. Sci. 41:200-208.

Carey, C.C., Ching, M.P., Collins, S.M., Early, A.M., Fetzer, W. W., Char, David and Hairson Jr., N.G. 2009. Predator-dependent diel migration by Halocaridina rubra shrimp (Malacostraca: Atyidae) in Hawaiian anchialine pools.

Clark, W.N. 1974. A comparison of numbers of aerosolized coliforms associated with sewage treatment by the trickling filter and the activated sludge process. A report submitted to the University of Hawaiʻi School of Public Health.

Colt, J.E. and D.A. Armstrong. 1981. Nitrogen toxicity to crustaceans, fish, and mollusks. Pp. 34-

47. In: L.J. Allen and E.C. Kinney (eds.). Proceedings of the bioengineering symposium for fish culture. Fish culture section, American Fisheries Society, Bethesda, Maryland.

Colt, J.E. and G. Tchobanoglous. 1976. Evaluation of the short-term toxicity of nitrogenous compounds to channel catfish, Ictalurus punctatus. Aquaculture 8:209-224.

Costas-Ferreira, C., Duran, R., and Faro, L.R.F. 2022. Toxic Effects of Glyphosate on the Nervous System: A Systematic Review. International Journal of Molecular Science 2022 May, 23(9):4605. Accessed from: 10.3390/ijms23094605.

Dalton, C.M., Mokiao-Lee, A., Sakihara, T.S., Weber, M.G., Roco, C.A., Han, Z., Dudley, B., MacKenzie, R.A., and Hairston, Jr., N.G. 2012, Density- and trait-mediated top-down effects modify bottom-up control of a highly endemic tropical aquatic food web. Oikos, Nordic Society Oikos 000:001-011, 2012.

U.S. Environmental Protection Agency. 2023. Safe Drinking Water Act. Retrieved from https://www.epa.gov/sdwa

Gradba, E., T. Einszporn-Orecta and R. Zbanysek. 1974. Experimental methemoglobinemia in trout. Acta Ichthyol. Piscatoria 4:43-71.

Grasshoff, K. 1983. Methods of seawater analysis. Verlag Chemie, Weinheim. 419p. Green, R.E. 1981. Placement of nitrogen fertilizers. Pp 89-101 in Proceedings, 14th Hawai‘i Fertilizer Conference, College of Tropical Agriculture and Human Resources Research Extension Series 005, University of Hawai‘i, Honolulu, Hawai‘i.

Hawaii Water Service. 2023. Personal communication from Stephan Green of Hawaii Water Service, March 23, 2023.

Johannes, R.E. 1980. The ecological significance of the submarine discharge of groundwater. Mar. Ecol. Prog. Ser. 3:365-373.

Kanehiro, B.Y. and Peterson, F.L. 1977. Groundwater recharge and coastal discharge for the northwest coastal discharge for the northwest coast of the Island of Hawaii: A computerized budget approach. Technical Report No. 110. Water Resources Research Center, University of Hawaii.

Kinne, O. (ed.). 1976. Marine ecology. Vol. 3. John Wiley & Sons Ltd., London.

Knee, K.L., Street, J.H., Grossman, E.E., Boehm, A.B. and Paytan, Adina. 2010. Nutrient inputs to the coastal ocean from submarine groundwater discharge in a groundwater-dominated system Relation to land use (Kona Coast, Hawaii, USA). Limnology and Oceanography 55(3), 1105-1122.

Knepp, G.L. and G.F. Arkin. 1973. Ammonia toxicity levels and nitrate tolerance of channel catfish. Prog. Fish Cult. 35:221-224.

Marine Research Consultants. 1989. Results of the marine water quality monitoring program to assess the effects of Kapa‘anui Subdivision North Kohala, Hawai‘i. Report No. 1. Prepared for Chelon International of Hawai‘i, Inc., P.O. Box 249, Hawi, Hawai‘i 96719. 7p.

Marsh, J.A., Jr. 1977. Terrestrial inputs of nitrogen and phosphorus on fringing reefs in Guam. pp. 332-336. In: Proceedings of the 2nd International Coral Reef Symposium, Vol. 1. Great Barrier Reef Committee, Brisbane, Australia.

Motoh, H. 1985. Biology and ecology of Penaeus monodon. Pp.27-36. In: Y. Taki, J.H. Primavera and A.L. Jose (eds.). Proceedings of the first international conference on the culture of penaeid prawns/shrimps. Aquaculture Department, Southeast Asian Fisheries Development Center, Iloilo, Philippines.

Muir, P.R., D.C. Sutton and L. Owens. 1991. Nitrate toxicity to Penaeus monodon protozoa. Mar. Biol. 108:67-71.

Nance, Tom. 2003. Personal communication.

Rand, G.M. and S.R. Petrocelli. 1985. Fundamentals of aquatic toxicology: Methods and applications. McGraw-Hill International Book Co., New York. xviii+666p.

Rubin, A.J. and G.A. Elmaraghy. 1977. Studies on the toxicity of ammonia, nitrate, and their mixtures to guppy fry. Water Res. 11:927-935.

Spencer, C. 1975. The micronutrient elements. <u>In:</u> J.P. Riley and G. Skirrow (eds.). Chemical oceanography, Vol. 2. 2nd Ed. Academic Press, London.

Spotte, S. 1979. Seawater aquariums. John Wiley & Sons, New York.

Standard Methods. 2017. Standard methods for the examination of water and wastewater. 20th Edition. American Public Health Assoc., Washington, D.C. Port City Press, Baltimore, Md.

Strickland, J.D.H. and T.R. Parsons. 1968. A practical handbook of sea-water analysis. Fish. Res. Bd. Canada, Bull. 167. 311p.

Trama, F.B. 1954. The acute toxicity of common salts of sodium, potassium, and calcium to the common bluegill (Lepomis macrochirus Rafinesque). Proc. Acad. Nat. Sci. Phil. 106:18-205

Vitousek, P., Chadwick, O., Matson, P., Allison, S., Derry, L., Kettley, L., Luers, A., Mecking, E.,Monastra, V., and Porder, S. 2003. Erosion and the Rejuvenation of Weathering-Derived Nutrient Supply in an Old Tropical Landscape. Ecosystems, Vol. 6, No. 8, pp. 762-772.

Waimea Water Services (WWS). 2020. Annual Review of the Water Quality Monitoring Program for Waikoloa Resort 2019. Prepared for Waikoloa Development Company by Waimea Water Services LLC.

Waimea Water Services (WWS). 2021. Annual Review of the Water Quality Monitoring Program for Waikoloa Resort 2020. Prepared for Waikoloa Development Company by Waimea Water Services LLC.

Waimea Water Services (WWS). 2022. Annual Review of the Water Quality Monitoring Program for Waikoloa Resort 2021. Prepared for Waikoloa Development Company by Waimea Water Services LLC.

Waimea Water Services (WWS). 2023. Annual Review of the Water Quality Monitoring Program for Waikoloa Resort 2022. Prepared for Waikoloa Development Company by Waimea Water Services LLC.

Waimea Water Services (WWS). 2024. Annual Review of the Water Quality Monitoring Program for Waikoloa Resort 2023. Prepared for Waikoloa Development Company by Waimea Water Services LLC.

Waimea Water Services (WWS). 2025. Annual Review of the Water Quality Monitoring Program for Waikoloa Resort 2024. Prepared for Waikoloa Development Company by Waimea Water Services LLC.

West Hawaiʻi Coastal Monitoring Task Force. 1992. West Hawaiʻi coastal monitoring program monitoring protocol guidelines. May 1992. Unpublished report, 30p.

Westin, D.T. 1974. Nitrate and nitrite toxicity to salmonoid fishes. Prog. Fish Cult. 36:86-89.

Wickens, J.F. 1976. The tolerance of warm water shrimp to recirculated water. Aquaculture 9:19-37.

Wolfe, E.W., and Morris, J. 1996. Geologic Map of the Island of Hawaii. U.S. Department of the Interior, U.S. Geological Survey. Map I-2524-A.

Summary of the geometric means for DOH water quality criteria for marine samples collected during 131 quarterly surveys carried out from March 1991 through 2025.
Underlined and Bold values exceed state standards for open coastal (marine) waters for "wet" conditions for all marine samples collected before July 2000.
Nutrient values are in ug/l unless otherwise noted.

Date Sampled	Field Data				General Chemistry									
	Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
	%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
03/06/1991	102	8.13	23.8	0.17	**3.92**	0.120	**26.46**	9.30	32.500	733.04	80.22	4.03	134.54	14.26
07/23/1991	102	8.09	26.8	0.32	**5.32**	0.300	**16.52**	7.44	31.950	791.00	91.14	4.96	123.62	13.64
11/19/1991	102	8.16	26.4	0.14	**5.18**	0.260	**22.96**	6.51	31.270	1064.28	86.52	6.51	134.82	14.88
12/28/1991	102	8.14	26.1	0.12	**5.32**	0.160	**20.86**	6.82	31.170	1166.76	86.10	4.34	131.32	13.02
04/10/1992	101	7.95	25.4	0.14	3.22	0.204	**18.90**	7.75	29.860	1559.88	73.64	4.65	113.54	14.26
07/08/1992	102	8.06	27.4	0.19	**5.04**	0.258	**5.32**	4.34	32.307	449.68	83.72	5.89	102.06	11.47
10/01/1992	102	8.10	27.6	0.10	**5.18**	0.184	**21.98**	6.82	32.166	767.76	95.20	6.20	142.52	13.33
12/17/1992	103	8.13	26.1	0.20	**4.48**	0.270	**43.40**	11.78	31.024	1384.32	86.10	6.82	**156.94**	19.53
03/03/1993	102	8.17	24.9	0.13	3.50	0.104	**16.80**	7.13	31.095	708.12	75.74	6.82	114.52	15.50
05/12/1993	102	8.18	27.4	0.23	3.50	0.206	**22.82**	9.30	29.757	994.56	56.14	8.06	104.44	**20.15**
09/28/1993	102	7.91	29.2	0.12	2.80	0.294	**25.34**	7.13	30.450	896.84	113.26	8.06	**168.42**	17.05
12/06/1993	103	8.16	26.2	0.28	**3.64**	0.237	**40.32**	8.99	30.578	1397.76	84.42	8.68	**155.68**	19.22
03/31/1994	102	8.11	26.8	0.18	3.50	0.135	**19.60**	11.16	30.675	995.40	104.30	15.81	**151.20**	**26.97**
06/07/1994	102	8.05	26.2	0.23	2.52	0.179	**19.60**	8.68	32.226	623.56	98.00	2.79	140.56	12.40
10/10/1994	102	8.12	27.5	0.27	1.68	0.165	**18.90**	8.06	32.514	596.40	74.20	3.72	109.90	11.78
12/06/1994	102	8.08	23.6	0.16	**4.90**	0.103	**10.50**	9.61	31.852	372.68	72.52	7.44	106.68	19.22
04/11/1995	103	8.00	24.4	0.16	**9.10**	0.280	**5.46**	7.13	33.335	529.48	60.90	9.61	76.30	16.74
07/14/1995	102	7.97	26.7	0.14	**8.40**	**0.334**	**29.54**	13.02	30.298	1086.12	136.08	10.23	**228.20**	**26.04**
10/22/1995	103	8.17	27.1	0.23	**8.12**	**0.550**	**9.66**	8.06	32.837	655.48	84.98	7.13	103.18	15.19
01/04/1996	102	7.99	23.9	0.14	**7.84**	0.211	**32.48**	11.78	29.730	1026.48	76.72	7.44	140.28	**21.39**
03/18/1996	103	8.09	22.8	0.14	**7.84**	0.124	1.96	8.68	33.240	157.08	68.46	7.75	78.82	16.12
07/02/1996	102	8.07	27.0	0.10	**8.82**	0.136	**23.80**	10.85	27.916	775.04	82.88	3.10	142.80	13.33
09/19/1996	103	8.07	27.6	0.08	**6.86**	0.190	**5.04**	8.37	32.826	264.88	90.02	23.87	103.18	**32.55**
12/03/1996	102	8.11	25.3	0.14	**8.54**	0.202	**18.76**	8.06	31.236	599.20	67.48	4.34	131.88	15.19
03/20/1997	103	8.08	23.0	0.08	**3.64**	0.160	**13.72**	5.27	32.935	1472.24	121.66	4.96	140.70	10.54
07/11/1997	102	8.08	24.9	0.12	**12.60**	0.248	**15.26**	5.89	31.316	540.12	128.52	9.61	**163.38**	19.53
08/27/1997	102	8.12	25.4	0.06	**5.18**	0.241	2.66	4.03	33.947	151.48	97.16	16.74	105.00	**20.77**
12/17/1997	102	8.11	24.1	0.13	**12.04**	0.183	**24.22**	13.95	33.269	493.64	80.36	3.72	124.18	17.05
03/20/1998	102	8.05	25.1	0.11	**7.56**	0.157	**38.50**	9.30	31.188	1196.72	105.56	9.92	**182.42**	**22.63**
07/14/1998	103	8.10	25.0	0.06	**24.36**	0.179	**17.92**	6.51	32.188	568.40	61.74	11.16	126.00	**23.56**
10/19/1998	102	8.00	27.2	0.05	**6.30**	0.167	**67.90**	13.95	29.642	1862.00	81.06	6.51	**211.82**	**22.32**
11/13/1998	101	8.01	25.7	0.28	**7.28**	0.239	**26.60**	18.91	28.991	1028.16	86.66	25.11	**154.56**	**56.42**
04/26/1999	101	8.08	24.3	0.28	**11.48**	0.125	**28.00**	15.19	30.493	782.32	76.16	2.79	**160.30**	17.98
06/04/1999	102	8.01	24.9	0.10	**15.68**	0.111	**19.32**	18.29	31.620	922.32	113.12	7.44	**183.40**	**28.52**
10/06/1999	102	7.99	26.3	0.08	3.22	0.185	**18.34**	8.68	31.808	833.56	88.48	6.51	131.46	16.74
12/29/1999	100	8.08	23.6	0.09	**4.06**	0.234	**7.98**	5.58	34.680	327.60	99.12	11.47	111.16	17.05

Date Sampled	Field Data				General Chemistry									
	Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
	%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
04/28/2000	101	8.10	24.1	0.08	**5.74**	0.149	**21.98**	9.30	32.092	726.32	100.24	9.92	**152.46**	**21.08**
06/30/2000	101	8.03	25.7	0.19	**6.86**	0.174	**39.20**	14.88	31.438	1310.68	129.36	4.65	**223.16**	**25.73**
11/09/2000	101	8.16	27.5	0.18	**8.12**	0.115	**18.62**	8.99	32.482	734.72	102.76	7.13	**153.44**	16.74
01/29/2001	100	7.96	23.2	0.13	**3.91**	0.065	**9.46**	7.60	34.145	434.59	80.10	8.03	106.20	16.01
02/12/2001	101	8.16	26.0	0.19	**4.86**	0.131	**35.87**	11.83	32.910	1309.94	115.65	12.65	**174.39**	**25.09**
05/30/2001	101	8.09	26.7	0.13	2.00	**0.419**	4.76	8.80	34.076	482.45	141.33	5.15	**156.84**	15.59
10/25/2001	101	8.00	27.4	0.38	2.66	**0.432**	**13.33**	7.05	34.216	628.76	125.74	9.67	145.22	16.97
12/10/2001	101	8.06	26.0	0.24	**4.89**	**0.355**	**21.95**	7.83	33.450	841.46	142.22	6.61	**191.95**	14.90
03/28/2002	101	8.08	26.6	0.24	**5.16**	0.252	**17.46**	14.58	33.278	989.44	90.70	6.38	123.84	**23.19**
07/18/2002	100	8.01	27.8	0.17	3.37	0.180	**10.67**	6.78	34.266	239.00	105.74	16.27	128.33	**23.26**
10/28/2002	101	8.05	27.0	0.27	**4.44**	**0.380**	**14.68**	7.18	34.207	479.84	132.02	7.91	**167.71**	15.33
12/09/2002	101	7.94	24.2	0.16	2.64	0.187	**13.75**	5.68	34.577	444.90	159.04	4.25	**181.85**	10.60
01/30/2003	101	8.03	25.6	**0.71**	3.17	**0.459**	**23.34**	10.01	33.362	1119.99	167.38	5.94	**212.14**	16.60
07/16/2003	101	8.14	27.4	0.22	**7.07**	0.237	4.71	19.46	33.738	592.26	172.45	4.97	**195.65**	**25.37**
10/21/2003	101	8.10	27.8	0.28	**4.24**	0.220	2.62	6.21	34.445	373.58	142.89	4.63	**153.71**	10.98
12/09/2003	100	8.00	25.8	0.24	3.07	0.209	**25.34**	9.77	33.768	636.67	43.34	4.09	92.89	15.17
03/09/2004	100	8.10	24.2	0.19	1.28	0.225	**22.43**	10.39	33.021	614.77	112.28	2.78	**164.16**	14.58
05/06/2004	100	8.09	26.1	0.15	**4.01**	0.252	**18.65**	9.61	33.097	523.56	101.19	5.64	144.86	16.23
11/05/2004	99	8.21	28.6	0.22	**4.19**	**0.407**	**14.78**	4.69	34.123	412.04	100.24	5.61	131.60	10.78
12/07/2004	100	8.04	24.1	0.18	**4.04**	**0.311**	**26.12**	8.42	33.830	640.94	112.90	8.04	**158.78**	16.91
03/01/2005	99	8.00	24.4	0.25	2.80	0.253	**20.02**	8.66	33.397	741.97	92.57	18.79	132.98	**28.00**
08/02/2005	99	8.05	26.9	0.17	**4.88**	**0.337**	**16.17**	6.74	33.727	449.81	65.21	5.45	97.35	12.57
11/02/2005	100	7.99	26.2	0.28	**4.47**	**0.469**	**11.89**	8.97	33.969	857.10	67.12	6.75	99.92	15.96
01/20/2006	98	8.01	24.4	0.23	**3.56**	0.293	**22.31**	7.14	33.956	536.36	94.38	5.99	140.92	13.69
01/31/2006	100	7.97	24.7	0.31	1.54	**0.342**	**17.59**	7.97	33.942	703.51	93.25	6.54	132.36	15.23
04/21/2006	100	7.93	24.6	0.22	**3.65**	0.256	**19.48**	8.61	33.693	644.46	90.82	4.93	138.79	13.99
09/08/2006	100	7.99	29.0	0.21	**7.96**	**0.443**	**27.18**	10.79	32.345	743.99	96.84	2.88	**208.34**	16.11
12/05/2006	99	8.03	25.6	0.17	**3.88**	**0.380**	**26.15**	9.70	34.018	561.75	104.40	8.12	**150.81**	18.80
03/23/2007	99	7.97	24.8	0.14	**4.40**	0.283	**36.15**	12.40	32.576	1347.96	109.23	7.24	**176.40**	**20.22**
08/21/2007	100	8.03	26.7	0.14	**4.51**	0.240	**13.27**	4.68	34.342	540.83	132.72	10.52	**159.07**	15.44
11/02/2007	100	7.98	26.1	0.19	**5.69**	0.260	**16.65**	7.55	33.934	516.27	97.93	8.22	131.12	15.98
12/10/2007	99	8.10	26.3	0.27	**5.90**	**0.357**	**63.41**	14.98	32.199	1287.48	150.04	10.98	**254.79**	**26.88**
01/08/2008	99	8.04	24.6	0.21	**4.89**	**0.400**	**21.93**	11.78	33.641	937.44	103.67	8.28	**153.12**	**20.75**
07/11/2008	100	8.00	27.0	0.23	**3.92**	0.288	**14.14**	7.40	33.832	387.22	128.26	3.35	**162.44**	11.38
09/23/2008	100	8.04	28.0	0.25	**4.72**	0.283	**11.66**	6.40	33.993	279.91	121.40	7.67	147.69	14.71
11/17/2008	99	8.04	26.5	0.35	**6.59**	**0.438**	**30.13**	12.00	32.418	749.82	111.07	9.64	**178.15**	**22.42**
05/18/2009	97	7.98	25.5	0.37	**4.07**	**0.634**	**39.56**	17.35	32.827	1478.59	95.49	7.83	**168.98**	**26.87**
08/20/2009	98	7.92	26.9	0.13	**4.84**	**0.337**	**30.88**	14.26	32.898	1138.38	122.59	7.12	**185.09**	**23.03**
10/02/2009	99	7.99	25.3	0.29	**5.57**	**0.356**	**40.10**	17.47	32.561	1425.21	86.22	8.31	**153.28**	**26.64**
07/28/2010	99	7.94	25.7	0.21	**6.16**	**0.431**	**20.97**	11.75	33.496	773.86	112.48	10.97	**160.74**	**23.60**
10/19/2010	99	7.97	25.9	0.19	**6.23**	**0.403**	**26.82**	10.43	33.192	997.55	123.44	8.22	**178.44**	19.93
11/19/2010	99	7.91	24.8	0.47	**7.81**	**0.603**	**30.70**	14.09	32.965	1240.06	106.93	9.72	**158.46**	**25.68**

TABLE 1. *Geometric Means*

Date Sampled	Field Data				General Chemistry									
	Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
	%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
04/08/2011	99	8.01	25.6	0.21	**4.61**	**0.377**	**51.28**	19.37	31.649	2315.38	174.73	14.82	**262.65**	**36.65**
06/09/2011	97	7.94	25.8	0.22	**3.56**	**0.371**	**10.23**	7.26	34.108	455.57	130.00	7.12	147.27	14.69
08/04/2011	99	7.97	26.5	0.38	**4.36**	0.251	**11.19**	10.22	33.792	514.70	152.25	11.28	**179.27**	**22.31**
11/03/2011	99	8.02	25.9	0.27	**4.20**	**0.330**	**11.35**	8.31	34.135	497.21	99.00	6.16	126.70	15.40
03/06/2012	98	8.01	24.6	0.21	**3.76**	**0.434**	**23.49**	16.31	32.191	1161.31	120.95	16.71	**186.31**	**34.27**
05/31/2012	98	7.88	24.2	0.35	3.13	**0.406**	**20.22**	13.12	33.537	1045.03	101.46	10.44	138.84	**24.28**
08/03/2012	98	7.93	25.3	0.18	2.98	**0.316**	**25.43**	14.50	33.184	981.07	109.47	5.97	**168.91**	**24.51**
11/08/2012	97	7.95	24.5	0.22	**3.71**	0.230	**9.38**	11.52	34.382	566.39	101.93	5.90	123.57	17.58
03/12/2013	97	8.03	25.5	0.49	3.21	**0.534**	**22.42**	19.66	32.868	1351.81	120.78	10.53	**166.37**	**32.45**
06/21/2013	97	7.91	27.3	0.16	**4.69**	0.270	**17.71**	12.66	33.396	1045.90	149.69	7.29	**188.89**	**20.18**
09/19/2013	98	7.86	27.2	0.19	**4.02**	**0.311**	**16.83**	11.97	32.487	643.38	161.24	10.04	**202.44**	**22.90**
12/09/2013	98	7.88	26.1	0.15	**4.57**	**0.315**	**10.39**	9.88	34.123	433.67	122.20	11.21	144.40	**21.36**
04/07/2014	97	7.96	25.5	0.23	**4.73**	0.295	**23.70**	12.29	32.903	763.60	108.72	11.37	**152.44**	**24.80**
06/09/2014	98	7.90	26.8	0.20	**4.02**	**0.350**	**16.70**	6.14	32.601	502.86	200.97	5.90	**240.95**	12.25
09/19/2014	99	7.87	27.6	0.22	**13.66**	**0.368**	**25.18**	14.07	33.167	673.85	134.42	9.79	**191.18**	**24.84**
11/14/2014	99	7.83	27.1	0.26	**5.37**	**0.349**	**17.97**	12.56	33.528	678.94	137.39	6.86	**170.20**	19.66
04/02/2015	98	7.96	25.1	0.20	**4.05**	**0.428**	**19.39**	15.21	31.519	1087.30	165.68	9.07	**218.65**	**25.50**
09/15/2015	97	7.78	28.6	0.19	**6.15**	**0.612**	**19.21**	9.94	33.229	536.68	115.42	8.27	148.91	18.98
11/30/2015	98	7.88	25.1	0.27	**4.36**	**0.397**	**16.88**	11.92	33.655	538.30	95.45	2.85	131.00	15.52
12/08/2015	98	7.83	25.2	0.25	**11.28**	**0.402**	**47.86**	15.93	30.511	1474.18	112.55	6.63	**199.12**	**23.28**
03/23/2016	96	7.95	25.4	0.31	2.61	0.108	**15.64**	11.46	31.642	898.96	86.72	5.31	123.27	**22.71**
05/13/2016	97	7.95	26.6	0.23	3.21	**0.362**	**7.61**	4.58	33.234	476.87	71.59	15.52	92.31	**21.87**
08/05/2016	95	7.90	27.4	0.18	2.86	**0.331**	4.07	3.31	32.342	356.34	61.15	7.20	93.23	12.18
11/22/2016	98	7.91	25.3	0.17	1.15	0.271	4.34	3.35	33.160	361.20	85.90	2.67	104.76	3.35
04/28/2017	98	7.87	27.6	0.26	3.43	**0.424**	**25.70**	13.60	30.354	1416.92	91.13	5.98	**151.71**	**23.15**
07/18/2017	98	7.93	26.5	0.14	0.96	**0.307**	**6.19**	6.08	32.834	463.57	56.01	22.34	82.60	**31.99**
09/06/2017	98	7.98	26.6	0.24	2.60	0.299	**7.74**	5.74	31.695	748.99	61.68	9.59	88.26	19.31
02/21/2018	97	7.96	23.8	0.21	**10.56**	0.227	**22.32**	9.48	32.071	619.34	49.91	9.72	104.94	**21.84**
06/05/2018	97	7.84	26.5	0.21	**6.58**	0.285	**46.66**	9.41	31.166	636.20	65.49	5.52	129.58	16.52
11/30/2018	98	7.92	25.5	0.22	**4.63**	**0.334**	**13.72**	8.18	33.029	356.61	95.55	7.22	123.16	16.75
05/01/2019	98	7.94	28.2	0.37	2.91	**0.420**	**16.59**	7.79	32.590	732.88	92.29	5.53	122.78	13.53
08/01/2019	99	8.10	28.2	0.15	**6.11**	0.160	**6.36**	6.38	32.440	283.79	91.51	9.09	109.11	16.08
12/01/2019	98	8.13	28.4	0.34	2.42	**0.610**	**45.04**	14.26	31.660	1966.21	110.22	11.35	**180.61**	**26.15**
05/21/2020	101	8.04	26.8	0.32	2.95	**0.346**	**14.97**	9.60	30.683	799.47	78.97	7.24	118.51	19.31
07/16/2020	103	7.92	28.7	0.49	2.06	**0.866**	**6.62**	5.83	32.740	538.37	81.72	5.58	108.37	12.81
09/16/2020	99	8.02	28.0	0.44	1.50	**0.548**	**20.89**	10.63	32.304	999.42	80.60	3.47	121.58	15.72
11/16/2020	91	8.06	26.2	**1.22**	**5.40**	**0.836**	**68.25**	14.24	32.195	2405.18	87.78	4.85	**161.44**	19.09
03/01/2021	99	8.03	29.0	**0.73**	**4.68**	**0.395**	**60.74**	18.82	29.367	2427.74	83.74	8.24	**189.35**	**30.76**
06/01/2021	101	8.11	26.4	**0.69**	**5.61**	**0.390**	**20.66**	9.52	30.907	935.84	86.63	7.07	139.79	19.71
09/01/2021	97	8.17	27.8	**0.80**	**6.39**	**0.395**	**40.30**	15.68	29.374	1829.20	88.94	2.60	**159.39**	**20.17**
12/01/2021	88	8.12	25.7	**0.52**	**5.09**	**0.424**	**29.13**	11.11	31.598	937.28	77.00	3.75	133.85	16.76
03/09/2022	98	8.12	26.2	**0.51**	**6.97**	**0.54**	**47.01**	15.12	31.168	2992.45	78.59	2.72	**154.05**	**20.00**

TABLE 1. *Geometric Means*

Date Sampled	Field Data				General Chemistry									
	Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
	%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
04/21/2022	100	8.16	27.1	0.20	**20.36**	0.24	**27.82**	17.96	31.024	1691.76	74.36	1.79	**167.69**	**22.10**
07/26/2022	95	7.92	27.5	0.27	**7.01**	**0.39**	**29.10**	14.96	28.731	1053.18	43.98	6.09	**156.86**	**23.15**
11/29/2022	77	7.99	26.8	**0.58**	**4.49**	**0.40**	**31.08**	11.91	32.320	979.41	67.97	3.23	117.68	16.58
03/01/2023	99	8.03	29.0	**0.73**	**4.68**	**0.40**	**47.01**	18.82	29.367	2427.74	83.74	8.24	**189.35**	**30.76**
06/01/2023	101	8.14	27.5	0.37	**5.89**	**0.36**	**8.90**	7.10	33.247	454.17	78.54	2.75	101.91	10.16
08/01/2023	104	8.12	28.4	0.26	**6.92**	**0.30**	**13.45**	12.21	32.542	792.00	80.76	4.46	114.46	17.95
11/01/2023	98	8.16	26.2	**0.65**	**7.22**	**0.31**	**11.43**	7.04	34.276	406.82	75.47	4.16	100.94	11.90
03/06/2024	104	8.13	24.5	**0.68**	**9.46**	0.10	**27.42**	14.18	23.875	1043.09	58.86	3.93	**167.64**	**21.14**
07/11/2024	105	7.96	27.5	**0.55**	**5.45**	**0.47**	**36.56**	17.40	24.863	1472.61	94.78	5.91	**180.77**	**24.48**
09/03/2024	120	8.05	28.9	0.45	**3.80**	**0.63**	**27.38**	8.56	26.321	906.94	77.29	5.98	143.68	16.45
11/20/2024	104	8.08	27.5	0.43	**6.75**	**0.48**	**42.02**	17.75	25.102	1474.36	78.32	6.17	**179.51**	**25.21**
03/20/2025	104	8.20	29.3	0.32	**6.79**	**0.42**	**49.17**	17.20	30.799	1684.10	70.88	8.33	**167.17**	**28.51**
07/10/2025	107	8.09	28.6	0.48	**4.84**	0.23	**20.90**	14.791	31.12	1031.13	72.53	5.81	**127.29**	**21.91**
10/01/2025	106	8.12	29.9	**0.75**	**8.63**	0.15	**11.19**	9.268	34.02	541.21	65.38	4.95	**91.79**	14.44
12/30/2025	98	8.17	25.9	0.34	**7.08**	**0.32**	**27.93**	12.363	32.59	1120.51	61.90	5.95	**110.89**	18.68

Table 2.
Annual fertilizer use on the two golf courses at Waikoloa given in metric tons. Data courtesy of Waikoloa Land Co. This table presents values of total metric tons of product

Year	Metric Tons Nitrogen	Phosphorus
1991	41.97	1.85
1992	36.07	12.13
1993	38.07	15.89
1994	37.46	6.40
1995	44.92	11.54
1996	40.57	10.65
1997	32.59	5.78
1998	33.17	5.83
1999	27.81	5.52
2000	42.06	10.08
2001	21.03	14.43
2002	13.68	0.53
2003	14.58	2.50
2004	21.64	12.69
2005	38.73	14.30
2006	22.76	0.52
2007	16.58	1.17
2008	14.71	3.89
2009	10.01	1.40
2010	4.78	0.01
2011	2.74	0.74
2012	7.88	0.55
2013	6.30	0.16
2014	3.08	0.07
2015	4.61	0.34
2016	5.36	0.14
2017	1.93	0.03
2018	3.45	0.25
2019	3.06	0.08
2020	0.38	0.10
2021	2.11	0.19
2022	1.47	0.14
2023	3.35	0.30
2024	1.79	0.11
2025	3.29	0.22
Annual Mean Value	17.26	4.01
Latest vs mean %	0.19	0.06

Table 3. *Summary of Annual Rainfall Irrigation Water Used.*

Summary of Annual Rainfall & Irrigation Water Used. Summary of annual rainfall measured at Waikoloa, the annual volume of irrigation water from coastal wells, the annual volume of irrigation water from all sources (irrigation + treated sewage effluent) used at Waikoloa, the annual volume of treated wastewater effluent used as an irrigant at Waikoloa (through May 2008) and the percent of the total volume of irrigation water comprised of this treated sewage effluent by year from 1992 through May 2008 and subsequently from 2013 to present. Note that after 27 May 2008 through 2012, all treated effluent went to two disposal pits. Volumes are given in millions of gallons. Data compliments of West Hawaii Utilities Co. Notes follow next page.

Year	Total Rainfall	Irrigation Water Pumped	Total Irrigation Water Used	Volume of WWTP Effluent	WWTP % of Total Irrigation
	(in)	(mg)	(mg)	(mg)	(%)
1992	5.36	826.77	919.37	92.61	10.07%
1993	9.58	889.46	1005.13	115.66	11.51%
1994	5.97	1031.71	1145.68	113.98	9.95%
1995	3.47	783.82	911.14	127.32	13.97%
1996	19.16	709.72	846.99	137.27	16.21%
1997	11.79	689.13	809.38	120.24	14.86%
1998	2.20	751.49	898.74	147.25	16.38%
1999	2.76	747.53	889.09	141.56	15.92%
2000	4.60	783.79	953.62	169.83	17.81%
2001	5.16	846.96	961.10	114.14	11.88%
2002	10.68	831.87	951.42	119.58	12.57%
2003	6.92	867.66	993.32	125.66	12.65%
2004	26.78	667.92	855.02	177.10	20.71%
2005	11.52	755.59	921.73	166.14	18.02%
2006	8.05	698.26	863.01	164.74	19.09%
2007	9.53	653.96	735.15	81.18	11.04%
2008	4.38	394.21	469.83	75.62	16.10%
2009	8.22	830.99	830.99	196.98	23.70%
2010	4.41	844.31	844.31	202.88	24.03%
2011	8.76	932.97	932.97	195.64	20.97%
2012	1.15	894.89	894.89	193.63	21.64%
2013	3.76	905.14	905.14	204.63	22.61%
2014	10.84	941.85	941.85	226.94	24.10%
2015	11.33	844.29	844.29	232.08	27.49%
2016	10.44	967.56	967.56	227.96	23.56%
2017	10.30	992.33	992.33	233.83	23.56%
2018	11.26	1085.74	1085.74	237.92	21.91%
2019	9.48	649.80	879.27	229.47	26.10%
2020	7.41	957.12	1077.98	120.86	11.21%
2021	5.60	822.61	1013.15	190.54	18.81%

Table 3. *Summary of Annual Rainfall Irrigation Water Used.*

Year	Total Rainfall	Irrigation Water Pumped	Total Irrigation Water Used	Volume of WWTP Effluent	WWTP % of Total Irrigation
	(in)	(mg)	(mg)	(mg)	(%)
2022	8.25	791.97	998.49	206.52	20.68%
2023	3.80	845.39	1057.31	211.92	20.04%
2024	5.90	886.09	1084.10	198.01	18.27%
2025	11.26	670.64	861.16	190.53	22.12%

Geometric mean values(given as ug/l unless otherwise noted) of measured parameters from water samples collected in anchialine pools and the nearshore marine environment at two control sites, Kukio (1993 to 1999 after which construction commenced) and Makalawena (1994 to present) in North Kona. Underlined and Bold values exceed State Wet Standards for open coastal marine samples for data collected prior to July 2000.

Site Group Name	Date Sampled	Field Data					General Chemistry								
		Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
		%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
KUKIO - Anchialine Pool Samples	03/01/1993	100	8.36	21.20	0.12	2.80	0.11	**2177.14**	3.72	3.95	19688.48	103.18	68.82	**2284.10**	**72.54**
KUKIO - Anchialine Pool Samples	05/01/1993	101	8.37	24.60	0.36	1.54	0.07	**2202.48**	64.48	4.02	24269.28	8.96	3.72	**2217.88**	**68.20**
KUKIO - Anchialine Pool Samples	12/01/1993	101	8.31	22.60	0.23	**6.30**	0.17	**2093.84**	66.96	3.93	22250.20	41.58	2.48	**2148.44**	**69.44**
KUKIO - Anchialine Pool Samples	06/01/1994	99	8.21	24.40	0.15	**32.20**	0.07	**2344.58**	56.42	4.04	27239.52	324.94	14.88	**2670.78**	**71.61**
KUKIO - Anchialine Pool Samples	12/01/1994	95	8.25	22.70	0.14	**6.30**	0.09	**2535.12**	80.60	4.06	29094.52	20.44	4.03	**2555.70**	**84.63**
KUKIO - Anchialine Pool Samples	04/01/1995	94	8.34	24.50	0.15	**8.40**	0.09	**2234.54**	48.67	3.97	26856.20	65.24	8.37	**2315.88**	**58.28**
KUKIO - Anchialine Pool Samples	01/01/1996	82	7.81	21.40	0.39	**14.00**	0.17	**1671.04**	93.62	3.79	36573.04	50.26	4.03	**2311.68**	**102.61**
KUKIO - Anchialine Pool Samples	03/01/1996	101	8.27	22.20	0.12	**13.58**	0.13	**2520.14**	52.70	3.88	37169.72	90.02	4.03	**2624.02**	**57.04**
KUKIO - Anchialine Pool Samples	03/01/1997	102	8.33	22.40	0.20	**12.04**	0.09	**1759.24**	44.95	3.58	25522.84	999.04	14.57	**2989.98**	**66.34**
KUKIO - Anchialine Pool Samples	03/01/1998	99	8.28	24.80	0.16	**17.36**	0.03	**2941.54**	64.48	3.90	28119.84	98.00	32.24	**3072.02**	**98.27**
KUKIO - Anchialine Pool Samples	04/01/1999	100	8.42	23.90	0.10	**20.44**	0.05	**2556.26**	42.78	3.98	25985.12	96.74	2.48	**2676.80**	**46.50**
KUKIO - Marine Samples	03/01/1993	101	8.21	24.90	0.13	**6.30**	0.13	**92.12**	5.58	32.92	1347.08	60.20	8.37	**162.40**	13.95
KUKIO - Marine Samples	05/01/1993	102	8.15	26.50	0.20	**5.18**	0.13	**33.46**	3.41	33.60	682.64	53.06	4.03	92.54	7.75
KUKIO - Marine Samples	12/01/1993	102	8.11	26.10	0.21	**7.28**	0.13	**5.88**	2.17	34.62	179.76	87.22	8.37	101.22	10.85
KUKIO - Marine Samples	06/01/1994	102	8.25	27.90	0.38	**10.08**	**0.42**	**49.70**	5.89	33.84	859.88	103.60	6.51	**157.22**	12.40
KUKIO - Marine Samples	12/01/1994	102	8.12	24.70	0.23	**12.46**	0.18	**83.72**	11.16	32.77	1300.60	67.76	7.13	**160.72**	19.22
KUKIO - Marine Samples	04/01/1995	103	8.12	26.00	0.10	**13.16**	0.30	**62.30**	7.75	33.10	1037.40	65.66	10.54	144.48	18.29
KUKIO - Marine Samples	01/01/1996	102	8.08	24.90	0.18	**18.62**	0.16	**26.88**	9.30	31.84	620.76	76.16	8.99	**157.08**	19.22
KUKIO - Marine Samples	03/01/1996	103	8.08	25.00	0.16	**20.72**	0.24	**108.64**	14.26	31.60	2233.00	72.80	10.54	**206.92**	**24.80**
KUKIO - Marine Samples	03/01/1997	103	8.09	24.90	0.10	**9.52**	0.17	**114.52**	5.27	31.84	4473.56	129.08	4.96	**253.26**	10.54
KUKIO - Marine Samples	03/01/1998	102	8.11	25.30	0.16	**3.64**	0.15	**9.66**	10.54	34.51	335.44	83.44	3.10	99.12	14.57
KUKIO - Marine Samples	04/01/1999	102	8.23	25.10	0.37	**10.78**	0.12	**72.24**	14.88	32.84	1194.76	104.02	0.93	**187.32**	15.81
MAKALAWENA - Anchialine Pool Samples	01/20/1989					2.52	0.00	**811.72**	190.03	8.40	19371.43				
MAKALAWENA - Anchialine Pool Samples	08/01/1989				0.22			2.01					7.59	**199.33**	**20364.21**
MAKALAWENA - Anchialine Pool Samples	05/29/1990					**5.55**	0.14	**832.67**	189.51	7.38	21174.25				
MAKALAWENA - Anchialine Pool Samples	12/06/1990		8.12	21.73		**6.69**	0.02	**937.32**	193.85	7.41	21437.36				
MAKALAWENA - Anchialine Pool Samples	04/22/1991					2.97	0.04	**825.33**	185.82	6.67	22232.47				
MAKALAWENA - Anchialine Pool Samples	11/14/1991		8.16	21.73		**6.39**	0.02	**832.67**	189.72	6.70	22808.99				
MAKALAWENA - Anchialine Pool Samples	06/25/1992		7.95	21.87		3.41	0.12	**825.53**	182.90	6.80	21597.15				
MAKALAWENA - Anchialine Pool Samples	03/31/1994	98	8.17	22.63	0.04	**12.27**	0.01	**597.71**	190.34	7.61	21855.12	246.40	11.99	**856.38**	**202.33**
MAKALAWENA - Anchialine Pool Samples	10/10/1994	86	8.01	22.43	0.05	**4.25**	0.00	**775.51**	171.84	7.24	22910.25	114.75	41.02	**894.51**	**212.87**
MAKALAWENA - Anchialine Pool Samples	10/22/1995	98	8.01	22.30	0.11	**27.16**	0.10	**729.91**	206.15	6.29	25250.31	171.59	8.78	**928.67**	**214.93**
MAKALAWENA - Anchialine Pool Samples	09/19/1996	102	8.14	22.37	0.05	2.29	0.03	**823.20**	199.43	6.12	29187.20	169.07	17.36	**994.56**	**216.79**
MAKALAWENA - Anchialine Pool Samples	08/27/1997		8.17	21.33	0.05	2.80	0.08	**462.19**	177.01	7.13	24662.40	389.43	24.28	**919.75**	**191.37**
MAKALAWENA - Anchialine Pool Samples	10/19/1998	99	8.01	22.13	0.05	**8.26**	0.08	**934.87**	139.81	6.99	24023.16	85.21	73.57	**1028.35**	**213.38**
MAKALAWENA - Anchialine Pool Samples	10/06/1999	95	8.04	21.90	0.08	**3.97**	0.13	**787.03**	187.55	7.08	21848.87	251.30	3.62	**1042.30**	**191.17**
MAKALAWENA - Anchialine Pool Samples	11/09/2000	94	8.13	21.90	0.10	**24.45**	0.19	**1019.01**	178.97	6.59	22667.31	141.12	4.96	**1184.59**	**183.93**
MAKALAWENA - Anchialine Pool Samples	10/25/2001	91	7.97	22.73	0.10	**4.06**	0.08	**649.18**	190.75	7.82	14455.56	517.35	50.94	**1170.59**	**241.70**
MAKALAWENA - Anchialine Pool Samples	10/28/2002	96	8.02	21.73	0.09	3.17	0.03	**833.79**	193.13	7.50	23860.85	457.52	103.54	**1294.49**	**296.67**
MAKALAWENA - Anchialine Pool Samples	10/21/2003	94	8.19	22.30	0.07	**8.46**	0.05	**781.64**	202.80	7.69	22709.03	757.93	135.20	**1548.03**	**338.00**
MAKALAWENA - Anchialine Pool Samples	11/05/2004	93	8.07	22.73	0.13	**4.89**	0.04	**615.16**	148.76	8.26	22622.93	527.58	305.91	**1147.63**	**454.67**
MAKALAWENA - Anchialine Pool Samples	11/02/2005	94	8.15	22.03	0.13	**16.55**	0.12	**770.72**	186.52	7.61	22433.30	877.47	94.65	**1664.74**	**281.17**
MAKALAWENA - Anchialine Pool Samples	09/08/2006	93	8.12	22.90	0.15	**23.77**	0.03	**987.38**	178.76	8.07	21519.67	757.10	61.28	**1768.25**	**240.04**
MAKALAWENA - Anchialine Pool Samples	12/10/2007	92	8.28	22.20	0.09	**13.03**	0.04	**891.35**	172.83	8.63	20576.80	540.37	74.55	**1444.75**	**247.38**
MAKALAWENA - Anchialine Pool Samples	11/17/2008	82	8.14	22.37	0.16	**10.73**	0.04	**719.48**	120.19	9.14	21381.24	1092.78	106.42	**1822.99**	**226.61**
MAKALAWENA - Anchialine Pool Samples	10/19/2010	94	8.08	22.17	0.10	1.63	0.05	**794.41**	212.04	7.72	23536.89	741.11	2.17	**1537.15**	**214.21**
MAKALAWENA - Anchialine Pool Samples	03/20/2012	83	8.14	22.83	0.23	**5.09**	0.16	**649.55**	125.86	8.25	23861.23	584.97	82.87	**1239.61**	**208.73**
MAKALAWENA - Anchialine Pool Samples	08/26/2013	83	8.14	22.83	0.23	**5.09**	0.16	**649.55**	125.86	8.25	23861.23	584.97	82.87	**1239.61**	**208.73**
MAKALAWENA - Anchialine Pool Samples	10/14/2014	88	8.03	25.63	0.10	**9.15**	0.01	**784.89**	189.82	9.09	24054.61	451.41	43.81	**1245.44**	**233.64**
MAKALAWENA - Anchialine Pool Samples	11/19/2015	81	7.88	25.77	0.08	0.84	0.06	**54.68**	6.55	8.95	1190.35	24.67	0.69	80.18	7.24

Site Group Name	Date Sampled	Field Data				General Chemistry									
		Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
		%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
MAKALAWENA - Anchialine Pool Samples	08/02/2016	82	8.15	26.10	0.10	**31.75**	0.25	**679.98**	168.61	10.05	25708.96	140.58	21.72	**852.31**	**190.33**
MAKALAWENA - Anchialine Pool Samples	10/31/2017	81	8.10	24.70	0.09	**6.36**	0.22	**604.18**	184.60	9.38	25697.06	178.62	5.73	**789.17**	**190.32**
MAKALAWENA - Anchialine Pool Samples	12/10/2018	79	8.03	24.60	0.14	1.04	0.09	**615.56**	169.78	14.49	27410.42	105.53	7.18	**722.13**	**176.96**
MAKALAWENA - Anchialine Pool Samples	11/20/2019	87	8.15	17.50	0.17	**17.41**	0.04	**612.45**	157.35	11.02	25409.11	216.42	33.86	**846.28**	**191.20**
MAKALAWENA - Anchialine Pool Samples	12/27/2020	88	8.11	23.00	0.39	1.10	0.02	**633.98**	155.07	14.06	25932.49	111.23	33.32	**746.32**	**188.39**
MAKALAWENA - Anchialine Pool Samples	12/21/2021	88	8.09	22.97	0.13	**6.57**	0.01	**601.90**	185.87	12.78	20064.54	81.98	12.83	**694.38**	**199.33**
MAKALAWENA - Anchialine Pool Samples	12/30/2022	104	8.23	23.66	0.48	**5.21**	0.02	**928.70**	151.97	12.81	19567.76	28.31	31.98	**965.60**	**183.96**
MAKALAWENA - Anchialine Pool Samples	12/29/2023	95	8.17	23.89	0.36	0.92	0.01	**637.66**	154.60	13.77	19924.79	44.73	26.87	**705.70**	**181.65**
MAKALAWENA - Anchialine Pool Samples	12/19/2024	103	8.17	24.52	0.30	1.26	0.00	**680.73**	161.99	12.16	26727.67	65.90	13.58	**748.47**	**175.64**
MAKALAWENA - Anchialine Pool Samples	12/23/2025	103	8.33	23.40	0.20	0.89	0.03	**639.99**	141.44	11.94	24035.85	100.75	7.55	**741.71**	**153.06**
MAKALAWENA - Marine Samples	01/20/1989					**6.02**	**0.60**	**78.54**	20.77	15.43	2244.20				
MAKALAWENA - Marine Samples	08/01/1989					**11.90**	**0.35**	**28.14**	14.57	33.11	1065.96				
MAKALAWENA - Marine Samples	05/29/1990					**5.53**	0.27	**6.08**	8.06	34.29	337.37				
MAKALAWENA - Marine Samples	12/06/1990		8.07	25.10		**7.08**	0.22	3.81	8.27	34.54	169.79				
MAKALAWENA - Marine Samples	04/22/1991					**4.80**	0.27	**12.16**	11.13	32.69	839.55				
MAKALAWENA - Marine Samples	11/14/1991		8.15	26.60		**7.05**	0.22	3.91	7.27	34.41	150.26				
MAKALAWENA - Marine Samples	06/25/1992		7.67	26.80		**4.61**	**0.34**	**13.54**	11.02	32.11	388.56				
MAKALAWENA - Marine Samples	03/31/1994	103	8.15	25.13	0.08	**3.66**	0.10	0.89	2.88	34.31	112.92	94.09	1.38	99.75	9.76
MAKALAWENA - Marine Samples	10/10/1994	102	8.15	26.90	0.18	0.95	0.17	2.25	6.53	34.43	121.29	60.22	6.27	63.70	12.82
MAKALAWENA - Marine Samples	10/22/1995	102	8.14	26.80	0.17	**5.99**	**0.48**	**8.12**	7.34	33.83	412.05	89.00	8.14	105.17	15.65
MAKALAWENA - Marine Samples	09/19/1996	103	8.08	27.45	0.05	**4.80**	0.17	**24.49**	6.62	32.88	142.77	47.53	15.93	80.54	**22.86**
MAKALAWENA - Marine Samples	08/27/1997	99	8.16	25.90	0.11	2.97	**0.31**	2.60	1.86	33.96	79.60	82.41	24.55	108.20	**30.84**
MAKALAWENA - Marine Samples	10/19/1998	102	7.99	26.25	0.10	**11.58**	0.22	**29.73**	10.50	33.38	746.32	175.61	14.80	**232.99**	**25.54**
MAKALAWENA - Marine Samples	10/06/1999	101	7.99	25.45	0.05	2.16	0.13	**5.66**	5.23	34.40	367.05	82.87	7.59	91.60	12.86
MAKALAWENA - Marine Samples	11/09/2000	101	7.98	25.80	0.13	**6.92**	**0.32**	**12.85**	5.68	34.00	574.85	103.06	7.59	125.89	13.41
MAKALAWENA - Marine Samples	10/25/2001	101	8.11	26.40	0.16	2.37	0.21	1.79	4.59	34.87	239.80	139.57	9.77	144.23	14.36
MAKALAWENA - Marine Samples	10/28/2002	102	8.04	26.63	0.15	1.38	0.26	4.51	4.57	34.85	245.00	107.50	7.91	113.88	12.50
MAKALAWENA - Marine Samples	10/21/2003	101	8.07	26.90	0.39	2.77	0.26	0.18	4.96	34.73	212.57	192.71	4.74	**195.86**	9.71
MAKALAWENA - Marine Samples	11/05/2004	101	8.15	27.13	0.29	3.05	**0.31**	3.39	5.69	34.75	127.38	95.13	5.06	101.58	11.45
MAKALAWENA - Marine Samples	11/02/2005	100	8.02	26.10	0.15	2.25	**0.37**	0.66	4.58	34.76	195.02	74.49	5.37	77.52	10.00
MAKALAWENA - Marine Samples	09/08/2006	100	7.98	27.84	0.14	**3.79**	0.30	1.26	4.77	34.70	145.14	118.42	6.03	123.66	10.89
MAKALAWENA - Marine Samples	12/10/2007	100	8.14	25.10	0.16	**4.15**	**0.35**	**18.08**	9.97	33.61	290.81	129.38	7.74	**183.59**	17.80
MAKALAWENA - Marine Samples	11/17/2008	100	7.96	27.47	0.24	**3.92**	**0.35**	3.18	5.32	34.87	145.58	120.01	11.36	128.56	16.70
MAKALAWENA - Marine Samples	10/19/2010	100	8.12	26.47	0.20	**7.25**	0.26	3.96	4.60	34.87	270.03	156.20	10.13	**170.25**	14.77
MAKALAWENA - Marine Samples	08/26/2013	94	8.03	26.60	0.19	3.22	0.27	3.49	7.44	35.01	168.18	107.42	5.60	114.57	13.08
MAKALAWENA - Marine Samples	10/14/2014	100	7.94	26.00	0.15	**4.17**	0.01	2.58	7.59	34.79	1259.85	92.62	8.12	101.62	15.73
MAKALAWENA - Marine Samples	11/19/2015	100	7.92	27.00	0.21	0.39	**0.46**	0.35	0.24	34.33	7.13	7.18	0.11	7.94	0.35
MAKALAWENA - Marine Samples	08/02/2016	99	7.98	26.97	0.26	**21.23**	**0.44**	**44.96**	16.67	31.95	1647.81	70.00	7.03	149.54	**25.61**
MAKALAWENA - Marine Samples	10/31/2017	99	7.93	26.23	0.13	**3.90**	0.29	**45.98**	16.38	32.47	1624.08	44.78	8.91	103.70	**27.34**
MAKALAWENA - Marine Samples	12/10/2018	100	8.05	25.63	0.16	0.80	0.26	**5.73**	3.40	34.78	54.35	71.39	4.52	78.11	7.93
MAKALAWENA - Marine Samples	11/20/2019	95	8.20	26.13	0.47	1.02	**0.38**	1.59	7.42	34.25	299.04	101.20	7.94	108.36	16.00
MAKALAWENA - Marine Samples	12/17/2020	105	8.08	26.40	**0.94**	2.78	**0.92**	**25.07**	13.64	32.57	1129.93	67.13	4.77	104.86	18.85
MAKALAWENA - Marine Samples	12/01/2021	99	8.08	26.40	**0.82**	**14.24**	**0.31**	**21.56**	15.72	32.16	1191.57	75.84	3.80	124.81	19.91
MAKALAWENA - Marine Samples	12/30/2022	108	8.23	26.00	0.28	**5.99**	**0.51**	**10.17**	6.26	34.36	378.28	68.11	3.08	90.79	10.39
MAKALAWENA - Marine Samples	12/29/2023	102	8.05	23.70	**1.05**	0.85		3.42	3.97	35.07	62.68	84.08	2.27	88.36	6.24
MAKALAWENA - Marine Samples	12/19/2024	114	8.27	25.20	**0.55**	**4.55**	**0.62**	**78.26**	34.75	31.08	4986.44	73.05	3.70	**155.86**	**38.45**
MAKALAWENA - Marine Samples	12/23/2025	113	8.09	25.7	0.18	**4.67**	**0.466**	**41.49**	20.87	30.511	2450.05	68.07	2.76	120.69	**24.17**

TABLE 5. *Department of Health water quality standards*

Specific water quality criteria specified by the Department of Health water quality standards for open coastal waters and used up through June 2000 on the West Hawaii coast.

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/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 5.00 ug/L.

TABLE 6. *West Hawai'i coast Department of Health tiers of water quality*

Three tiers of water quality criteria used by the Department of Health for the West Hawai'i coast. Also included are the criteria for three parameters under all salinity regimes as well as those for sites with no significant groundwater discharge. Note that criteria are presented in ug/L unless otherwise noted.

1.	All Salinity Regimes:	Single Value "Not To Exceed" Criterion For:			
		Ammonia Nitrogen	=	2.5	ug/L
		Chlorophyll-a	=	0.3	ug/L
		Turbidity	=	0.1	NTU
2.	No Salinity Gradient Observed:	Single Value "Not To Exceed" Criterion For:			
		Total Nitrogen	=	100.0	ug/L
		Total Phosphorus	=	12.5	ug/L
		Nitrate + Nitrite Nitrogen	=	4.5	ug/L
		Orthophosphorous	=	5.0	ug/L
3.	Salinity Gradient Observed:	Regression Coefficient (Slope) Criterion For:			
		Total Nitrogen			
		Total Phosphorus			
		Nitrate+Nitrite Nitrogen			
		Orthophosphorous			

Linear mixing criteria for marine sampling transectss along the West Hawai'i coast with significant groundwater discharge as given by the Department of Health. Note that conformance to standards are made by comparing the absolute value of the slope of the regression line (first numeric term below) with the absolute value of the upper 95% confidence limit of the slope calculated from the study site data. Standards are exceeded when the absolute value of the calculated 95% confidence limit is greater than the absolute value of the slope as given below:

Total Nitrogen (ug/L):	Y = -40.35X + 1474.85
Nitrate+Nitrite Nitrogen (ug/L):	Y = -31.92X + 1100.59
Total Phosphorus (ug/L):	Y = -2.86X + 111.42
Orthophosphorous (ug/L):	Y = -3.22X + 116.06

TABLE 7. *Summary of Compliance*

Summary of compliance and non-compliance with West Hawaiʻi Regional Water Quality Standards by year for Waikoloa and the Makalawena control site which is sampled once annually. Regional standards were implemented in mid-2000. Data in this table are summarized from Appendix 15. In the table below, the "Total Possible/Year" is simply the number of water quality parameters with standards (here 7) multiplied by the number of quarters when sampling occurred in that year (usually 4 for Waikoloa and 1 for Makalawena) multiplied by the number of transects sampled (at Waikoloa 3 transects and 1 at Makalawena). "Number Non-compliant" is the total number of instances of non-compliance for all parameters and transects in that year and the "Percent Non-compliant" is the percentage based on the totals.

Please Note:* = Shoreline sampled only

Year	Location	Total Possible per Year	Number Non-compliant	Percent Non-compliant
2000	Waikoloa	42	24	57.1%
	Makalawena	7	7	100.0%
2001	Waikoloa	84	66	78.6%
	Makalawena	7	3	42.9%
2002	Waikoloa	84	57	67.9%
	Makalawena	7	3	42.9%
2003	Waikoloa	84	54	64.3%
	Makalawena	7	3	42.9%
2004	Waikoloa	84	60	71.4%
	Makalawena	7	5	71.4%
2005	Waikoloa	84	58	69.0%
	Makalawena	7	5	71.4%
2006	Waikoloa	84	55	65.5%
	Makalawena	7	5	71.4%
2007	Waikoloa	84	56	66.7%
	Makalawena	7	5	71.4%
2008	Waikoloa	84	67	79.8%
	Makalawena	7	6	85.7%
2009	Waikoloa	56	43	76.8%
	Makalawena	-- Not Sampled --		
2010	Waikoloa	63	50	79.4%
	Makalawena	7	4	57.1%
2011	Waikoloa	84	70	83.3%
	Makalawena	7	4	57.1%

TABLE 7. *Summary of Compliance*

Year	Location	Total Possible per Year	Number Non-compliant	Percent Non-compliant
2012	Waikoloa	84	65	77.4%
	Makalawena	7	5	71.4%
2013	Waikoloa	77	62	80.5%
	Makalawena	-- Not Sampled --		
2014	Waikoloa	84	63	75.0%
	Makalawena	7	5	71.4%
2015	Waikoloa	84	63	75.0%
	Makalawena	7	6	85.7%
2016	Waikoloa	84	34	40.5%
	Makalawena	7	5	71.4%
2017	Waikoloa	63	33	52.4%
	Makalawena	7	5	71.4%
2018	Waikoloa	63	33	52.4%
	Makalawena	7	4	57.1%
2019	Waikoloa	63	51	81.0%
	Makalawena	7	5	71.4%
2020	Waikoloa	84	62	73.8%
	Makalawena	7	5	71.4%
2021	Waikoloa	84	59	70.2%
	Makalawena	7	7	100.0%
2022	Waikoloa	84	68	81.0%
	Makalawena	7	6	85.7%
2023	Waikoloa	84	54	64.3%
	Makalawena	7	6	85.7%
2024	Waikoloa	84	67	79.8%
	Makalawena*	7	3	42.9%
2025	Waikoloa	84	61	72.6%
	Makalawena*	7	3	42.9%

Results of the true ststistical difference test addressing the question, "Have there been any significant changes in the water parameters since 1991 at Waikoloa?" In the body of the table are given the sample date and arithmetic mean for a given parameter on that date. Means are expressed in ug/L unless otherwise noted. This analysis is applied to all Anchialine Ponds from 1991 to 2025.

Nitrate+Nitrite P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	1510.48	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
1992	2046.65		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	1098.41			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	1075.93				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	841.88					NO	**YES**	**YES**	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	1169.08						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	1443.46							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	1278.31								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
1999	960.04									NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	1017.52										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	1247.89											NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	1122.10												NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	1129.83													NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	1660.93														NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2005	1679.32															NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2006	1493.21																NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	1646.77																	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	1426.49																		NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	1047.67																			NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	805.50																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	753.82																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	716.41																						NO	NO	**YES**	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2013	830.40																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	1150.02																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	1275.60																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	1074.00																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	1339.41																											NO	NO	NO	NO	NO	NO	NO	NO
2018	1134.27																												NO	NO	NO	NO	NO	NO	NO
2019	994.34																													NO	NO	NO	NO	NO	NO
2020	887.80																														NO	NO	NO	NO	NO
2021	1255.86																															NO	NO	NO	NO
2022	992.35																																NO	NO	NO
2023	1162.12																																	NO	NO
2024	1053.18																																		NO
2025	1172.33																																		

Ammonia P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	20.13	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
1992	32.62		NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	31.86			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	28.64				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	29.88					**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
1996	20.13						NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	NO	**YES**	NO	NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	NO
1997	21.84							NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
1998	27.55								NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	43.34									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	47.26										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	35.63											NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	35.04												NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	53.91													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	55.39														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	48.07															NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	46.21																NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	61.94																	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
2008	36.46																		NO	NO	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	29.40																			NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	29.99																				NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2011	28.78																					NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	44.35																						NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	34.61																							**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	96.82																								NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2015	142.86																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	21.72																										NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2017	37.06																											NO	NO	NO	NO	NO	NO	NO	NO
2018	26.25																												NO	NO	NO	**YES**	NO	NO	NO
2019	34.55																													NO	NO	NO	NO	NO	NO
2020	22.77																														NO	**YES**	NO	NO	NO
2021	46.24																															NO	NO	NO	NO
2022	48.03																																NO	NO	NO
2023	34.38																																	NO	NO
2024	31.92																																		NO
2025	32.14																																		

Total Dissolved Nitrogen P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	1492.40	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	1752.04		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	1290.99			NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	1213.83				NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	1060.42					NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	1269.35						NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	1759.88							NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	1419.12								NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	1313.76									NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	1254.40										**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	2557.02											NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2002	2427.24												NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2003	2302.78													NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2004	2969.32														NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2005	2510.95															NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2006	2597.08																NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2007	3211.96																	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2008	2598.82																		NO	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**
2009	1891.34																			NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO
2010	1750.14																				NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO
2011	1621.14																					NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2012	1299.40																						NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	1518.10																							NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2014	1916.24																								NO	NO	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO
2015	2093.87																									**YES**	NO	NO	**YES**	**YES**	NO	**YES**	NO	NO	NO
2016	1276.74																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	1760.57																											NO	NO	NO	NO	NO	NO	NO	NO
2018	1634.34																												NO	NO	NO	NO	NO	NO	NO
2019	1280.10																													NO	NO	NO	NO	NO	NO
2020	1053.24																														NO	NO	NO	NO	NO
2021	1449.31																															NO	NO	NO	NO
2022	1232.21																																NO	NO	NO
2023	1575.47																																	NO	NO
2024	1215.90																																		NO
2025	1362.49																																		

Phosphate P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	139.45	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	116.13		NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	NO	NO	NO	NO	NO
1993	161.26			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	196.29				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	204.79					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	205.16						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	216.57							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	198.09								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	185.38									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	150.85										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	190.67											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	212.85												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	269.29													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	283.43														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	269.87															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	257.25																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	223.35																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	237.15																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	178.82																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	172.36																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	161.94																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	184.51																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	208.75																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	288.67																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	346.77																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	317.45																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	358.71																											NO	NO	NO	NO	NO	NO	NO	NO
2018	350.58																												NO	NO	NO	NO	NO	NO	NO
2019	259.06																													NO	NO	NO	NO	NO	NO
2020	274.00																														NO	NO	NO	NO	NO
2021	340.58																															NO	NO	NO	NO
2022	277.47																																NO	NO	NO
2023	271.81																																	NO	NO
2024	236.85																																		NO
2025	249.46																																		

Total Dissolved Phosphorus P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	147.87	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
1992	118.23		NO	NO	**YES**	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO
1993	177.22			NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	206.83				NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	219.91					NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	214.77						NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	223.51							NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	231.32								NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	195.92									NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	161.51										NO	NO	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	446.71											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	340.32												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	418.81													NO	NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	510.01														NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2005	377.95															NO	NO	NO	**YES**	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	382.23																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	316.51																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	297.04																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	208.38																			NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	198.77																				NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	250.98																					NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	223.76																						NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	263.44																							NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	331.20																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	472.94																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	403.23																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	444.96																											NO	NO	NO	NO	NO	NO	NO	NO
2018	447.46																												NO	NO	NO	NO	NO	NO	NO
2019	338.34																													NO	NO	NO	NO	NO	NO
2020	301.31																														NO	NO	NO	NO	NO
2021	424.03																															NO	NO	NO	NO
2022	314.40																																NO	NO	NO
2023	325.45																																	NO	NO
2024	264.96																																		NO
2025	296.95																																		

Silicate P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	21556.15	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**
1992	21319.46		NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**
1993	21106.68			**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**
1994	24453.30				NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
1995	23977.97					**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
1996	30338.78						**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**
1997	24622.14							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
1998	24410.23								NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
1999	22851.30									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**
2000	22661.24										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**
2001	22278.42											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**
2002	23033.53												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	NO
2003	22208.48													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**
2004	21761.55														**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	NO	NO	**YES**
2005	24638.26															NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
2006	22781.43																NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	NO
2007	23566.99																	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	NO
2008	22606.23																		NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	NO
2009	24113.96																			NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
2010	22320.14																				NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**
2011	23782.30																					NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
2012	22480.92																						NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**
2013	20422.19																							NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**
2014	21280.90																								**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**
2015	28527.52																									NO	NO	NO	NO	NO	**YES**	NO	**YES**	NO	NO
2016	30296.22																										NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**
2017	31631.42																											NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	NO
2018	27749.35																												NO	NO	NO	NO	**YES**	NO	NO
2019	24962.21																													NO	NO	**YES**	NO	NO	NO
2020	24616.65																														NO	**YES**	NO	NO	NO
2021	24128.21																															**YES**	NO	NO	NO
2022	30798.16																																**YES**	**YES**	**YES**
2023	23276.65																																	NO	NO
2024	23209.01																																		NO
2025	25552.54																																		

Salinity P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	6.39	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	8.16		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	8.43			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	7.28				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	7.64					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	8.63						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	8.66							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	7.81								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	6.60									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	5.46										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	8.03											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	6.87												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	9.80													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	10.54														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	6.46															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	8.16																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	6.39																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	9.02																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	6.42																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	6.09																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	8.30																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	6.82																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	6.84																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	6.21																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	8.21																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	7.55																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	7.87																											NO	NO	NO	NO	NO	NO	NO	NO
2018	6.94																												NO	NO	NO	NO	NO	NO	NO
2019	8.05																													NO	NO	NO	NO	NO	NO
2020	8.85																														NO	NO	NO	NO	NO
2021	8.81																															NO	NO	NO	NO
2022	7.86																																NO	NO	NO
2023	8.27																																	NO	NO
2024	7.93																																		NO
2025	6.72																																		

Turbidity P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	0.23	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO
1992	0.27		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
1993	0.79			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	0.45				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	0.21					NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
1996	0.46						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	0.37							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO
1998	0.18								NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
1999	0.39									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	0.41										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO
2001	0.40											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	**YES**
2002	0.43												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO
2003	0.66													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	0.43														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO
2005	0.47															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	0.43																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	0.41																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO
2008	0.59																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	0.52																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	0.30																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**
2011	0.54																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	0.63																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	0.62																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	0.52																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	0.55																									NO	NO	NO	NO	NO	NO	NO	NO		NO
2016	0.41																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	0.39																											NO	NO	NO	NO	**YES**	NO	NO	NO
2018	0.25																												NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
2019	1.44																													NO	NO	NO	NO	NO	NO
2020	0.87																														NO	NO	NO	NO	NO
2021	1.68																															NO	NO	NO	NO
2022	1.08																																NO	NO	NO
2023	0.93																																	NO	NO
2024	0.55																																		NO
2025	0.70																																		

CHL P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	0.22	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO
1992	3.23		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	1.31			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	0.42				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	1.07					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	1.32						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	1.01							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	0.61								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	0.48									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	1.85										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	0.86											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	0.51												NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	1.91													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	1.69														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	1.07															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO
2006	0.62																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	0.79																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	1.41																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	0.97																			NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO
2010	0.73																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	1.33																					NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO
2012	1.54																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	2.13																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	1.15																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	0.68																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	1.19																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	0.61																											NO	NO	NO	NO	NO	NO	NO	NO
2018	0.38																												NO	NO	NO	NO	NO	NO	NO
2019	2.73																													NO	NO	NO	NO	NO	NO
2020	3.51																														NO	NO	NO	NO	NO
2021	2.63																															NO	NO	NO	NO
2022	7.65																																NO	NO	NO
2023	0.89																																	NO	NO
2024	2.04																																		NO
2025	2.25																																		

Temperature P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	27.15	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**
1992	29.34		NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
1993	28.40			NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	28.82				NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	27.48					NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	**YES**	NO
1996	26.20						**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1997	24.62							**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1998	27.54								NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	**YES**	NO
1999	26.50									NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2000	27.48										NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	**YES**	NO
2001	29.04											NO	NO	NO	**YES**	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2002	28.76												NO	NO	**YES**	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2003	29.64													NO	**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**
2004	29.02														**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2005	26.22															**YES**	NO	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2006	30.04																**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	**YES**
2007	25.78																	**YES**	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2008	28.86																		**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2009	26.70																			**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2010	25.12																				**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2011	27.20																					**YES**	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	NO
2012	24.96																						NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2013	26.26																							NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2014	26.34																								NO		NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2015	27.72																									NO	NO	NO	**YES**	NO	NO	NO	NO	**YES**	NO
2016	26.34																										NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2017	26.44																											NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	NO
2018	26.40																												**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2019	29.66																													NO	NO	NO	**YES**	NO	**YES**
2020	30.16																														NO	NO	NO	NO	NO
2021	29.16																															NO	NO	NO	NO
2022	29.10																																NO	NO	NO
2023	28.60																																	NO	NO
2024	29.62																																		**YES**
2025	28.18																																		

Dissolved Oxygen P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	101.50	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1992	112.40		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	NO
1993	105.50			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1994	102.80				NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1995	103.00					NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1996	103.80						NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1997	103.20							NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1998	102.20								NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1999	101.60									NO	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2000	101.00										NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2001	100.20											NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2002	104.80												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2003	99.80														**YES**	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2004	99.80														**YES**	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2005	98.20															NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2006	100.80																NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2007	99.80																	NO	NO	**YES**	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2008	99.40																		NO	**YES**	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2009	97.80																			NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2010	96.00																				NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2011	98.00																					NO	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2012	93.20																						NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2013	93.00																							NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2014	96.00																								NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2015	92.80																									NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2016	87.60																										NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2017	85.80																											NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2018	86.20																												NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2019	108.24																													NO	**YES**	**YES**	**YES**	NO	NO
2020	129.82																														NO	**YES**	**YES**	NO	NO
2021	136.12																															**YES**	**YES**	NO	NO
2022	170.76																																NO	NO	NO
2023	168.56																																	NO	NO
2024	149.76																																		NO
2025	140.52																																		

pH P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	8.07	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	8.26		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
1993	8.19			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
1994	8.22				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
1995	8.19					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	7.92						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO
1997	8.09							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
1998	8.02								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO
1999	8.26									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2000	8.19										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2001	8.18											NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2002	8.13												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2003	8.14													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2004	8.11														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO
2005	7.98															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2006	8.01																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	7.95																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	8.04																		NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO
2009	7.84																			NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO
2010	7.83																				NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO
2011	8.19																					NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2012	8.11																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	8.05																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	8.06																								NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO
2015	7.75																									NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2016	7.67																										NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO
2017	7.59																											NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO
2018	7.61																												**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO
2019	8.14																													NO	NO	NO	NO	NO	NO
2020	8.24																														NO	NO	NO	NO	**YES**
2021	8.35																															NO	NO	NO	**YES**
2022	8.31																																NO	NO	**YES**
2023	8.20																																	NO	NO
2024	8.11																																		NO
2025	7.94																																		

Results of the true ststistical difference test addressing the question, "Have there been any significant changes in the water parameters since 1991 at Waikoloa?" In the body of the table are given the sample date and arithmetic mean for a given parameter on that date. Means are expressed in ug/L unless otherwise noted. This analysis only include Ocean Samples from 1991 to 2025.

Nitrate+Nitrite P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	121.88	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	120.33		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	124.25			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	103.38				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	107.80					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	124.49						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	69.64							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	199.44								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	109.03									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	129.09										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	83.92											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	45.66												NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2003	53.50													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	75.41														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	62.39															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	92.14																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	117.72																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	82.90																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	93.77																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	65.32																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	96.52																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	75.23																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	76.37																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	55.77																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	106.76																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	69.16																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	83.07																											NO	NO	NO	NO	NO	NO	NO	NO
2018	92.66																												NO	NO	NO	NO	NO	NO	NO
2019	87.90																													NO	NO	NO	NO	NO	NO
2020	72.36																														NO	NO	NO	NO	NO
2021	167.12																															NO	NO	NO	NO
2022	139.47																																NO	NO	NO
2023	129.46																																	NO	NO
2024	151.45																																		NO
2025	142.98																																		

Ammonia P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	7.36	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
1992	7.87		NO	NO	NO	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
1993	6.72			NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
1994	7.91				NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO
1995	11.24					NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	**YES**	NO	NO	NO
1996	12.96						NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	NO	NO	NO	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO
1997	16.88							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	62.26								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	28.94									NO	**YES**	**YES**	NO	**YES**	**YES**	NO	**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO
2000	10.22										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2001	6.81											NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
2002	7.38												NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
2003	12.08													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	6.76														NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
2005	6.92															NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
2006	10.38																NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2007	8.30																	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO
2008	9.02																		NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2009	6.39																			**YES**	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2010	13.14																				**YES**	**YES**	**YES**	NO	NO	NO	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO
2011	5.83																					NO	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2012	5.82																						NO	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2013	8.09																							**YES**	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	**YES**	NO
2014	15.23																								NO	**YES**	**YES**	NO	**YES**	**YES**	NO	NO	**YES**	NO	NO
2015	13.03																									NO	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO
2016	7.49																										NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2017	6.73																											**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**
2018	13.69																												**YES**	**YES**	NO	NO	NO	NO	NO
2019	8.77																													NO	NO	**YES**	NO	NO	NO
2020	6.95																														**YES**	**YES**	NO	**YES**	**YES**
2021	15.32																															NO	NO	NO	NO
2022	19.08																																**YES**	**YES**	NO
2023	10.39																																	NO	NO
2024	12.27																																		NO
2025	12.98																																		

Total Dissolved Nitrogen P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	217.78	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	214.13		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	221.52			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	232.60				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	260.34					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	213.85						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	229.56							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	310.84								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	249.42									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	266.63										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	241.98											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	199.92												NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	303.53													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	232.98														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	173.43															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	233.28																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	277.22																	NO	NO	**YES**	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2008	222.67																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	215.40																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	201.93																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	295.25																					NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO
2012	207.65																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	244.86																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	250.03																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	263.46																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	162.24																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	186.59																											NO	NO	NO	NO	NO	NO	NO	NO
2018	188.09																												NO	NO	NO	NO	NO	NO	NO
2019	208.42																													NO	NO	NO	NO	NO	NO
2020	161.49																														NO	NO	NO	NO	NO
2021	283.80																															NO	NO	NO	NO
2022	237.80																																NO	NO	NO
2023	223.03																																	NO	NO
2024	241.20																																		NO
2025	220.59																																		

Phosphate P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	14.70	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	16.49		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	19.41			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	17.89				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	18.23					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	18.48						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	18.82							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	30.10								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	23.75									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	29.45										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	17.38											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	26.03												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	254.57													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	15.47														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	12.61															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2006	18.14																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	19.43																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	17.37																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	26.19																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	22.08																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	28.06																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	23.80																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	26.97																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	19.04																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	24.80																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	19.56																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	25.36																											NO	NO	NO	NO	NO	NO	NO	NO
2018	19.89																												NO	NO	NO	NO	NO	NO	NO
2019	20.11																													NO	NO	NO	NO	NO	NO
2020	17.72																														NO	NO	NO	NO	NO
2021	34.16																															NO	NO	NO	NO
2022	34.26																																NO	NO	NO
2023	26.59																																	NO	NO
2024	26.96																																		NO
2025	31.23																																		

Total Dissolved Phosphorus P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	19.84	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
1992	23.16		NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	27.37			NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	33.51				NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	29.11					NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	29.14						NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	28.95							**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	64.98								**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1999	32.95									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	36.21										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	29.85											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	37.69												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2003	266.84													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	21.28														NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2005	31.09															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	32.04																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	31.02																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2008	27.63																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2009	34.10																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	33.37																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	45.97																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	39.13																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	37.78																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	29.16																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	33.92																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	32.44																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	40.43																											NO	NO	NO	NO	NO	NO	NO	NO
2018	31.37																												NO	NO	NO	NO	NO	NO	NO
2019	31.70																													NO	NO	NO	NO	NO	NO
2020	24.19																														NO	NO	NO	NO	NO
2021	41.87																															NO	NO	NO	NO
2022	41.96																																NO	NO	NO
2023	30.72																																	NO	NO
2024	32.10																																		NO
2025	39.41																																		

Silicate P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	2865.35	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	4028.16		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	3715.82			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	3104.14				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	2966.24					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	3296.50						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	2199.82							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	3788.85								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	2808.29									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	3120.60										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	2256.70											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2002	1492.32												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**
2003	1779.61													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO
2004	1449.45														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**
2005	1482.03															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	**YES**
2006	2118.99																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2007	2342.79																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2008	1742.28																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO
2009	2396.97																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	2044.88																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO
2011	3012.86																					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2012	2359.98																						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2013	2549.68																							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2014	1612.38																								NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO
2015	3404.36																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	2026.25																										NO	NO	NO	NO	NO	**YES**	NO	NO	NO
2017	2610.83																											NO	NO	NO	NO	NO	NO	NO	NO
2018	2087.55																												NO	NO	NO	NO	NO	NO	NO
2019	3104.17																													NO	NO	NO	NO	NO	NO
2020	2641.68																														NO	NO	NO	NO	NO
2021	6068.84																															NO	NO	NO	NO
2022	5991.23																																NO	NO	NO
2023	4567.79																																	NO	NO
2024	4957.10																																		NO
2025	4616.31																																		

Salinity P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	33.40	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1992	33.12		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1993	32.33			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	33.39				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	31.30					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1996	32.30						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1997	33.40							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1998	33.02								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1999	32.65									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2000	33.01										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2001	34.50											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2002	34.66												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2003	34.53													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2004	34.21														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2005	34.19															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	34.43																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	34.51																	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2008	34.51																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2009	33.68																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	34.04																				NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2011	34.49																					NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2012	34.51																						NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2013	34.61																							NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2014	33.87																								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2015	33.88																									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2016	33.79																										NO	NO	NO	NO	NO	NO	NO	NO	NO
2017	33.21																											NO	NO	NO	NO	NO	NO	NO	NO
2018	33.44																												NO	NO	NO	NO	NO	NO	NO
2019	34.09																													NO	NO	NO	NO	NO	NO
2020	33.69																														NO	NO	NO	NO	NO
2021	32.35																															NO	NO	NO	NO
2022	33.13																																NO	NO	NO
2023	34.39																																	NO	NO
2024	33.29																																		NO
2025	34.12																																		

Turbidity (ntu) P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	0.34	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1992	0.28		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1993	0.31			NO	**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1994	0.50				**YES**	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**
1995	0.17					NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1996	0.19						NO	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1997	0.17							NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1998	0.12								**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1999	0.31									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2000	0.21										**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2001	0.54											NO	NO	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**
2002	0.40												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2003	0.98													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2004	0.30														NO	NO	NO	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2005	0.35															NO	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2006	0.40																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2007	0.30																	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2008	0.43																		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2009	0.42																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2010	0.73																				NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	NO	NO	NO	NO	NO	NO	NO
2011	0.49																					NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2012	0.43																						NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2013	0.48																							NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2014	0.36																								NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2015	0.40																									NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2016	0.62																										NO	NO	NO	NO	**YES**	NO	NO	NO	NO
2017	0.33																											NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2018	0.36																												NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2019	0.52																													NO	**YES**	NO	NO	NO	**YES**
2020	1.23																														NO	NO	NO	NO	NO
2021	1.41																															**YES**	**YES**	NO	NO
2022	0.74																																NO	NO	NO
2023	0.73																																	NO	NO
2024	0.76																																		NO
2025	0.88																																		

TABLE 9 *Results of the True Statistical Differences Test – For all Ocean Samples*

Chl P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	0.39	NO	NO	YES	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	YES	NO	NO	NO	YES	YES	NO	YES	NO	YES	NO
1992	0.41		NO	YES	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	YES	NO	NO	NO	YES	YES	NO	YES	NO	YES	NO
1993	0.60			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1994	0.21				YES	NO	NO	YES	NO	NO	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
1995	0.47					NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
1996	0.45						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
1997	0.30							NO	NO	NO	YES	NO	NO	YES	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	NO
1998	0.29								NO	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
1999	0.26									NO	YES	YES	NO	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2000	0.20										YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2001	0.72											NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2002	0.47												NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2003	0.52													NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2004	0.53														NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2005	0.66															NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2006	0.62																NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2007	0.41																	YES	NO	YES	NO	NO	NO	NO	YES	NO	NO	NO	YES	YES	NO	YES	NO	YES	NO
2008	0.61																		NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO
2009	0.71																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2010	0.71																				NO	NO	NO	NO	NO	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO
2011	0.53																					NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2012	0.57																						NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2013	0.54																							NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2014	0.52																								NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO
2015	0.78																									YES	YES	YES	NO	NO	NO	NO	NO	NO	NO
2016	0.44																										NO	NO	YES	YES	NO	YES	NO	NO	NO
2017	0.47																											NO	NO	YES	NO	YES	NO	NO	NO
2018	0.41																												YES	YES	NO	YES	NO	YES	NO
2019	0.67																													NO	NO	NO	NO	NO	NO
2020	1.41																														NO	NO	YES	NO	NO
2021	0.74																															NO	NO	NO	NO
2022	0.80																																NO	NO	NO
2023	0.52																																	NO	NO
2024	0.67																																		NO
2025	0.72																																		

Temperature P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	27.14	YES	YES	NO	NO	NO	YES	NO	YES	NO	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
1992	27.96		YES	NO	YES	YES	YES	YES	YES	NO	YES	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES	YES	NO	NO	YES	YES	NO	YES	YES	YES	YES	NO	NO	YES	YES
1993	29.16			YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	NO	YES
1994	27.56				YES	NO	YES	NO	YES	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES
1995	26.77					NO	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
1996	27.15						YES	NO	YES	NO	NO	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
1997	25.05							YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
1998	27.25								YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
1999	26.31									YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
2000	27.51										NO	NO	NO	YES	YES	YES	YES	NO	NO	YES	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES
2001	27.41											YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
2002	27.84												NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	YES	NO	YES	YES	YES	YES	NO	YES	YES	YES
2003	27.84													YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	YES	NO	YES	YES	YES	YES	NO	YES	YES	YES
2004	28.62														YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO	NO	YES	YES	NO	NO	YES
2005	26.88															YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2006	29.01																YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	NO	NO	YES
2007	26.67																	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
2008	28.01																		YES	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	NO	YES	YES	YES
2009	26.96																			YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2010	26.09																				YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2011	26.50																					YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES
2012	25.34																						YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
2013	27.69																							NO	YES	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES
2014	27.64																								YES	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES
2015	28.58																									YES	YES	YES	NO	NO	NO	YES	NO	NO	YES
2016	27.41																										NO	YES	YES	YES	YES	YES	YES	YES	YES
2017	27.76																											YES	YES	YES	YES	NO	NO	YES	YES
2018	26.52																												YES	YES	YES	YES	YES	YES	YES
2019	28.80																													NO	NO	YES	NO	NO	YES
2020	28.67																														NO	YES	NO	NO	YES
2021	29.24																															YES	NO	NO	YES
2022	28.00																																NO	YES	YES
2023	28.54																																	NO	YES
2024	28.94																																		YES
2025	30.40																																		

Dissolved Oxygen P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	102.80	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1992	103.40		NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1993	103.20			NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1994	103.20				NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1995	102.60					NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1996	103.20						NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1997	102.50							**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1998	103.40								**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
1999	102.10									**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
2000	101.20										NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2001	101.43											NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
2002	101.43												NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
2003	101.36													**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**
2004	100.64														**YES**	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2005	99.93															**YES**		NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2006	100.64																**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2007	99.93																	NO	NO	NO	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2008	100.36																		**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2009	99.14																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
2010	99.21																				NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**
2011	99.14																					NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
2012	98.50																						NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2013	98.50																							NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2014	99.07																								NO	NO	NO	NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
2015	98.50																									NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2016	98.43																										NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2017	99.07																											NO	NO	**YES**	NO	**YES**	**YES**	**YES**	**YES**
2018	98.07																												NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2019	100.21																													**YES**	NO	NO	**YES**	**YES**	**YES**
2020	108.04																														NO	NO	NO	**YES**	NO
2021	103.98																															NO	**YES**	**YES**	**YES**
2022	103.36																																**YES**	**YES**	**YES**
2023	110.84																																	NO	NO
2024	115.83																																		NO
2025	112.84																																		

pH P<0.0001

Year	Mean	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1991	8.18	NO	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO
1992	8.18		NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO
1993	8.23			**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO
1994	8.14				**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	NO	**YES**
1995	8.00					**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
1996	8.12							NO	NO	NO	NO	NO	NO	**YES**	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**
1997	8.12							NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**
1998	8.13								NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	**YES**	**YES**	**YES**	NO	**YES**
1999	8.11									**YES**	NO	NO	NO	**YES**	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**
2000	8.16										NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	**YES**
2001	8.16											**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	NO	**YES**
2002	8.10												**YES**	**YES**	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**
2003	8.14													**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	NO	**YES**
2004	8.21														**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	NO	NO	**YES**	NO
2005	8.07															NO	NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2006	8.06																NO	NO	NO	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2007	8.10																	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**
2008	8.08																		**YES**	**YES**	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	NO	NO	**YES**	**YES**	**YES**	NO	**YES**
2009	8.01																			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2010	7.99																				NO	NO	NO	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2011	8.04																					NO	NO	**YES**	**YES**	**YES**	NO	**YES**	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2012	8.02																						NO	NO	**YES**	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2013	8.02																							NO	**YES**	NO	NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**
2014	7.98																								NO	NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2015	7.96																									NO	NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2016	7.98																										NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2017	7.99																											NO	NO	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2018	7.97																												**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
2019	8.06																													NO	**YES**	**YES**	**YES**	**YES**	**YES**
2020	8.15																														NO	NO	NO	NO	NO
2021	8.19																															NO	NO	**YES**	NO
2022	8.18																																NO	**YES**	**YES**
2023	8.18																																	**YES**	**YES**
2024	8.13																																		**YES**
2025	8.25																																		

Table 10.
Summary of pesticide use at Waikoloa for 2025 for the Beach and King's Golf Courses. Note that the products are listed as dry weight (in kilograms) in terms of active ingredients (AI). Data courtesy of Waikoloa Land Co.

Category	Product	EPA Registration Number	Beach Course AI	King's Course AI	AI Annual Total
Fungicide	Daconil	100-1364	19.60		19.60
Fungicide	Daconil action	100-1364		30.62	30.62
Fungicide	Heritage	100-1093	0.96	0.64	1.60
Fungicide	Junction	67690-35	0.00		0.00
Fungicide	JunctionWSP	67690-35			0.00
Fungicide	Lexicon	7969-350	0.40	0.40	0.80
Fungicide	Mirage	432-1529	5.46	5.27	10.73
Fungicide	Secure action	100-1633	0.70	0.79	1.49
Fungicide	Signature	432-890	5.99	5.99	11.97
Herbicide	Barricade	100-1139	0.18	0.00	0.18
Herbicide	Certainty	524-534		0.02	0.02
Herbicide	Cheetah pro	228-743			0.00
Herbicide	Dismiss	279-3295	4.40	3.42	7.82
Herbicide	Fusilade	100-1084	0.23	0.00	0.23
Herbicide	MSMA	19713-42	2.12	1.17	3.29
Herbicide	Primo	100-937	0.00	0.00	0.00
Herbicide	Ronstar Flo	432-1465	0.00	0.24	0.24
Herbicide	Ronstar-flo	101563-125			0.00
Herbicide	Roundup	524-517		2.79	2.79
Herbicide	Roundup pro	524-529	16.28		16.28
Herbicide	Sencor	432-1469	0.53	0.36	0.89
Herbicide	Specticle Flo	432-1518	0.24	0.15	0.39
Herbicide	sureguard	59639-120	0.40	0.07	0.48
Herbicide	Tenacity	100-1267	0.65	0.44	1.09
Insecticide	Acephate97up	70506-8			0.00
Insecticide	Arena	59639-152	0.57	0.43	0.99
Insecticide	Avatar PLX	94396-29	10.98	11.23	22.20
Insecticide	Gralic oil				0.00
Insecticide	imidacloprid				0.00
Insecticide	Merit	432-1318	0.00		0.00
Insecticide	Merit 75 wsp	432-1318		0.00	0.00
Insecticide	Scimitar	100-1088	0.00	0.00	0.00
Insecticide	Talstar select	279-3155	1.67	0.76	2.43

Table 11.

Summary table of high-use pesticides and their active ingredients (in parentheses) used in the 2009 through 2025 period on the Beach and King's golf courses at Waikoloa. For each pesticide the annual total used for each year is given in either liters or kilograms. Note that a star (*) in the body of the table next to the amount used indicates those products that were

Type	Product	Active Ingredient	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Tested
Herbicide	Aqua Cap	Pendimethalin			53.0* L															
Herbicide	Barricade	Prodiamine	48.8* L		23 L	37.8 L	47.1 L	50 L	7.3 L			29.1 L						0.78 Kg	0.45 Kg	
Herbicide	Certainty	sulfosulforon														0.03 kg	0.80 kg	0.05 Kg	0.03 Kg	
Herbicide	Cheetah Pro	Glufosinate ammonium												1.4 l	12.4 kg	16.62 kg	16.62 kg	57.79 Kg	0 Kg	
Herbicide	CrossRoad	2,4-D													3.0 kg		2.98 kg			
Herbicide	Dismiss	Sulfentrazone								22.1 L			9.5 L	0.2 L	1.8 kg	4.35 kg	6.27 kg	13.08 Kg	19.76 Kg	
Herbicide	Monument	Trifloxysulfuron-sodium														0.05 kg	0.03 kg			
Herbicide	MSMA	Arsenic	45.7* L	46.4 L	85.8* L	66.1* L	47.8* L	40.6* L	16.8 L	24.4 L	21.3 L	27.2 L	12.2 L		5.3 kg	6.22 kg		11.12 Kg	6.92 Kg	
Herbicide	Revolver	Foramsulfuron		35.5 L	64.4* L	16.4 L	21.8 L	10.8 L	0.3 L											
Herbicide	Ranger Pro	Glyphosate + AMPA					43.9* L	62.8* L	17.5* L			89.7 L				11.18 kg				*
Herbicide	Ronstar Flo	Oxadiazon								14.6 L			8.5 L	0.5 L	2.1 kg	2.68 kg		5.01 Kg	0.71 Kg	
Herbicide	Roundup	Glyphosate + AMPA																4.03 Kg*	6.8 Kg	*
Herbicide	Roundup Max	Glyphosate + AMPA	159.9* L	7.6* L																*
Herbicide	Roundup Pro	Glyphosate + AMPA				76.2* L	17.2* L		4.7* L	46.4* L	59.8* L		102.3 L	9.1 L				18.82 Kg*	32.43 Kg	*
Herbicide	Specticle Flo	Indaziflam								17.2 L	18.3 L		29.0 L			11.22 kg	1.40 kg	5.56 Kg	5.26 Kg	
Herbicide	Touchdown	Glyphosate + AMPA		68.4* L	64.3* L	3.9* L														*
Herbicide	Tribute	Halosulfuron-methyl + Foramsulfuron							39.5* L		21.7 L									
Herbicide	PowerZone	MCPA, 2-ethylhexyl ester										47.6 L	1.8 L							
Herbicide	Sencor	Metribuzin											1.2 L	0.1 L	1.1 kg	1.34 kg		1.44 Kg	1.18 Kg	
Herbicide	Sureguard	flumioxazin															0.10 kg	0.48 Kg	0.94 Kg	
Herbicide	Tenacity	Nesotrione											3.1 L	0.3 L	2.7 kg	1.84 kg		3.58 Kg	2.72 Kg	
Herbicide	Primo	Trinexapac											4.1 L		0.4 kg	0.47 kg	0.19 kg	2.07 Kg	0 Kg	
Insecticide	E-Pro 4-Chlorpyrifos	Chlopyrifos	104.3* L	155.7* L	48.9* L		49.7* L	122.2* L	17.9* L	39.3* L										
Insecticide	Chlorpyrifos	Chlorpyrifos				146.7* L	103.1* L	66.6* L	16.5* L	42.0* L	26.8* L									
Insecticide	Merit 75 wsp	Imidacloprid												0.6 L	0.6 kg	1.91 kg	0.39 kg	2.42 Kg	0 Kg	
Insecticide	Talstar Select	Bifenthrin		68.2 L	31.0* L	40.2* L	57.4* L	70.3* L	7.6 L	125.8* L	104.7* L	93.1 L	27.1 L	22.2 L	2.6 kg	4.43 kg		34.1 Kg	30.72 Kg	
Insecticide	M-pede	potassium salts					18.9 L	73.8 L	2.3 L	7.6 L			9.5 L			0.89 kg	0.89 kg			
Insecticide	Acephate 97 Up	Acephate										143 kg	276.4 kg	3.0 kg	6.2 kg	193.6 kg				
Insecticide	Safari	Dinotefuran												0.1 kg	0.1 kg		0.06 kg			
Insecticide	Scimitar	Lambda-cyhalothrin												4.0 kg	0.3 kg	0.08 kg	0.34 kg	6.09 Kg	0 Kg	
Insecticide	Triplecrown Golf	Imidacloprid, bifenthrin											3.1 kg							
Fungicide	Bayleton FLO	triadimefon												3.9 kg						
Fungicide	Fore	Mancozeb	126.6* kg			13.6 kg				21.7 kg			6.1 kg							
Fungicide	Honor	Propiconazole							58.6* kg	1 kg			7.8 kg	4.1 kg		7.84 kg	2.20 kg			
Fungicide	JunctionWSP	67690-59												7.7 kg	0.6 kg	4.72 kg	4.72 kg	7.62 Kg	0 Kg	
Fungicide	Lexicon	Fluxapyroaxd												1.3 kg		0.76 kg		3.64 Kg	2.38 Kg	
Fungicide	Transom	Thiophate-methyl			33.4 L															
Fungicide	Cleary 3336	Thiophanate-methyl				36.8* L				33.6 L		67.1 L								
Fungicide	Daconil 26GT	Iprodione	52.3* L																	

Type	Product	Active Ingredient	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Tested
Fungicide	Daconil	Chlorothalonil									112.6* L		85.2 L					62.72 Kg	36.29 Kg	
Fungicide	Daconil Action	Chlorothalonil									52 L		94.6 L	31.2 L	34.4 kg	29.45 kg	49.12 kg	66.53 Kg	56.7 Kg	
Fungicide	Dacon Weather Stik	Chlorothalonil									28.4 L									
Fungicide	Heritage	Azoxystrobin														0.06 kg	0.34 kg	4.7 Kg	18.14 Kg	
Fungicide	Interface	Iprodione								70.7* L										
Fungicide	Lexicon	Fluxapyroaxd													1.1 kg	0.50 kg	1.39 kg	3.64 Kg	2.38 Kg	
Fungicide	Mirage	Tebuconazole												20.1 L	7.9 kg	10.23 kg	9.68 kg	50.12 Kg	50.12 Kg	
Fungicide	Prostar	Flutolanil									21.8 kg									
Fungicide	Signature	Fosetyl aluminum								50.5* kg	39.9 kg		84.8 kg		1.4 kg		10.91 kg	22.62 Kg	14.97 Kg	
Fungicide	Tartan	Trifloxysulfuron Triadimefon												3.4 kg			1.35 kg			

Mean counts of native shrimp (in number/0.1m2) opaeula or Halocaridina rubra in four routinely surveyed anchialine pools at Waikoloa by date. In the body of the table are given the mean counts from quadrats placed in the pools. Native species at site 20 do not include H. rubra thus counts of the native limpet (Theodoxus cariosa) and glass shrimp or opae (Palaemon debilis) are given. A blank indicates that no sampling of that site occurred on that date and a zero indicates sampling carried out but no individuals were seen on that census date.

Date	Site 3 Best Efforts	Site 11 Pond 155	Site 20 P.deb	Site 20 T.car.	Site 21 Pond 48	Site 22 Pond 188
12/6/1990		41			144	108
4/22/1991		48			98	81
7/30/1991		33			103	102
11/14/1991		18			58	91
3/20/1992		21			82	29
4/10/1992		86	1	0	79	
5/19/1992		71			106	76
6/25/1992	86	67			97	94
7/8/1992		59	3	3	73	
7/29/1992	70	83	1	3	97	146
9/9/1992	101	93			93	56
10/1/1992		107	5	2	87	
12/3/1992	56	89	1	2	93	89
12/17/1992		100	2	3	89	
3/3/1993		74	2	2	119	
5/12/1993		93	3	4	72	
9/28/1993	104	89	2	7	107	
12/6/1993	88	89	1	6	87	
3/31/1994	94	74	2	3	80	97
6/7/1994	103	86	1	6	88	89
10/10/1994	96	92	3	4	107	107
12/6/1994	86	123	1	3	117	78
4/11/1995		120	1	3	89	56
7/14/1995	86	109	2	4	76	128
10/22/1995		65			73	53
1/4/1996	90	137	1	3	85	106
3/18/1996		79			96	78
7/2/1996	89	136	2	3	100	107
9/19/1996					106	105
12/3/1996	84	105	3	1	94	105
3/20/1997		142			109	85
7/11/1997	8*	99	3	0.01**	109	93
8/27/1997	7	97	2	0.005	120	90
12/17/1997	80	92	3	0.05	132	101
3/20/1998	18	168		0.05	103	80
7/14/1998	66	101		0.01	89	102
10/19/1998	33	78		0.13	98	68

Date	Site 3 Best Efforts	Site 11 Pond 155	Site 20 P.deb	Site 20 T.car.	Site 21 Pond 48	Site 22 Pond 188
11/13/1998	15	149		0.03	116	84
4/26/1999	24	149		0.33	116	84
6/4/1999	35	97		0.14	80	84
10/6/1999	92	105		0.4	91	71
12/29/1999	130	87		0.5	97	65
4/28/2000	70	88		0.5	94	74
6/30/2000	124	147		3.3	97	144
11/9/2000	114	121		3	139	119
1/29/2001	47	165		3	145	138
2/12/2001	71	153		6	98	86
5/30/2001	63	97		0.4	97	69
10/25/2001	8	155		4	183	175
12/10/2001	25	138		2	118	108
3/28/2002	133	190		2	143	84
7/18/2002	100	98		1	103	70
10/28/2002	91	210		1	143	232
12/9/2002	195	159		1	163	122
1/30/2003	116	171		2	186	96
7/16/2003	171	116		2	153	96
10/21/2003	223	130		4	215	145
12/9/2003	300	183		6	170	175
3/9/2004	209	0		3	149	61
5/6/2004	193	0		4	242	0
11/5/2004	222	0		4	212	0
12/7/2004	170	0		4	209	0
3/1/2005	176	0		4	289	0
8/2/2005	359	0		4	354	0
11/2/2005	378	0		4	242	0
1/20/2006	300	0		4	207	0
1/31/2006	323	0		2	229	0
4/21/2006	180	0		4	251	0
9/8/2006	252	0		2	209	0
12/5/2006	262	0		1	248	0
3/23/2007	176	0		2	202	0
8/21/2007	237	0		0	160	0
11/2/2007	224	0		1	179	0
12/10/2007	240	0		0	228	0
1/8/2008	217	0		1	197	0
7/11/2008	212	0		1	0	0
9/23/2008	186	0		0.5	0	0
11/17/2008	134	0		1	0	0
5/18/2009	142	0		0	0	0
8/20/2009	125	0		3	0	0
10/2/2009	106	0		3	0	0

Date	Site 3 Best Efforts	Site 11 Pond 155	Site 20 P.deb	Site 20 T.car.	Site 21 Pond 48	Site 22 Pond 188
7/28/2010	199	0		0	0	0
10/19/2010	120	0		0	0	0
11/19/2010	232	0		0	0	0
4/8/2011	110	0		0	0	0
6/9/2011	152	0		0	0	0
8/4/2011	186	0		0	0	0
11/3/2011	135	0		0	0	0
3/6/2012	95	0		0	0	0
5/31/2012	175	0		0	0	0
8/3/2012	105	0		0	0	0
11/8/2012	135	0		0	0	0
3/12/2013	158	0		0	0	0
6/21/2013	330	0		0	0	0
9/19/2013	130	0		0	0	0
12/9/2013	198	0		0	0	0
4/7/2014	140	0		0	0	0
6/9/2014	241	0		0	0	0
9/19/2014	225	0		0	0	0
11/14/2014	262	0		0	0	0
4/2/2015	178	0		0	0	0
9/15/2015	221	0		0	0	0
11/30/2015	261	0		0	0	0
12/8/2015	223	0		0	0	0
3/23/2016	145	0		0	0	0
5/13/2016	178	0		0	0	0
8/5/2016	338	0		0	0	0
11/22/2016	249	0		0	0	0
4/28/2017	216	0		0	0	0
7/18/2017	155	0		0	0	0
9/6/2017	196	0		0	0	0
2/21/2018	257	0	0	0	0	0
6/29/2018	163	0	0	0	0	0
11/30/2018	174	0	0	0	0	0
5/14/2019	122	0	0	0	0	0
7/31/2019	133	0	0	0	0	0
12/27/2019	87	0	0	0	0	0
5/21/2020	102	0	0	0	0	0
7/16/2020	100	0	0	0	0	0
9/16/2020	75	0	0	0	0	0
11/16/2020	188	0	0	0	0	0
3/25/2021	77	0	0	0	0	0
6/30/2021	170	0	0	0	0	0
9/23/2021	165	0	0	0	0	0
12/17/2021	147	0	0	0	0	0

Date	Site 3 Best Efforts	Site 11 Pond 155	Site 20 P.deb	Site 20 T.car.	Site 21 Pond 48	Site 22 Pond 188
3/9/2022	133	0	0	0	0	0
4/21/2022	70	0	0	0	0	0
7/26/2022	67	0	0	0	0	0
11/29/2022	123	0	0	0	0	0
3/29/2023	120	0	0	0	0	0
6/29/2023	73	0	0	0	0	0
8/14/2023	65	0	0	0	0	0
11/20/2023	103	0	0	0	0	0
3/6/2024	310	0	0	0	0	0
7/11/2024	120	0	0	0	0	0
9/20/2024	60	0	0	0	0	0
11/20/2024	0	0	0	0	0	0
3/20/2025	65	0	0	0	0	0
7/10/2025	126	0	0	0	0	0
10/10/2025	80	0	0	0	0	0
12/30/2025	96	0	0	0	0	0
Mean	145	0	0	0	0	0

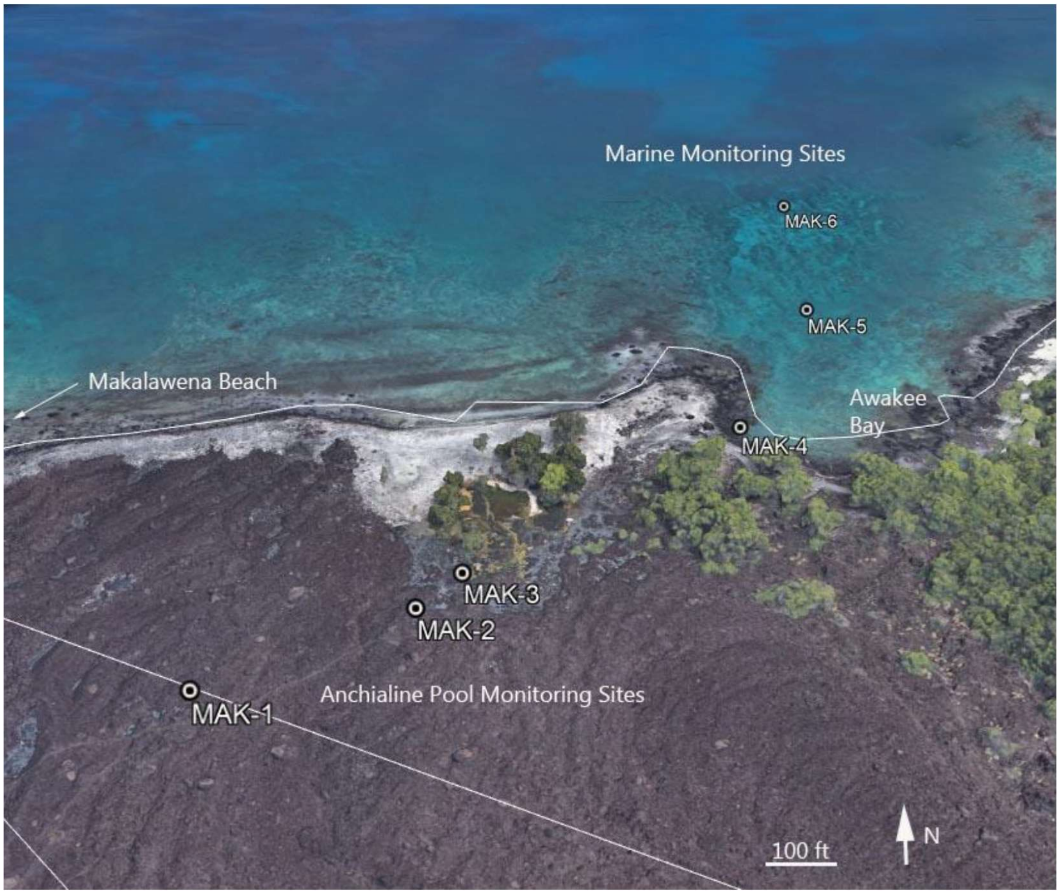
*NOTE: Halocaridina rubra apprarently impacted by some unknown variable. The orange crustose algae appeared to be grey and in poor condition. Other aquatic species in this pool appeared to be unaffected.

**NOTE: Sometime prior to the July 1997 survey someone apparently harvested the Theodoxus cariosa (or hihiwai) from this pool which drastically reduced the abundance of this species in the pool (1 or 2 individuals being counted for the

6.0 FIGURES

FIGURE 1. Map of Waikoloa Resorts Water Quality Monitoring Sites. Map showing the location of the twenty-five sites routinely sampled in this study (numbered circles). Note that 25 sites are shown; stations 8 and 16 are no longer routinely sampled. Station numbers 23, 24, 25 and 26 are new as of 2000 and were established to bring the monitoring program closer to conformance with the (then new) Department of Health regulations. Finally, Site 27 (not shown) is an irrigation holding pond located on the Beach Golf Course and was sampled from 1986 through 1993 and more recently from December 2013 to present. The boundaries of the Waikoloa Anchialine Pond Preserve Area (or WAPPA) are shown where sample numbers 9, 11, 21 and 22 are collected.

FIGURE 2. Makalawena-Awake'e Bay Monitoring Sites. These sites have been monitored annually since 1986 as the area and areas mauka are undeveloped.



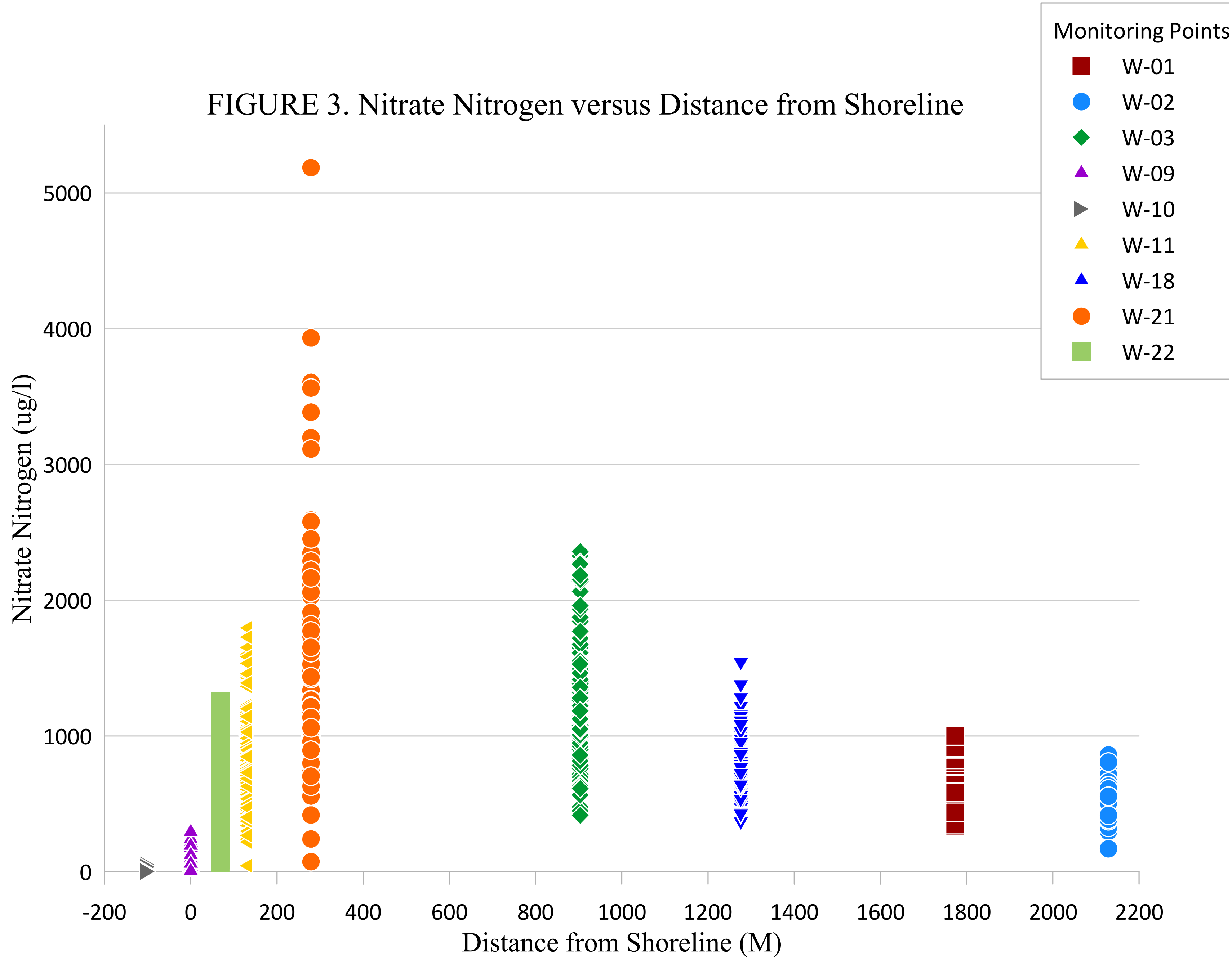


FIGURE 3. Nitrate Nitrogen versus Distance from Shoreline
Monitoring Points
W-01
W-02
W-03
W-09
W-10
W-11
W-18
W-21
W-22
Nitrate Nitrogen (ug/l)
5000
4000
3000
2000
1000
0
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Distance from Shoreline (M)

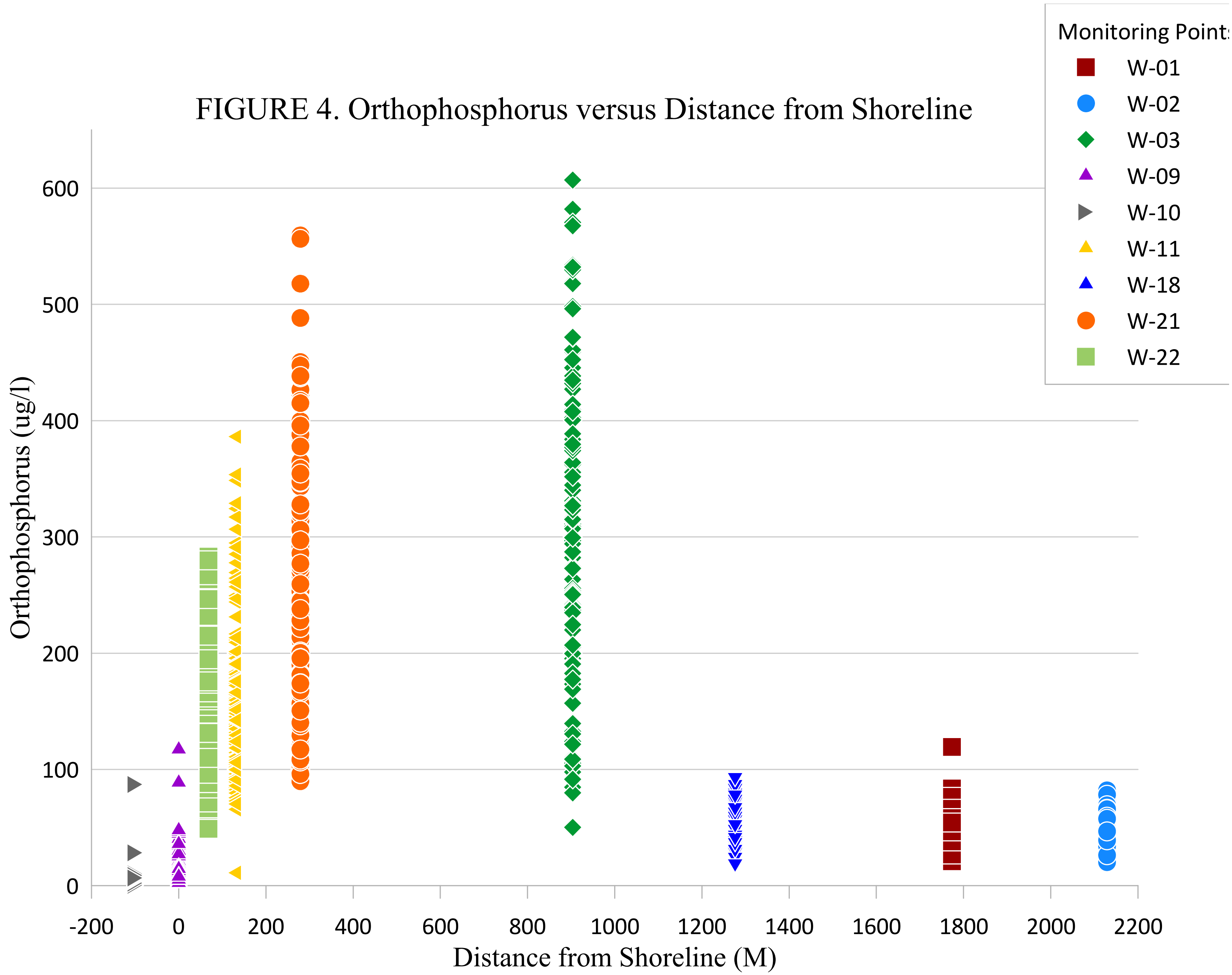


FIGURE 4. Orthophosphorus versus Distance from Shoreline
Monitoring Points
W-01
W-02
W-03
W-09
W-10
W-11
W-18
W-21
W-22
Orthophosphorus (ug/l)
0
100
200
300
400
500
600
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Distance from Shoreline (M)

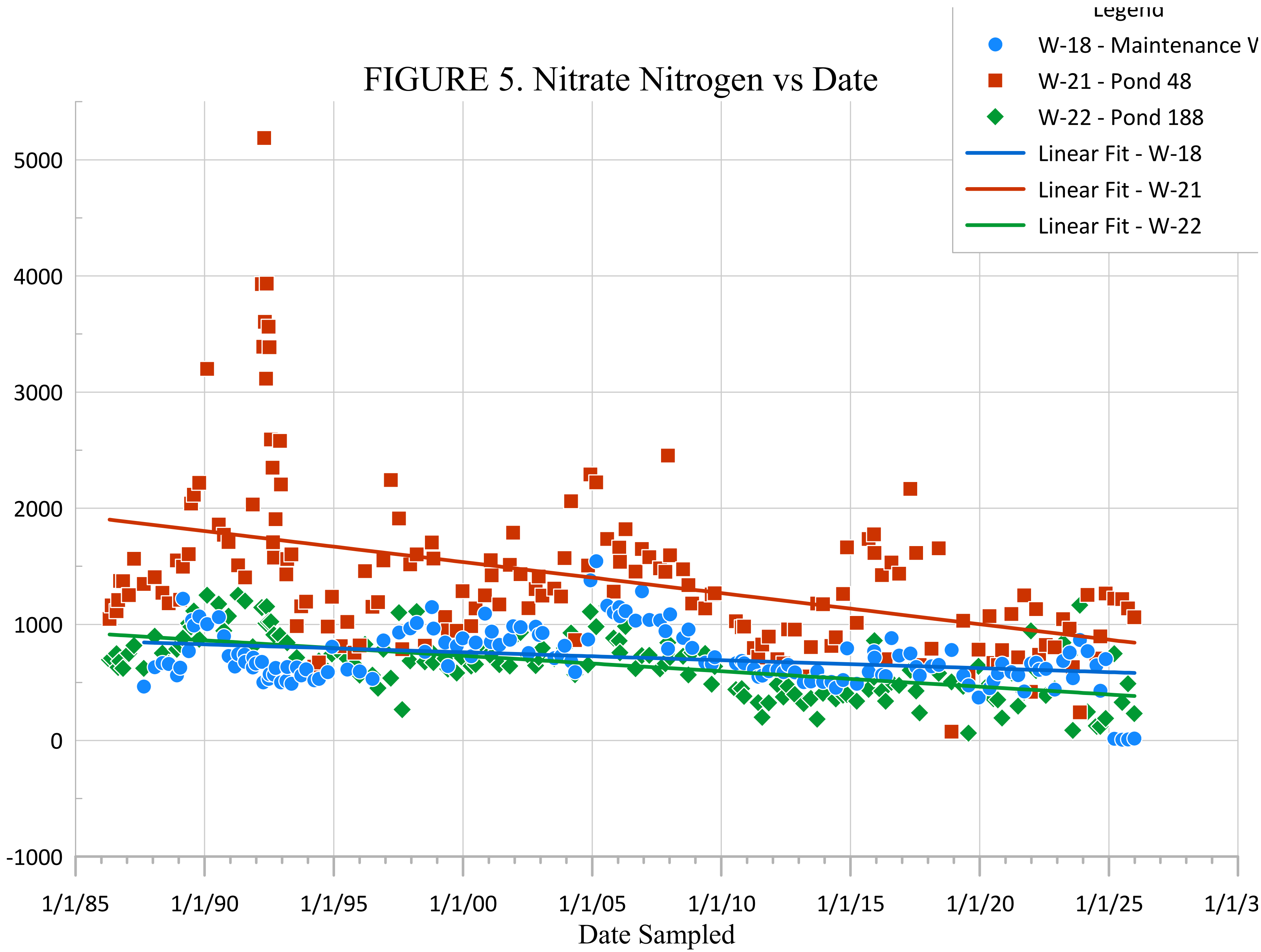


FIGURE 5. Nitrate Nitrogen vs Date
Legend
W-18 - Maintenance V
W-21 - Pond 48
W-22 - Pond 188
Linear Fit - W-18
Linear Fit - W-21
Linear Fit - W-22
5000
4000
3000
2000
1000
0
-1000
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
1/1/15
1/1/20
1/1/25
1/1/3
Date Sampled

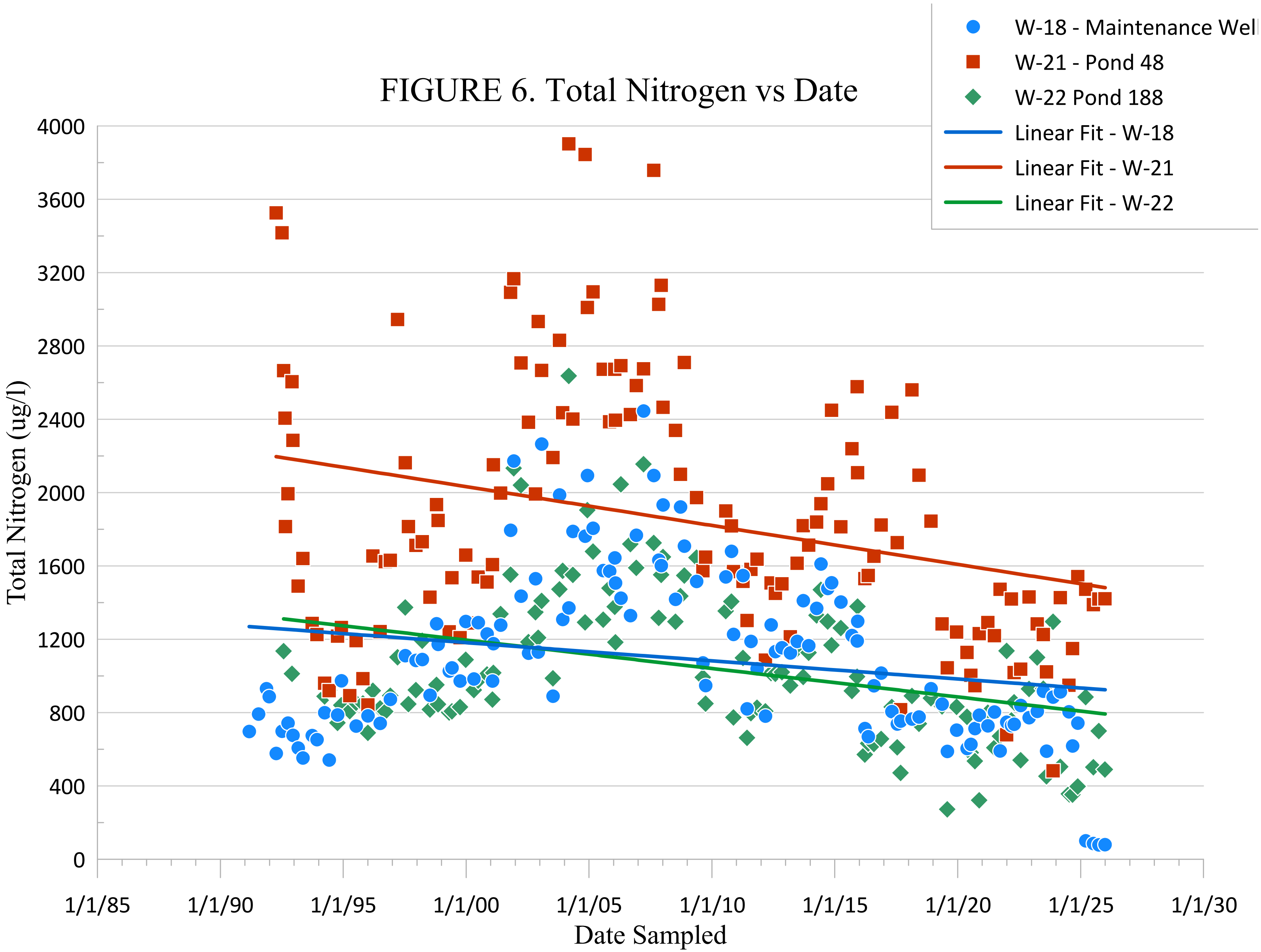


FIGURE 6. Total Nitrogen vs Date
W-18 - Maintenance Well
W-21 - Pond 48
W-22 Pond 188
Linear Fit - W-18
Linear Fit - W-21
Linear Fit - W-22
Total Nitrogen (ug/l)
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
1/1/15
1/1/20
1/1/25
1/1/30
Date Sampled

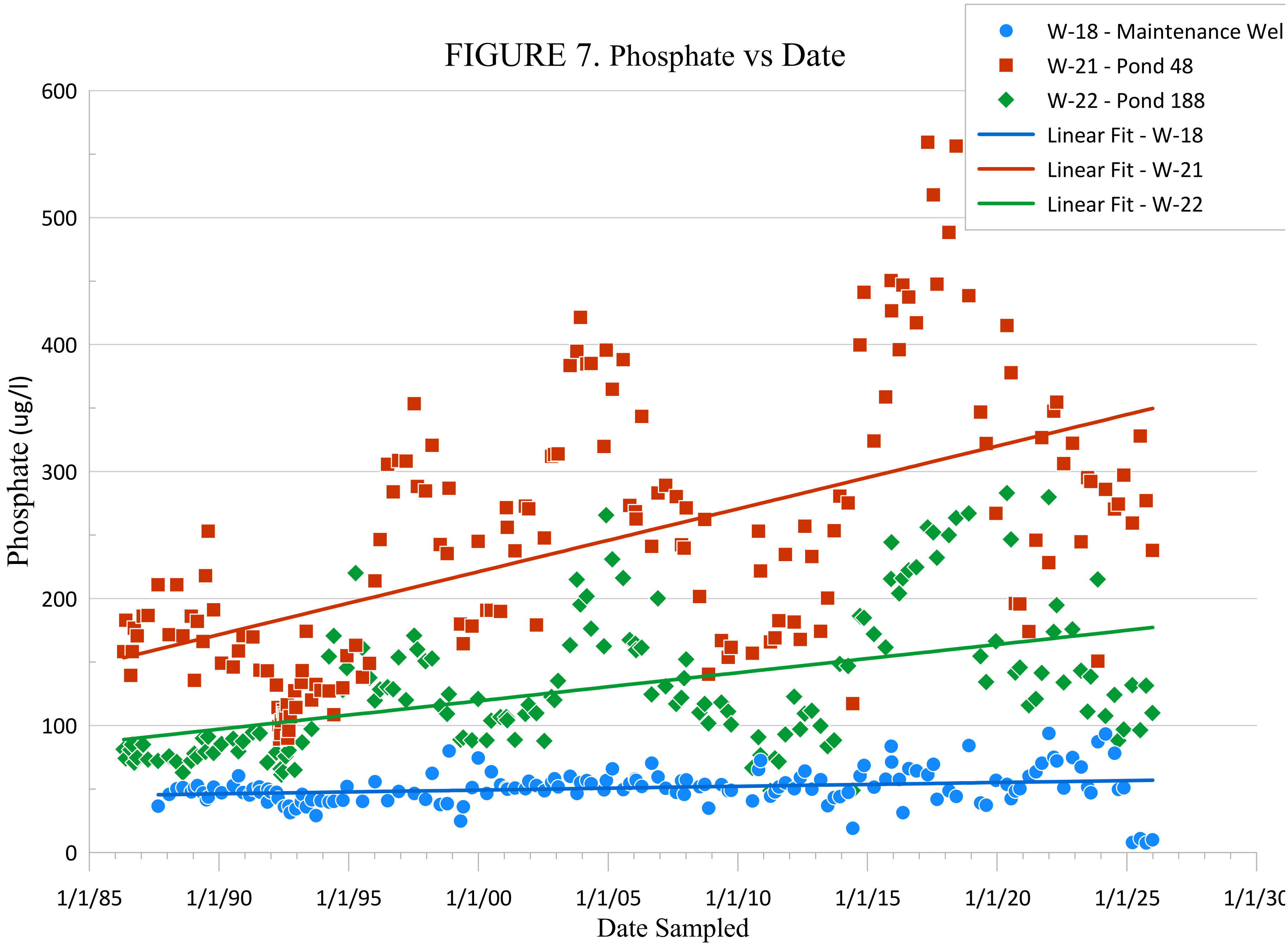


FIGURE 7. Phosphate vs Date
W-18 - Maintenance Wel
W-21 - Pond 48
W-22 - Pond 188
Linear Fit - W-18
Linear Fit - W-21
Linear Fit - W-22
600
500
400
300
200
100
0
Phosphate (ug/l)
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
1/1/15
1/1/20
1/1/25
1/1/30
Date Sampled

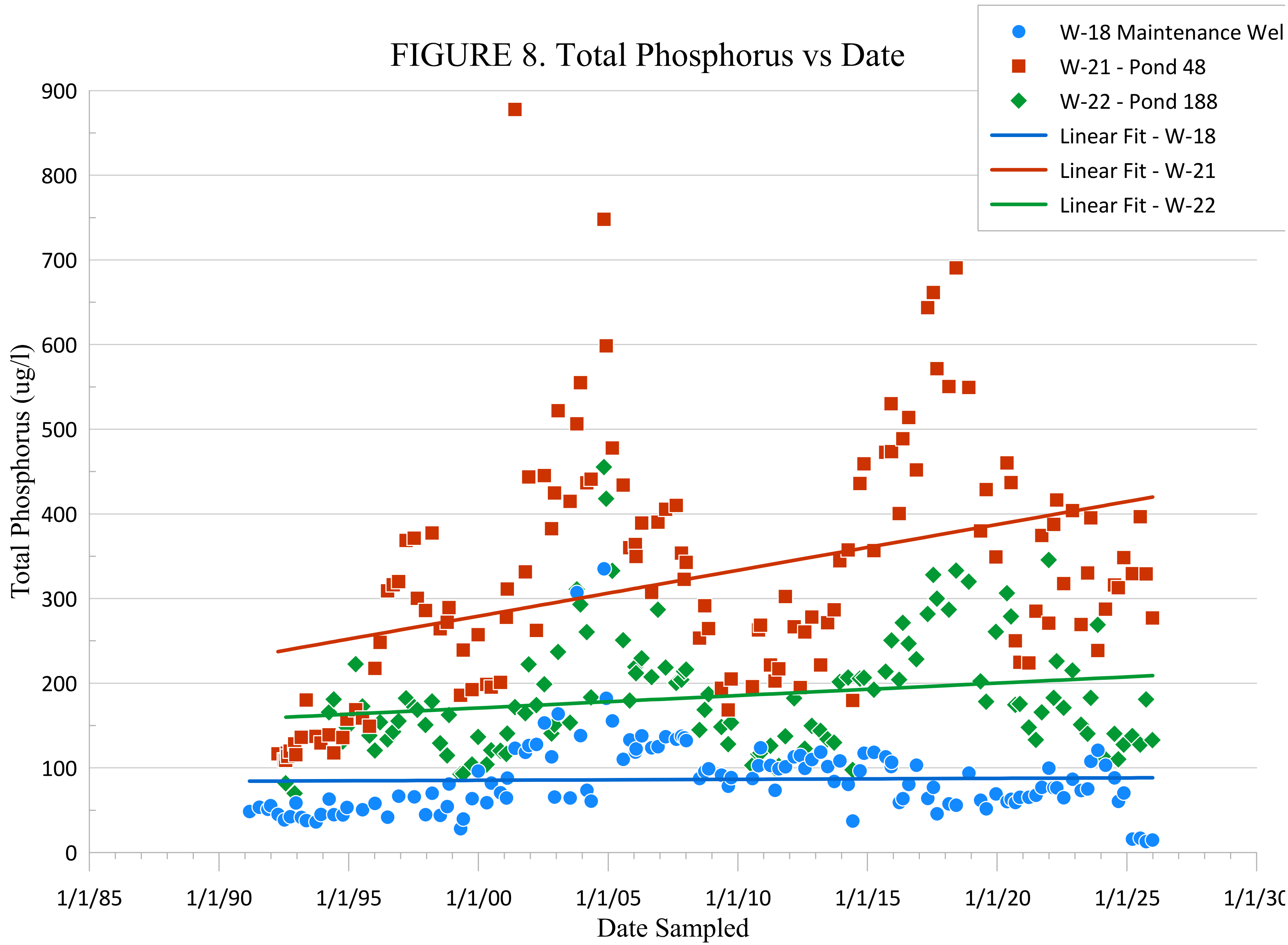


FIGURE 8. Total Phosphorus vs Date
W-18 Maintenance Wel
W-21 - Pond 48
W-22 - Pond 188
Linear Fit - W-18
Linear Fit - W-21
Linear Fit - W-22
Total Phosphorus (ug/l)
900
800
700
600
500
400
300
200
100
0
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
1/1/15
1/1/20
1/1/25
1/1/30
Date Sampled

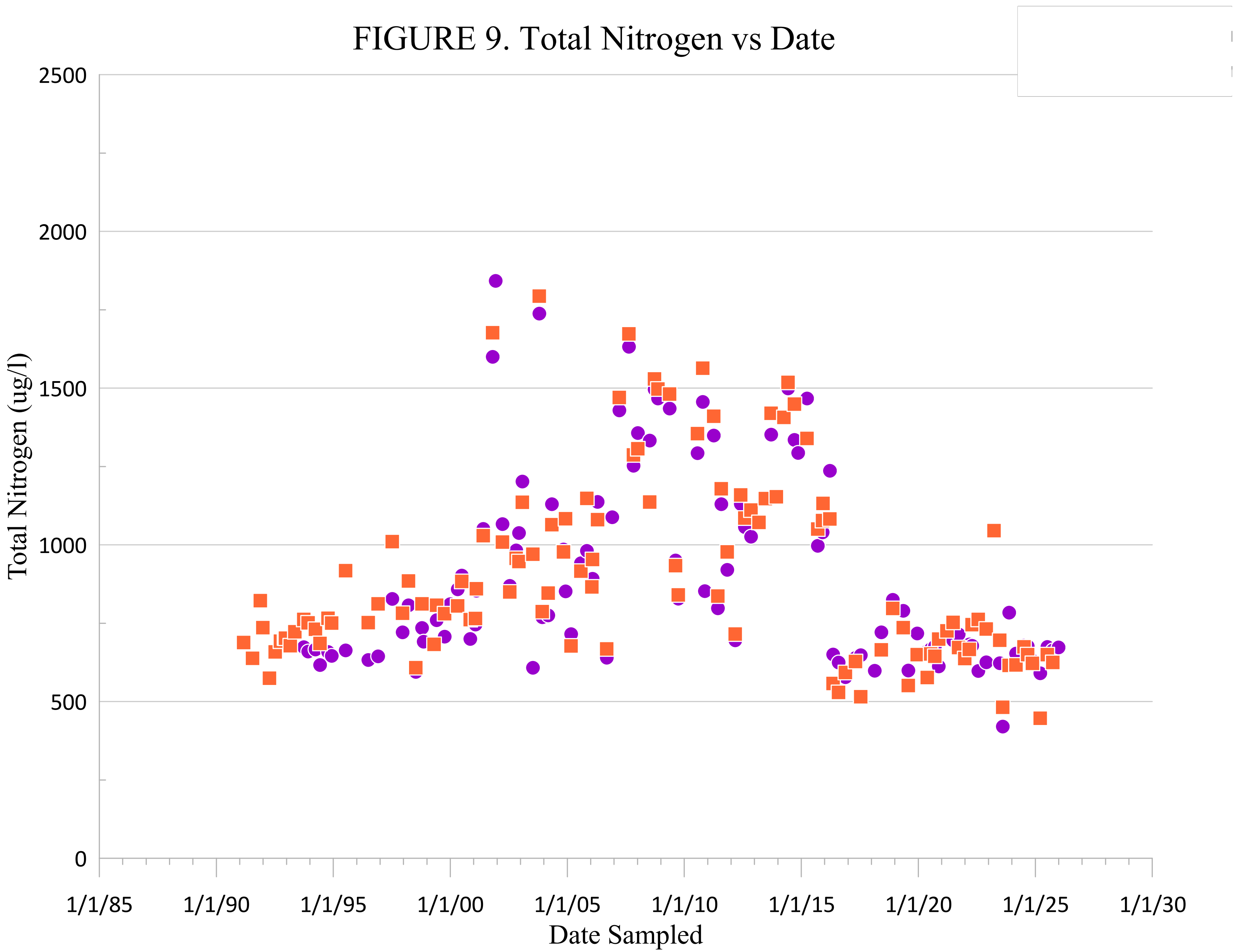


FIGURE 9. Total Nitrogen vs Date
2500
2000
1500
1000
500
0
Total Nitrogen (ug/l)
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
1/1/15
1/1/20
1/1/25
1/1/30
Date Sampled

FIGURE 10. Total Phosphorus vs Date

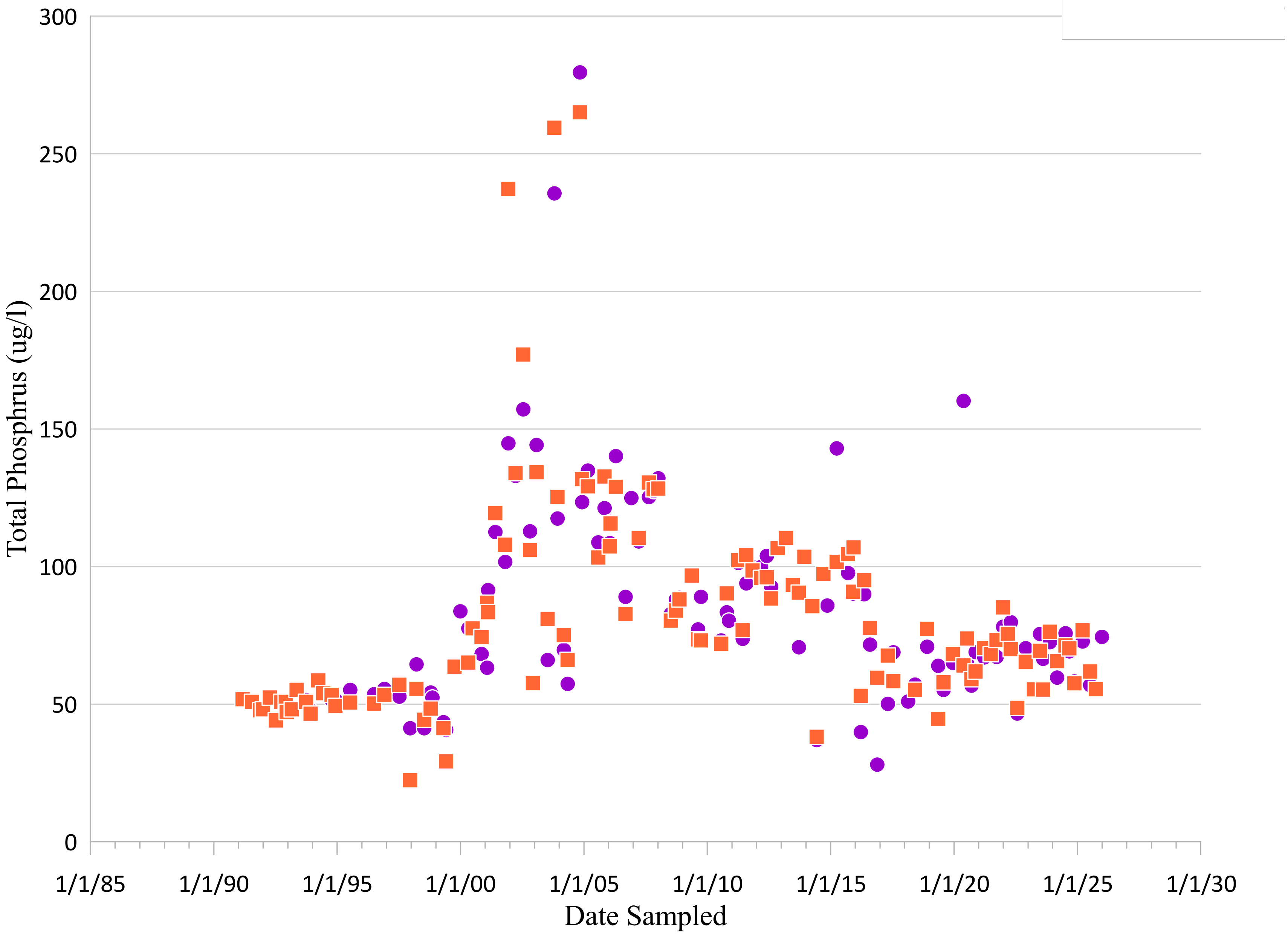


FIGURE 11. Volume of Irrigation Water and WWTP R-1 Discharge Used for Irrigation

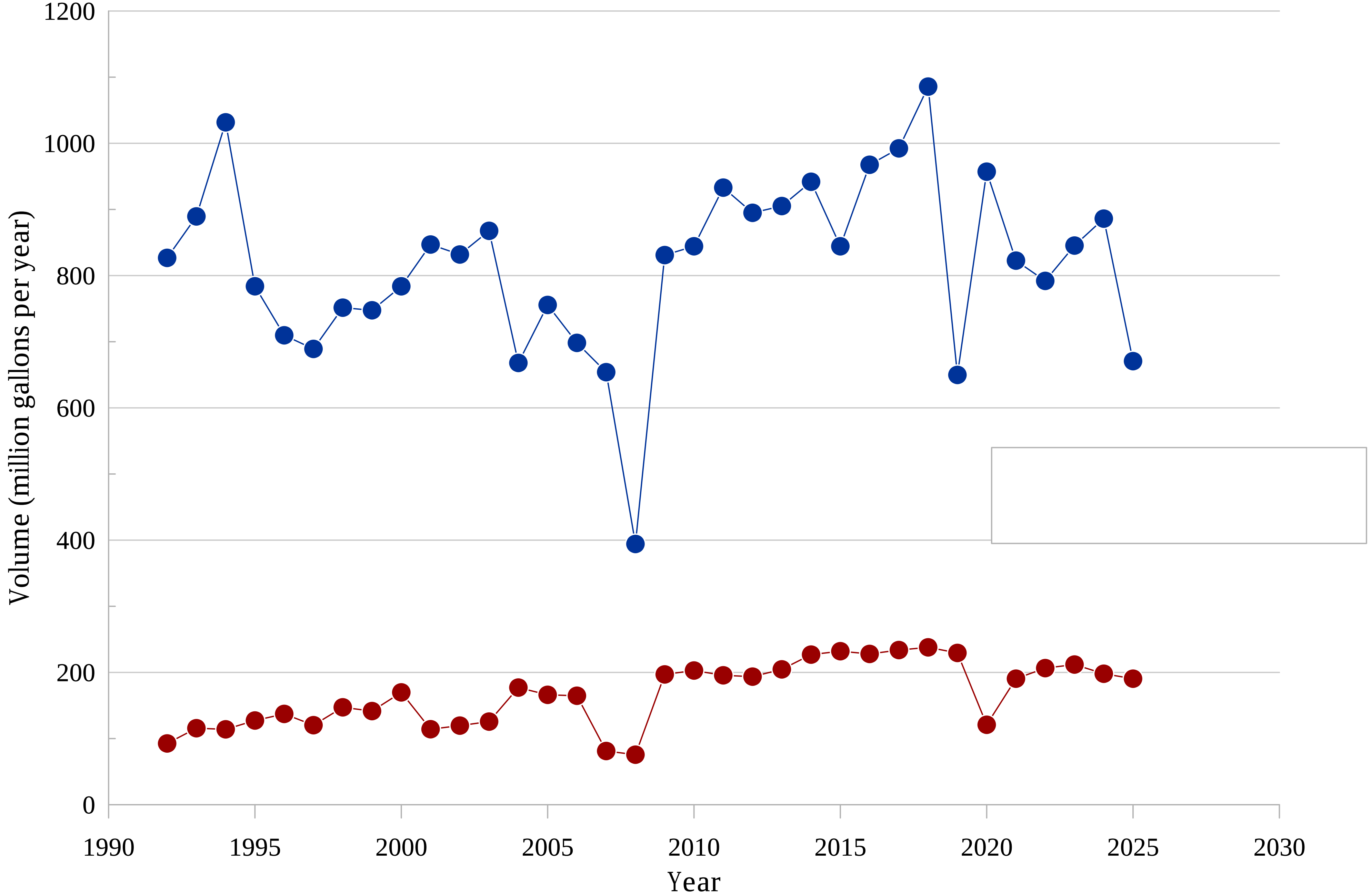
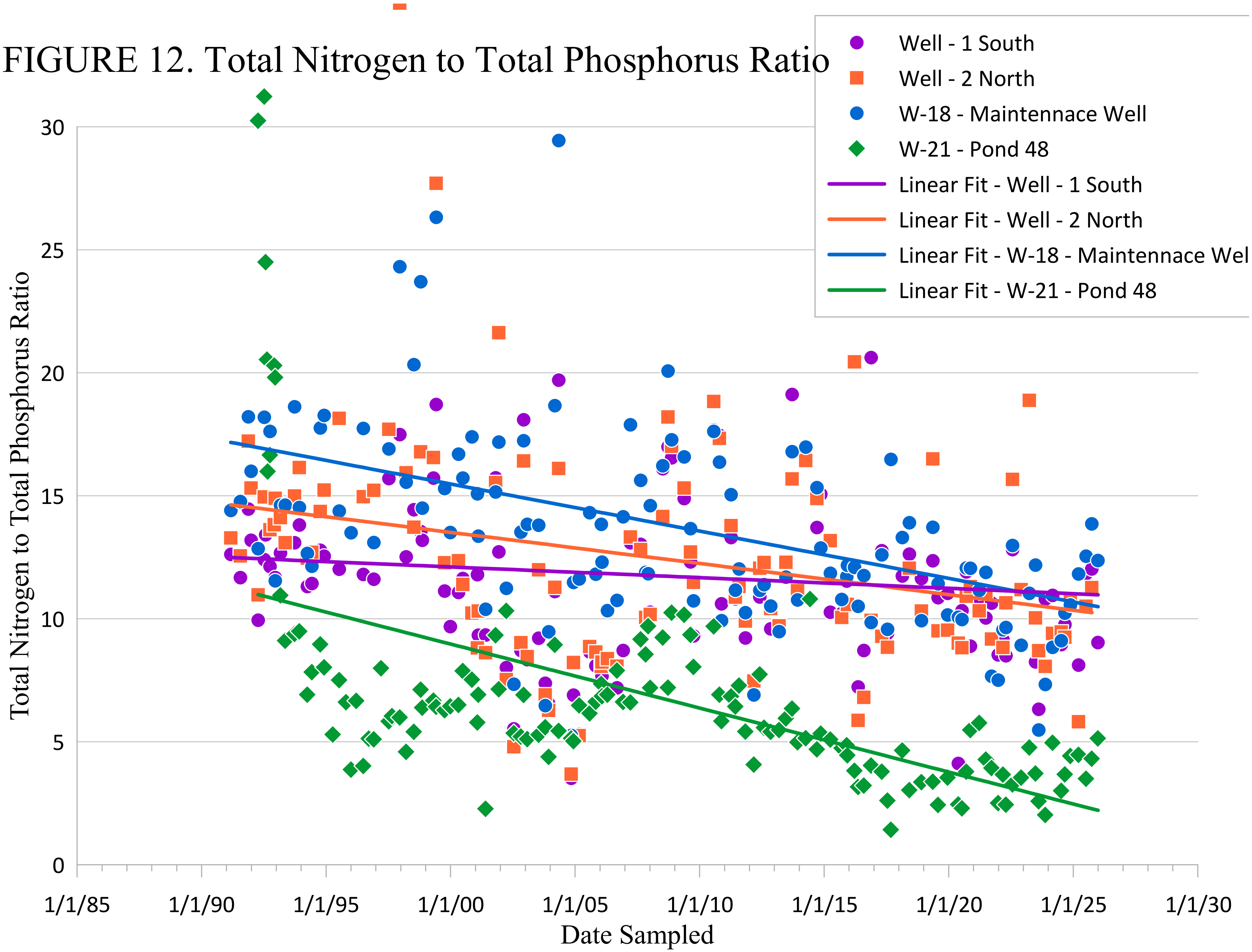


FIGURE 12. Total Nitrogen to Total Phosphorus Ratio



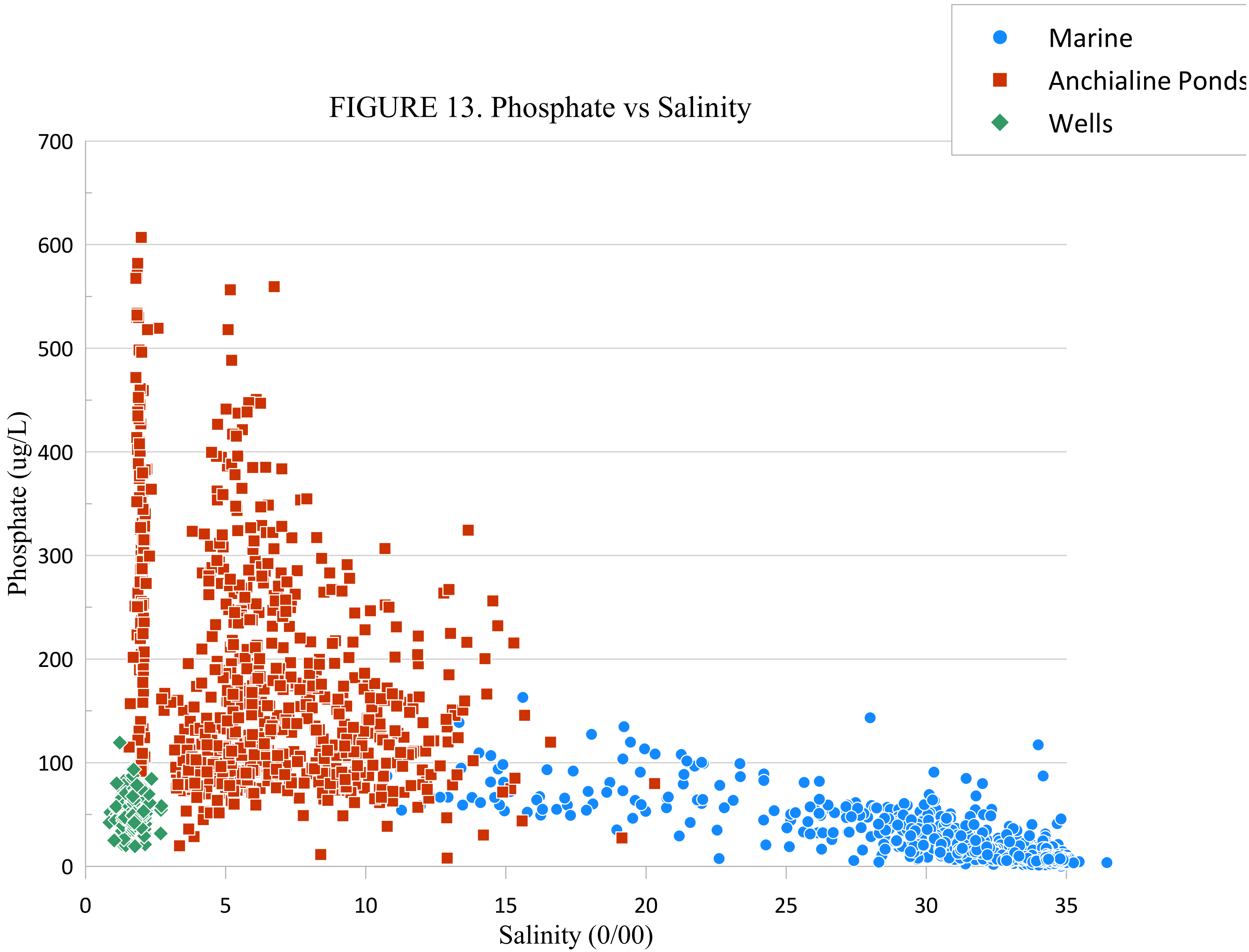

Marine
Anchialine Ponds
Wells
FIGURE 13. Phosphate vs Salinity
700
600
500
400
300
200
100
0
Phosphate (ug/L)
0
5
10
15
20
25
30
35
Salinity (0/00)


FIGURE 14. Nitrate Nitrogen vs Salinity
Marine
Anchialine Ponds
Wells
Nitrate Nitrogen (ug/L)
Salinity (0/00)
0
400
800
1200
1600
2000
2400
2800
0
5
10
15
20
25
30
35

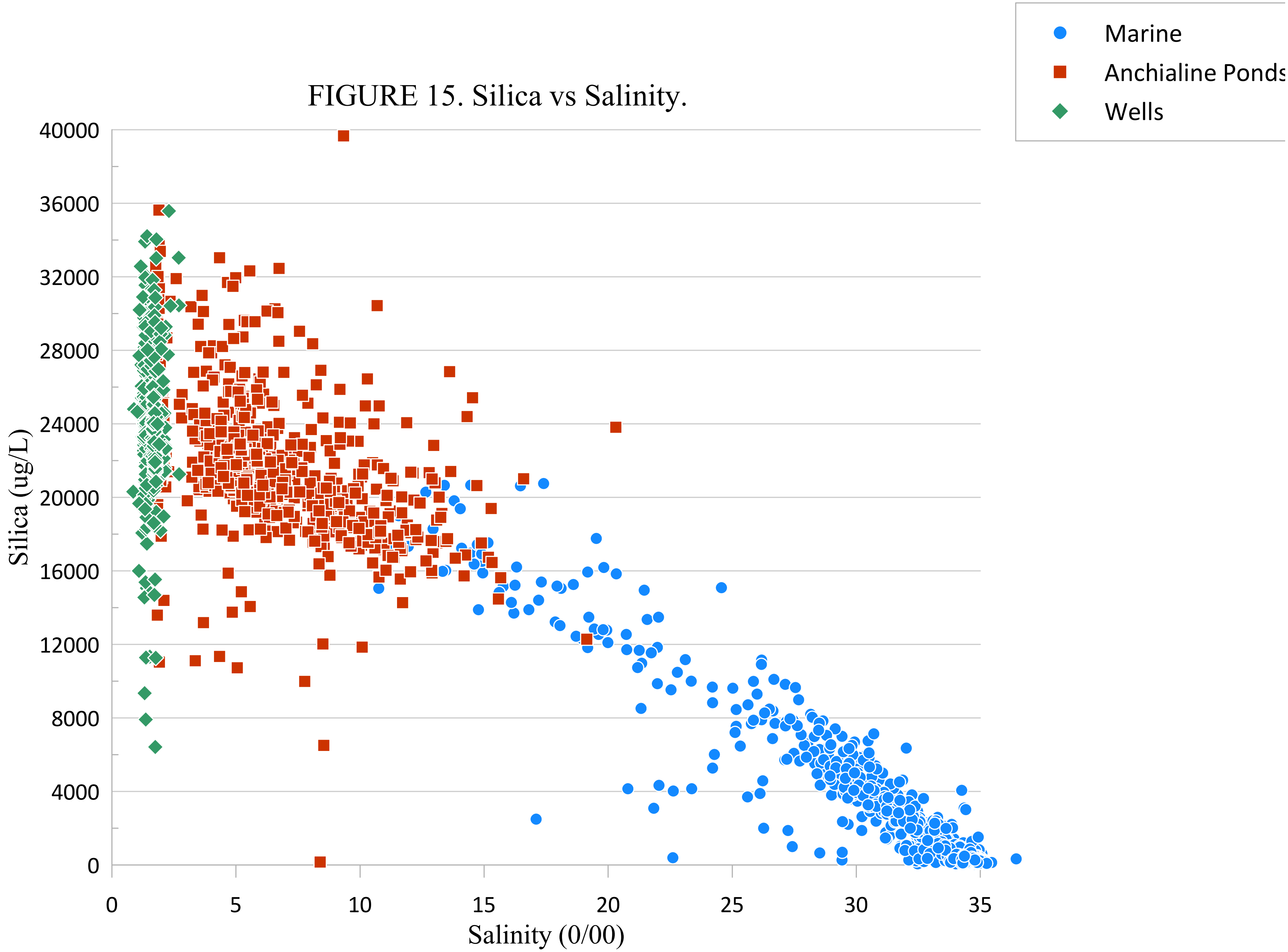


FIGURE 15. Silica vs Salinity.

Table 1 - Summary of the water quality parameters as measured at 25 sites at Waikoloa on March 20th 2025. Samples were from the ocean, anchialine pools, wells and fishponds. Given in the body of the table are the concentrations of dissolved nutrients in ug/l unless otherwise stated.
Table 2 - Calulated Geomeans are reported for each ocean transect and for the totality of all ocean samples.

ND = Below limits of detection.
* Note that chlorophyll-a samples are not collected from wells.
** Note Ocean salinity results less than 32 parts per thousand are indicated in bold and underlined.

Table 1

Station Group Name	Station ID (Point ID)	Station Name	Date Sampled	Field Data				General Chemistry										
				Dissolved Oxygen (%)	Field-PH (SU)	Temperature (C)	Turbidity (ntu)	Ammonia (ug/L)	Chl (ug/L)	Nitrate + Nitrite (ug/L)	pH (0/14)	Phosphate (ug/L)	Salinity (0/00)	Silicate (ug/L)	TON (ug/L)	TOP (ug/L)	Total Dissolved Nitrogen (ug/L)	Total Dissolved Phosphorus (ug/L)
Ocean Samples	**W-04**	**Waiulua Bay Shoreline**	03/20/2025	94.2	7.9	31.3	0.38	7.45	1.41	689.27	7.98	134.64	**19.22**	13479.7	66.46	3.31	763.17	137.94
Ocean Samples	**W-05**	**Waiulua Bay 50m**	03/20/2025	109.2	8.08	30.7	0.22	16.17	0.49	307.34		57.42	**27.14**	9824.77	55.6	19.19	379.11	76.6
Ocean Samples	**W-06**	**Waiulua Bay 100m Surface**	03/20/2025	103.7	8.1	31.1	0.21	14.68	0.29	315.58		56	**27.55**	9657.55	63.33	15.74	393.6	71.74
Ocean Samples	**W-07**	**Waiulua Bay 100m Bottom**	03/20/2025	110.5	8.2	30.9	0.43	5.4	0.25	38.28		13.53	34.09	973.77	71.03	6.73	114.72	20.26
Ocean Samples	**W-23**	**Waiulua Bay 300m**	03/20/2025	105.7	8.21	30.5	0.23	7.67	0.27	84.73		19.64	33.33	2193.86	68.37	6.42	160.77	26.06
Ocean Samples	**W-09**	**WAPPA - Shoreline**	03/20/2025	112.9	8.3	26.6	0.44	4.22	0.87	122.85	8.27	35.83	**30.16**	4760.36	116.55	4.7	243.61	40.53
Ocean Samples	**W-10**	**WAPPA - 100m**	03/20/2025	105.3	8.25	26.9	0.27	2.34	0.34	6.84		6.65	34.34	405.95	70.11	7.44	79.3	14.09
Ocean Samples	**W-24**	**WAPPA - 200m**	03/20/2025	108.7	8.3	27.3	0.22	4.06	0.22	3.89		5.99	34.78	181.26	75.91	8.68	83.86	14.67
Ocean Samples	**W-26**	**WAPPA - 300m**	03/20/2025	102	8.26	27.3	0.19	3.29	0.25	4.59		4.93	34.86	109.62	61.15	8.56	69.04	13.48
Ocean Samples	**W-12**	**Anaehoomalu (A) Bay Shoreline**	03/20/2025	94.5	8.27	32	0.39	8.18	1.09	243.83	8.18	32.43	**26.68**	10099.7	76.92	23.8	328.93	56.23
Ocean Samples	**W-13**	**Anaehoomalu (A) Bay 50m Surface**	03/20/2025	101.7	8.26	29.3	0.38	10.05	0.39	83.93		17.13	32.12	3445.76	59.51	4.58	153.49	21.71
Ocean Samples	**W-14**	**Anaehoomalu (A) Bay 100m Surface**	03/20/2025	101.6	8.25	28.8	0.35	7.52	0.37	38.99		8.03	33.14	1565.09	76.85	10.28	123.37	18.31
Ocean Samples	**W-19**	**Anaehoomalu (A) Bay 100m Bottom**	03/20/2025	103.5	8.24	29	0.59	10.87	0.41	14.84		7.96	34.32	558.94	76.08	7.81	101.79	15.76
Ocean Samples	**W-25**	**Anaehoomalu (A) Bay 300m**	03/20/2025	100.9	8.25	28.9	0.36	6.83	0.33	12.54		6.88	34.58	462.17	70.01	7.83	89.37	14.71
Wells	**W-01**	**Well - 1 South**	03/20/2025	105.9	7.8	25.4	0.31	ND		563.53		38.56	1.34	20966.4	27.21	34.19	590.74	72.75
Wells	**W-02**	**Well - 2 North**	03/20/2025	103.9	8.03	25.8	1.31	1.6		415.99		57.49	1.1	19670	29.15	19.33	446.73	76.81
Wells	**W-18**	**Maintenance Well**	03/20/2025	135.5	7.82	26.7	0.54	32.69		618.25		48.85	1.69	18604.6	252.22	27.54	903.16	76.39
Anchialine Ponds	**W-03**	**Best Efforts**	03/20/2025	165.2	8.08	28.1	0.61	35.25	0.37	2185.56		567.46	1.8	18478.2	160.73	50.83	2381.54	618.28
Anchialine Ponds	**W-11**	**Pond 155**	03/20/2025	118.2	7.77	26.6	0.75	13.02	1.89	847.71		124.1	6.21	20853.6	191.84	33.15	1052.56	157.25
Anchialine Ponds	**W-20**	**Unnamed Pool**	03/20/2025	166.3	8	29.1	0.6	53.79	4.99	563.5		51.39	4.46	20662.1	142.15	32.14	759.44	83.53
Anchialine Ponds	**W-21**	**Pond 48**	03/20/2025	133.8	7.66	25.7	0.39	30.34	0.87	1220.76		259.46	5.69	23376.3	221.32	69.81	1472.43	329.27
Anchialine Ponds	**W-22**	**Pond 188**	03/20/2025	92.8	7.34	25.5	0.29	9.78	1.1	747.31		131.75	8.35	16384	127.55	5.97	884.64	137.73
Fishponds	**W-15**	**Makaha**	03/20/2025	157	8.01	29	7.13	8.61	29.96	3.1		37.32	8.34	19512.3	482.83	48.25	494.54	85.56
Fishponds	**W-17**	**Kuualii**	03/20/2025	162.4	8.49	30.3	3.56	6.89	28.66	0.53		34.94	8.07	16247.9	379.73	13.2	387.15	48.14
Irrigation Lake	**W-27**	**Irrigation Lake**	03/20/2025	127.2	7.97	27.1	0.69	7.45	26.98	3682.58		935.49	1.4	17822.6	490.64	107.85	4180.68	1043.34

Table 2

Station Name		Date Sampled	Field Data				General Chemistry										
			Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	pH	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
			%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Geomean	Waiulua Bay	03/20/2025	104.50	8.10	30.90	0.28	9.40	0.42	185.02		40.94	**27.71**	######	64.73	8.45	291.38	52.54
Geomean	WAPPA	03/20/2025	107.15	8.28	27.02	0.27	3.39	0.36	11.07		9.16	33.48	442.67	78.48	7.14	102.84	18.33
Geomean	Anaehoomalu (A) Bay	03/20/2025	100.39	8.25	29.58	0.41	8.56	0.46	43.09	8.18	11.96	32.03	######	71.54	9.27	141.47	22.02
Geomean	All Ocean Samples	03/20/2025	103.75	8.20	29.28	0.32	6.79	0.42	49.17	8.14	17.20	**30.80**	######	70.88	8.33	167.17	28.51

Summary of compliance for the first sampling event of 2025. Waikoloa data from Ocean Transect with the Department of Health West Hawai‘i regional water quality standards applied.
Compliance for total nitrogen, total phosphorus, and nitrate nitrogen are determined by a linear regression fit, and compared to the criteria.
Compliance for ammonia nitrogen, chlorophyll-a and turbidity are determined using geomean results against fixed values.
The presence of one or more monitoring location on a particular ocean transect with salinity of less than or equal to 32 parts per thousand requires exceedance analysis using a regression approach defined within the HAR 11-54.
The results of the Geomean analysis within Apendix 1 identified that all ocean trancesects had atleast one or more monitoring location that were under the 32 parts per thousand limit requiring analysis of all ocean transects.
Data presented in ug/L unless otherwise noted

Station Group Name	Date Sampled	Analysis Method	Parameter	DOH Not To Exceed The Absolute Value	Calculated 95% Upper Limit Or Value	Geomean Results	Exceeds Standard ?
Waiulua Bay	3/20/2025	Regression	Total Nitrogen	-40.35	-27.41		Yes
Waiulua Bay	3/20/2025	Regression	Total Phosphorous	-2.86	-7.48		No
Waiulua Bay	3/20/2025	Regression	Nitrate + Nitrite	-31.92	-29.39		Yes
Waiulua Bay	3/20/2025	Regression	Orthophosphorous	-3.22	-5.72		No
Waiulua Bay	3/20/2025	Geomean	Ammonia Nitrogen (ug/	2.5		9.40	Yes
Waiulua Bay	3/20/2025	Geomean	Chlorophyll (ug/l)	0.3		0.42	Yes
Waiulua Bay	3/20/2025	Geomean	Turbidity (ntu)	0.1		0.28	Yes
WAPPA	3/20/2025	Regression	Total Nitrogen	-40.35	312.55		Yes
WAPPA	3/20/2025	Regression	Total Phosphorous	-2.86	26.33		Yes
WAPPA	3/20/2025	Regression	Nitrate + Nitrite	-31.92	20.32		Yes
WAPPA	3/20/2025	Regression	Orthophosphorous	-3.22	16.65		Yes
WAPPA	3/20/2025	Geomean	Ammonia Nitrogen (ug/	2.5		3.39	Yes
WAPPA	3/20/2025	Geomean	Chlorophyll (ug/l)	0.3		0.36	Yes
WAPPA	3/20/2025	Geomean	Turbidity (ntu)	0.1		0.27	Yes
Anaehoomalu (A) Bay	3/20/2025	Regression	Total Nitrogen	-40.35	-15.48		Yes
Anaehoomalu (A) Bay	3/20/2025	Regression	Total Phosphorous	-2.86	-1.91		Yes
Anaehoomalu (A) Bay	3/20/2025	Regression	Nitrate + Nitrite	-31.92	-9.18		Yes
Anaehoomalu (A) Bay	3/20/2025	Regression	Orthophosphorous	-3.22	2.65		Yes
Anaehoomalu (A) Bay	3/20/2025	Geomean	Ammonia Nitrogen (ug/	2.5		8.56	Yes
Anaehoomalu (A) Bay	3/20/2025	Geomean	Chlorophyll (ug/l)	0.3		0.46	Yes
Anaehoomalu (A) Bay	3/20/2025	Geomean	Turbidity (ntu)	0.1		0.41	Yes

Appendix 3.
Summary of visual censuses of red shrimp or opae'ula (Halocaridina rubra) in 0.1 m2 quadrats placed in anchialine pools at Waikoloa for the 20th March 2025 survey period.

Site	Site Name	Time	Shrimp Census	Comments
W-11	Pond 155	9:49:00 AM	0 $0.1m^2$	No shrimp, fish present
W-18	Maintenance	11:04:00 AM	60 $0.1m^2$	
W-21	Pond 48	10:07:00 AM	0 $0.1m^2$	No shrimp, fish present
W-22	Pond 188	9:56:00 AM	0 $0.1m^2$	No shrimp, fish present
W-20	Unnamed	12:18:00 PM	0 $0.1m^2$	No shrimp, fish present
W-3	Best Efforts	11:23:00 AM	65 $0.1m^2$	

Table 1 - Summary of the water quality parameters as measured at 25 sites at Waikoloa on July 10th 2025. Samples were from the ocean, anchialine pools, wells and fishponds. Given in the body of the table are the concentrations of dissolved nutrients in ug/l unless otherwise stated.
Table 2 - Calulated Geomeans are reported for each ocean transect and for the totality of all ocean samples.

ND = Below limits of detection.
* Note that chlorophyll-a samples are not collected from wells.
** Note Ocean salinity results less than 32 parts per thousand are indicated in bold and underlined.

Table 1

Station Group Name	Station ID (Point ID)	Station Name	Date Sampled	Field Data				General Chemistry										
				Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	pH	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
				%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Ocean Samples	W-04	Waiulua Bay Shoreline	07/10/2025	101.1	8.12	30.7	0.46	2.72	0.17	685.33	8.08	66.24	**14.6**	16364.6	51.19	19.18	739.24	85.42
Ocean Samples	W-05	Waiulua Bay 50m	07/10/2025	110.1	8.08	29.5	0.48	9.63	0.21	190.88		36.31	**29.6**	5966.93	67.74	14.1	268.26	50.41
Ocean Samples	W-06	Waiulua Bay 100m Surface	07/10/2025	105.4	8.1	29.3	0.4	11	0.15	146.62		28.02	**30.83**	5222.64	77.56	15.27	235.17	43.29
Ocean Samples	W-07	Waiulua Bay 100m Bottom	07/10/2025	102.5	8.09	29.1	0.34	3.36	0.23	8.49		10.77	34.58	272.28	69.56	5.91	81.41	16.68
Ocean Samples	W-23	Waiulua Bay 300m	07/10/2025	104	8.05	29.3	0.5	4.54	0.16	39.67		15.47	33.8	1044.92	68.25	3.67	112.46	19.14
Ocean Samples	W-09	WAPPA - Shoreline	07/10/2025	123.7	8.13	29.1	0.97	11.97	2.94	59.54	8.33	47.65	**27.33**	7943.46	125.07	0.81	196.58	48.46
Ocean Samples	W-10	WAPPA - 100m	07/10/2025	101.8	8.08	23.5	0.36	2.49	0.16	3.76		8.87	34.85	243.21	70.52	5.73	76.77	14.6
Ocean Samples	W-24	WAPPA - 200m	07/10/2025	99.6	8.1	27.6	0.23	2.37	0.13	3.72		6.3	34.86	180.56	69.54	5.76	75.63	12.05
Ocean Samples	W-26	WAPPA - 300m	07/10/2025	100.3	8.1	27.5	0.39	2.54	0.13	2.32		6.3	34.88	137.61	68.32	6	73.18	12.3
Ocean Samples	W-12	Anaehoomalu (A) Bay Shoreline	07/10/2025	114.3	8.1	30.2	0.75	7.25	0.71	69.98	8.37	16.23	**31.15**	3716.29	76.81	5.68	154.05	21.91
Ocean Samples	W-13	Anaehoomalu (A) Bay 50m Surface	07/10/2025	112.2	8.11	29.2	0.7	6.2	0.22	13.87		8.54	33.94	789.84	73.01	4.28	93.08	12.82
Ocean Samples	W-14	Anaehoomalu (A) Bay 100m Surface	07/10/2025	110.1	7.98	28.7	0.53	4.74	0.17	6.84		9.85	34.51	448.88	73.48	5.66	85.06	15.51
Ocean Samples	W-19	Anaehoomalu (A) Bay 100m Bottom	07/10/2025	110	8.1	28.6	0.61	6.26	0.17	6.41		10.96	34.87	499.86	73.2	6.06	85.86	17.02
Ocean Samples	W-25	Anaehoomalu (A) Bay 300m	07/10/2025	106.4	8.09	28.5	0.49	3.7	0.17	5.7		8.51	34.89	334.83	69.08	4.18	78.49	12.69
Wells	W-01	Well - 1 South	07/10/2025	103.7	8.37	26.7	1.27	2.14		570.095		38.15	1.31	19292.4	101.941	18.82	674.175	56.97
Wells	W-02	Well - 2 North	07/10/2025	103.1	8.49	28	4.03	1.31		556.007		39.11	1.34	19361.4	92.6199	22.71	649.936	61.82
Wells	W-18	Maintenance Well	07/10/2025	123	8.11	27.7	0.45	4.44		726.07		43.68	1.78	20845.8	12.68	15.58	743.2	59.25
Anchialine Ponds	W-03	Best Efforts	07/10/2025	131	8.06	27.9	0.64	8.4341	0.31	1766.98		326.9	1.97	20927.8	2.84	59.63	1778.26	386.53
Anchialine Ponds	W-11	Pond 155	07/10/2025	97.4	7.63	28.4	0.39	14.87	0.45	743.86		142.34	7.91	19730.3	124.34	50.11	883.07	192.45
Anchialine Ponds	W-20	Unnamed Pool	07/10/2025	101	7.67	28.6	0.36	5.46	0.25	860.3		59.95	5.31	20673.2	81.03	23.55	946.79	83.5
Anchialine Ponds	W-21	Pond 48	07/10/2025	125.6	7.92	27.5	0.53	24.93	2.08	1216.46		327.95	7.01	18328	147.18	68.59	1388.57	396.54
Anchialine Ponds	W-22	Pond 188	07/10/2025	119.1	7.71	27.5	1	22.63	1.91	327.19		96.3	11.32	16739	152.34	31.07	502.17	127.37
Fishponds	W-15	Makaha	07/10/2025	143.1	8.65	31.1	2.59	31.29	7.28	1.58		21.37	14.48	15390.2	234.47	11.66	267.34	33.03
Fishponds	W-17	Kuualii	07/10/2025	168.7	8.43	31	9.5	48.46	33.05	0.54		34.06	15.75	15098.5	367.62	21.37	416.62	55.43
Irrigation Lake	W-27	Irrigation Lake	07/10/2025	156.3	8.66	28.6	2.51	86.72	13.85	2899.08		656.55	1.37	20210.4	26	131.27	3011.79	787.83

Table 2

Station Name		Date Sampled	Field Data: Dissolved Oxygen	Field Data: Field-PH	Field Data: Temperature	Field Data: Turbidity	General Chemistry: Ammonia	General Chemistry: Chl	General Chemistry: Nitrate + Nitrite	General Chemistry: pH	General Chemistry: Phosphate	General Chemistry: Salinity	General Chemistry: Silicate	General Chemistry: TON	General Chemistry: TOP	General Chemistry: Total Dissolved Nitrogen	General Chemistry: Total Dissolved Phosphorus
			%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Geomean	Waiulua Bay	07/10/2025	104.57	8.09	29.57	0.43	5.35	0.18	91.63		25.71	**27.45**	######	66.26	9.78	211.88	35.89
Geomean	WAPPA	07/10/2025	105.91	8.10	26.84	0.42	3.66	0.30	6.63		11.38	32.80	468.08	80.46	3.56	95.60	18.00
Geomean	Anaehoomalu (A) Bay	07/10/2025	110.57	8.08	29.03	0.61	5.48	0.24	11.94	8.37	10.50	33.84	739.08	73.07	5.11	96.15	15.66
Geomean	All Ocean Samples	07/10/2025	107.06	8.09	28.58	0.48	4.84	0.23	20.90	8.26	14.79	**31.12**	######	72.53	5.81	127.29	21.91

Summary of compliance for the second sampling event of 2025. Waikoloa data from Ocean Transect with the Department of Health West Hawai‘i regional water quality standards applied.
Compliance for total nitrogen, total phosphorus, and nitrate nitrogen are determined by a linear regression fit, and compared to the criteria.
Compliance for ammonia nitrogen, chlorophyll-a and turbidity are determined using geomean results against fixed values.
The presence of one or more monitoring location on a particular ocean transect with salinity of less than or equal to 32 parts per thousand requires exceedance analysis using a regression approach defined within the HAR 11-54.
The results of the Geomean analysis within Apendix 1 identified that all ocean trancesects had atleast one or more monitoring location that were under the 32 parts per thousand limit requiring analysis of all ocean transects.
Data presented in ug/L unless otherwise noted

Station Group Name	Date Sampled	Analysis Method	Parameter	DOH Not To Exceed The Absolute Value	Calculated 95% Upper Limit Or Value	Geomean Results	Exceeds Standard ?
Waiulua Bay	7/10/2025	Regression	Total Nitrogen	-40.35	-30.82		Yes
Waiulua Bay	7/10/2025	Regression	Total Phosphorous	-2.86	-5.25		No
Waiulua Bay	7/10/2025	Regression	Nitrate + Nitrite	-31.92	-34.96		No
Waiulua Bay	7/10/2025	Regression	Orthophosphorous	-3.22	-3.59		No
Waiulua Bay	7/10/2025	Geomean	Ammonia Nitrogen (ug/l	2.5		5.35	Yes
Waiulua Bay	7/10/2025	Geomean	Chlorophyll (ug/l)	0.3		0.18	No
Waiulua Bay	7/10/2025	Geomean	Turbidity (ntu)	0.1		0.43	Yes
WAPPA	7/10/2025	Regression	Total Nitrogen	-40.35	-93.35		No
WAPPA	7/10/2025	Regression	Total Phosphorous	-2.86	777.08		Yes
WAPPA	7/10/2025	Regression	Nitrate + Nitrite	-31.92	156.36		Yes
WAPPA	7/10/2025	Regression	Orthophosphorous	-3.22	734.57		Yes
WAPPA	7/10/2025	Geomean	Ammonia Nitrogen (ug/l	2.5		3.66	Yes
WAPPA	7/10/2025	Geomean	Chlorophyll (ug/l)	0.3		0.30	No
WAPPA	7/10/2025	Geomean	Turbidity (ntu)	0.1		0.42	Yes
Anaehoomalu (A) Bay	7/10/2025	Regression	Total Nitrogen	-40.35	8.92		Yes
Anaehoomalu (A) Bay	7/10/2025	Regression	Total Phosphorous	-2.86	15.18		Yes
Anaehoomalu (A) Bay	7/10/2025	Regression	Nitrate + Nitrite	-31.92	-0.18		Yes
Anaehoomalu (A) Bay	7/10/2025	Regression	Orthophosphorous	-3.22	8.39		Yes
Anaehoomalu (A) Bay	7/10/2025	Geomean	Ammonia Nitrogen (ug/l	2.5		5.48	Yes
Anaehoomalu (A) Bay	7/10/2025	Geomean	Chlorophyll (ug/l)	0.3		0.24	No
Anaehoomalu (A) Bay	7/10/2025	Geomean	Turbidity (ntu)	0.1		0.61	Yes

Appendix 6.

Summary of visual census of red shrimp or opae‘ula (Halocaridina rubra) in 10th July 2025 0.1 m^2 quadrats placed in anchialine pools at Waikoloa for the survey period.

Site	Site Name	Time	Shrimp Census	Comments
W-11	Pond 155	9:35:00 AM	0 /0.1m^2	No shrimp, No fish
W-18	Maintenance	10:46:00 AM	0 /0.1m^2	No shrimp, No fish lohena: 0
W-21	Pond 48	9:52:00 AM	0 /0.1m^2	No shrimp, fish present
W-22	Pond 188	9:42:00 AM	0 /0.1m^2	No shrimp, fish present
W-20	Unnamed	11:44:00 AM	0 /0.1m^2	No shrimp, No fish
W-3	Best Efforts	10:08:00 AM	126 /0.1m^2	

Table 1 - Summary of the water quality parameters as measured at 25 sites at Waikoloa on October 1st 2025. Samples were from the ocean, anchialine pools, wells and fishponds. Given in the body of the table are the concentrations of dissolved nutrients in ug/l unless otherwise stated.
Table 2 - Calulated Geomeans are reported for each ocean transect and for the totality of all ocean samples.

ND = Below limits of detection.
* Note that chlorophyll-a samples are not collected from wells.
** Note Ocean salinity results less than 32 parts per thousand are indicated in bold and underlined.

Table 1

Station Group Name	Station ID (Point ID)	Station Name	Date Sampled	Field Data				General Chemistry										
				Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	pH	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
				%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Ocean Samples	**W-04**	**Waiulua Bay Shoreline**	10/01/2025	99.3	7.81	31.4	1.77	19.88	0.15	193.1		34.77	**<u>29.15</u>**	7409.8	88.33	24.82	301.31	59.59
Ocean Samples	**W-05**	**Waiulua Bay 50m**	10/01/2025	135.9	8.15	30.5	1.21	15.16	0.21	26.25	8.32	13.96	33.8	1498.26	76.66	3.36	118.08	17.32
Ocean Samples	**W-06**	**Waiulua Bay 100m Surface**	10/01/2025	129.4	8.24	32	1.01	9.2	0.13	16.84		10.83	34.21	1046.35	75.95	3.57	101.99	14.4
Ocean Samples	**W-07**	**Waiulua Bay 100m Bottom**	10/01/2025	109.7	8.21	29.8	0.57	5.36	0.15	5.86		7.53	34.68	302.21	69.68	4.9	80.9	12.43
Ocean Samples	**W-23**	**Waiulua Bay 300m**	10/01/2025	107.8	8.18	29.6	0.97	5.57	0.15	3.38		5.6	34.58	172.47	54.37	5.04	63.31	10.64
Ocean Samples	**W-09**	**WAPPA - Shoreline**	10/01/2025	126.1	8.05	28.9	0.62	8.32	0.29	3.17		8.43	34.54	443.23	77.46	4.25	88.95	12.68
Ocean Samples	**W-10**	**WAPPA - 100m**	10/01/2025	97.6	8.11	32.5	0.32	5.1	0.1	6.88		6.13	34.9	183.99	58.88	4.81	70.85	10.93
Ocean Samples	**W-24**	**WAPPA - 200m**	10/01/2025	95.8	8.15	29.9	0.35	2.45	0.1	5.35		6.72	34.73	361.18	61.03	5.06	68.83	11.78
Ocean Samples	**W-26**	**WAPPA - 300m**	10/01/2025	97.2	8.17	29.3	0.65	4.72	0.08	4.89		7.12	34.78	268.13	59.87	4.76	69.48	11.89
Ocean Samples	**W-12**	**Anaehoomalu (A) Bay Shoreline**	10/01/2025	102.7	8.15	29	1.14	19.49	0.57	31.98	8.23	11.19	33.29	2026.09	70.17	4.41	121.64	15.6
Ocean Samples	**W-13**	**Anaehoomalu (A) Bay 50m Surface**	10/01/2025	99.6	8.11	28.5	0.81	18.29	0.17	13.39		10.01	34.43	556.12	56.55	3.54	88.23	13.55
Ocean Samples	**W-14**	**Anaehoomalu (A) Bay 100m Surface**	10/01/2025	98.6	8.13	28.8	0.82	14.65	0.12	12.8		8.97	34.59	400.96	56.17	3.78	83.63	12.76
Ocean Samples	**W-19**	**Anaehoomalu (A) Bay 100m Bottom**	10/01/2025	98.5	8.08	30.1	1.18	8.15	0.13	8.94		7.48	34.59	257.49	61.78	5.48	78.86	12.96
Ocean Samples	**W-25**	**Anaehoomalu (A) Bay 300m**	10/01/2025	100.1	8.12	29.1	0.4	7.39	0.08	10.26		8.37	34.51	332.5	58.34	4.51	75.99	12.89
Wells	**W-01**	**Well - 1 South**	10/01/2025	105.1	8.09	25.6	0.38	ND		585.02		46.81	1.32	28156.7	78.3	8.34	663.32	55.15
Wells	**W-02**	**Well - 2 North**	10/01/2025	103.5	7.92	26.9	0.43	ND		556.33		46.71	1.35	29297	68.21	8.73	624.54	55.44
Wells	**W-18**	**Maintenance Well**	10/01/2025	116	8.06	27.9	0.78	10		636.18		41.86	1.75	30869.1	99.5	11.94	745.69	53.8
Anchialine Ponds	**W-03**	**Best Efforts**	10/01/2025	100.7	7.56	26.8	0.41	17.52	0.07	1960.38		379.63	2.04	25065.8	478.15	53.15	2456.04	432.78
Anchialine Ponds	**W-11**	**Pond 155**	10/01/2025	89.3	7.26	28.2	0.36	5.29	0.08	730.32		107.84	6.4	22862.3	138.81	58.06	874.42	165.89
Anchialine Ponds	**W-20**	**Unnamed Pool**	10/01/2025	112.6	7.92	28.7	0.3	2.75	0.29	711.19		51.35	4.77	27071.5	125.58	16.01	839.52	67.36
Anchialine Ponds	**W-21**	**Pond 48**	10/01/2025	92.4	7.42	27.6	0.47	34.18	0.17	1136.37		277	5.17	25235.5	249.77	52.09	1420.32	329.09
Anchialine Ponds	**W-22**	**Pond 188**	10/01/2025	88.2	7.36	27.7	0.42	10.45	0.12	488.68		131.39	8.24	26118.9	200.4	49.35	699.54	180.75
Fishponds	**W-15**	**Makaha**	10/01/2025	103.4	8.82	28.9	1.15	34.92	4.29	281.52		19.22	10.46	24820.4	108.32	1.37	424.76	20.59
Fishponds	**W-17**	**Kuualii**	10/01/2025	121.1	8.16	29.1	3.67	114.2	6.93	40.5	8.45	18.18	11.15	25605	174.07	1.99	328.77	20.18
Irrigation Lake	**W-27**	**Irrigation Lake**	10/01/2025	159.8	8.46	28.1	1.72	44.45	20.08	2704.07		539.12	1.6	31471.8	484.9	21.39	3233.42	560.51

Table 2

Station Name		Date Sampled	Field Data				General Chemistry										
			Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	pH	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
			%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Geomean	Waiulua Bay	10/01/2025	115.61	8.12	30.65	1.04	9.63	0.16	17.60	8.32	11.73	33.21	904.52	72.10	5.93	113.20	18.14
Geomean	WAPPA	10/01/2025	103.47	8.12	30.12	0.46	4.71	0.12	4.89		7.05	34.74	298.11	63.89	4.71	74.09	11.80
Geomean	Anaehoomalu (A) Bay	10/01/2025	99.89	8.12	29.10	0.81	12.58	0.16	13.81	8.23	9.11	34.28	521.79	60.39	4.29	88.34	13.51
Geomean	All Ocean Samples	10/01/2025	106.30	8.12	29.93	0.75	8.63	0.15	11.19	8.27	9.27	34.02	541.21	65.38	4.95	91.79	14.44

Summary of compliance for the third sampling event of 2025. Waikoloa data from Ocean Transect with the Department of Health West Hawai‘i regional water quality standards applied.
Compliance for total nitrogen, total phosphorus, and nitrate nitrogen are determined by a linear regression fit, and compared to the criteria.
Compliance for ammonia nitrogen, chlorophyll-a and turbidity are determined using geomean results against fixed values.
The presence of one or more monitoring location on a particular ocean transect with salinity of less than or equal to 32 parts per thousand requires exceedance analysis using a regression approach defined within the HAR 11-54.
The results of the Geomean analysis within Apendix 1 identified that all ocean trancesects had atleast one or more monitoring location that were under the 32 parts per thousand limit requiring analysis of all ocean transects.
Data presented in ug/L unless otherwise noted

Station Group Name	Date Sampled	Analysis Method	Parameter	DOH Not To Exceed The Absolute Value	Calculated 95% Upper Limit Or Value	Geomean Results	Exceeds Standard ?
Waiulua Bay	10/1/2025	Regression	Total Nitrogen	-40.35	21.61		Yes
Waiulua Bay	10/1/2025	Regression	Total Phosphorous	-2.86	0.99		Yes
Waiulua Bay	10/1/2025	Regression	Nitrate + Nitrite	-31.92	-9.31		Yes
Waiulua Bay	10/1/2025	Regression	Orthophosphorous	-3.22	0.24		Yes
Waiulua Bay	10/1/2025	Geomean	Ammonia Nitrogen (ug/	2.5		9.63	Yes
Waiulua Bay	10/1/2025	Geomean	Chlorophyll (ug/l)	0.3		0.16	No
Waiulua Bay	10/1/2025	Geomean	Turbidity (ntu)	0.1		1.04	Yes

Appendix 9.

Summary of visual censuses of red shrimp or opae‘ula (Halocaridina rubra) in 0.1 m^2 quadrats placed in anchialine pools at Waikoloa for the 10th October 2025 survey period.

Site	Site Name	Time	Shrimp Census	Comments
W-11	Pond 155	10:17:00 AM	0 /0.1m^2	No shrimp, fish present
W-18	Maintenance	11:02:00 AM	0 /0.1m^2	No shrimp, fish present lohena: 0
W-21	Pond 48	10:38:00 AM	0 /0.1m^2	No shrimp, fish present
W-22	Pond 188	10:22:00 AM	0 /0.1m^2	No shrimp, fish present
W-20	Unnamed	11:57:00 AM	0 /0.1m^2	No shrimp, fish present
W-3	Best Efforts	9:47:00 AM	80 /0.1m^2	

Table 1 - Summary of the water quality parameters as measured at 25 sites at Waikoloa on December 30th 2025. Samples were from the ocean, anchialine pools, wells and fishponds. Given in the body of the table are the concentrations of dissolved nutrients in ug/l unless otherwise stated.
Table 2 - Calulated Geomeans are reported for each ocean transect and for the totality of all ocean samples.

ND = Below limits of detection.
* Note that chlorophyll-a samples are not collected from wells.
** Note Ocean salinity results less than 32 parts per thousand are indicated in bold and underlined.
***Note: Well 2 was offline during the monitoring event; therefore, no monitoring data were collected for this location.

Table 1

Station Group Name	Station ID (Point ID)	Station Name	Date Sampled	Field Data				General Chemistry										
				Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	pH	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
				%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Ocean Samples	**W-04**	**Waiulua Bay Shoreline**	12/30/2025	93.2	8.1	24.6	0.28	8.06	0.11	271.76	7.98	44.58	**<u>24.2</u>**	9677.76	179.95	29.6	459.77	74.18
Ocean Samples	**W-05**	**Waiulua Bay 50m**	12/30/2025	103.5	8.17	24.1	0.45	5.84	0.4	92.35		20.9	**<u>31.87</u>**	4616.29	94.73	8.1	192.92	29.01
Ocean Samples	**W-06**	**Waiulua Bay 100m Surface**	12/30/2025	104.5	8.16	24.2	0.39	7.68	0.27	82.45		16.51	32.25	3815.63	63.26	11.79	153.4	28.3
Ocean Samples	**W-07**	**Waiulua Bay 100m Bottom**	12/30/2025	101.4	8.06	23.9	0.29	6.13	0.44	43.99		16.48	33.77	1132.57	45.59	3.29	95.71	19.77
Ocean Samples	**W-23**	**Waiulua Bay 300m**	12/30/2025	97.7	8.28	24.8	0.39	3.55	0.22	20.51		9.16	34.31	470.12	49.72	4.58	73.78	13.75
Ocean Samples	**W-09**	**WAPPA - Shoreline**	12/30/2025	104.9	8.38	26.1	0.32	10.25	0.31	5.64	8.3	7.92	34.59	341.61	58.52	6.21	74.4	14.12
Ocean Samples	**W-10**	**WAPPA - 100m**	12/30/2025	104.8	8.21	26	0.16	8.05	0.14	0.96		6.54	34.78	218.17	56.34	5.83	65.35	12.37
Ocean Samples	**W-24**	**WAPPA - 200m**	12/30/2025	92.6	8.19	26.4	0.27	5.13	0.21	15.55		9.59	34.34	472.98	50.77	4.78	71.44	14.37
Ocean Samples	**W-26**	**WAPPA - 300m**	12/30/2025	94	8.11	26	0.27	3.57	0.15	15.83		6.68	34.36	476.72	45	4.7	64.39	11.37
Ocean Samples	**W-12**	**Anaehoomalu (A) Bay Shoreline**	12/30/2025	104.6	8.14	27.8	0.44	2.11	0.9	178.01	8.16	21.16	**<u>28.49</u>**	7332.22	125.97	7.17	306.09	28.33
Ocean Samples	**W-13**	**Anaehoomalu (A) Bay 50m Surface**	12/30/2025	101.8	8.21	27.3	0.48	11.95	0.68	44.95		14.15	33.04	1596.75	46.49	3.16	103.4	17.31
Ocean Samples	**W-14**	**Anaehoomalu (A) Bay 100m Surface**	12/30/2025	94.6	8.07	27.3	0.48	29.47	0.66	32.73		10.74	33.56	1190.39	44.29	3.87	106.5	14.61
Ocean Samples	**W-19**	**Anaehoomalu (A) Bay 100m Bottom**	12/30/2025	90.9	8.14	27.3	0.44	12.62		17.41		9.97	34.33	475.77	50.44	4.76	80.47	14.72
Ocean Samples	**W-25**	**Anaehoomalu (A) Bay 300m**	12/30/2025	91.8	8.2	27.3	0.27	7.1	0.52	15.51		7.89	34.4	486.3	50.31	4.78	72.92	12.67
Wells	**W-01**	**Well - 1 South**	12/30/2025	106.5	8.46	24.7	0.42	5.73		438.03		54.37	1.29	26905.3	229.07	20.05	672.84	74.42
Wells	**W-02**	**Well - 2 North**	12/30/2025															
Wells	**W-18**	**Maintenance Well**	12/30/2025	121.3	8.52	24.8	0.35	7.54	0	642.52		52.9	2.07	26313.9	185.6	14.67	835.66	67.56
Anchialine Ponds	**W-03**	**Best Efforts**	12/30/2025	110	7.38	24.9	0.58	9.84		1769.91		407.63	1.93	26352.2	494.97	54.69	2274.72	462.31
Anchialine Ponds	**W-11**	**Pond 155**	12/30/2025	84	7.69	23.6	0.34	10.77	0.14	400.98		106.01	7.67	22884.8	266.85	43.77	678.59	149.77
Anchialine Ponds	**W-20**	**Unnamed Pool**	12/30/2025	126.2	8.19	26.5	0.35	7.65	0.3	650.34		77.82	5.15	25880	210.11	18.92	868.1	96.74
Anchialine Ponds	**W-21**	**Pond 48**	12/30/2025	109.5	7.97	23.9	0.38	14.08	0.15	1061.02		237.93	5.87	25335.4	346.33	38.92	1421.43	276.85
Anchialine Ponds	**W-22**	**Pond 188**	12/30/2025	82.1	7.52	23.9	0.23	10.65	0.15	232.03		109.83	11.25	21038.4	247.52	22.85	490.2	132.68
Fishponds	**W-15**	**Makaha**	12/30/2025	121	8.5	26	2.28	13.93	5.65	51.01		27.68	11.58	19434.4	155.4	4.47	220.35	32.15
Fishponds	**W-17**	**Kuualii**	12/30/2025	175.5	8.87	26.7	13.8	0.31	51.71	4.16		28.26	12.78	18779.2	161.56	4.55	166.02	32.81
Irrigation Lake	**W-27**	**Irrigation Lake**	12/30/2025	111.4	8.24	25.6	0.65	127.66	6.13	2839.24		907.54	1.67	27564.7	394.73	182.28	3361.62	1089.82

Table 2

Station Name		Date Sampled	Field Data: Dissolved Oxygen	Field Data: Field-PH	Field Data: Temperature	Field Data: Turbidity	General Chemistry: Ammonia	General Chemistry: Chl	General Chemistry: Nitrate + Nitrite	General Chemistry: pH	General Chemistry: Phosphate	General Chemistry: Salinity	General Chemistry: Silicate	General Chemistry: TON	General Chemistry: TOP	General Chemistry: Total Dissolved Nitrogen	General Chemistry: Total Dissolved Phosphorus
			%	SU	C	ntu	ug/L	ug/L	ug/L	0/14	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Geomean	Waiulua Bay	12/30/2025	99.97	8.15	24.32	0.35	6.01	0.26	71.49	7.98	18.76	31.04	######	75.45	8.43	157.23	27.78
Geomean	WAPPA	12/30/2025	98.91	8.22	26.12	0.25	6.23	0.19	6.04		7.59	34.52	360.05	52.39	5.34	68.77	13.00
Geomean	Anaehoomalu (A) Bay	12/30/2025	96.59	8.15	27.40	0.41	9.22	0.68	37.15	8.16	12.04	32.69	######	58.03	4.57	114.61	16.79
Geomean	All Ocean Samples	12/30/2025	98.45	8.17	25.90	0.34	7.08	0.32	27.93	8.15	12.36	32.59	######	61.90	5.95	110.89	18.68

Summary of compliance for the forth sampling event of 2025. Waikoloa data from Ocean Transect with the Department of Health West Hawaiʻi regional water quality standards applied.
Compliance for total nitrogen, total phosphorus, and nitrate nitrogen are determined by a linear regression fit, and compared to the criteria.
Compliance for ammonia nitrogen, chlorophyll-a and turbidity are determined using geomean results against fixed values.
The presence of one or more monitoring location on a particular ocean transect with salinity of less than or equal to 32 parts per thousand requires exceedance analysis using a regression approach defined within the HAR 11-54.
The results of the Geomean analysis within Apendix 1 identified that all ocean trancesects had atleast one or more monitoring location that were under the 32 parts per thousand limit requiring analysis of all ocean transects.
Data presented in ug/L unless otherwise noted

Station Group Name	Date Sampled	Analysis Method	Parameter	DOH Not To Exceed The Absolute Value	Calculated 95% Upper Limit Or Value	Geomean Results	Exceeds Standard ?
Waiulua Bay	12/30/2025	Regression	Total Nitrogen	-40.35	-21.74		Yes
Waiulua Bay	12/30/2025	Regression	Total Phosphorous	-2.86	-2.76		Yes
Waiulua Bay	12/30/2025	Regression	Nitrate + Nitrite	-31.92	-19.56		Yes
Waiulua Bay	12/30/2025	Regression	Orthophosphorous	-3.22	3.28		Yes
Waiulua Bay	12/30/2025	Geomean	Ammonia Nitrogen (ug/l	2.5		6.01	Yes
Waiulua Bay	12/30/2025	Geomean	Chlorophyll (ug/l)	0.3		0.26	No
Waiulua Bay	12/30/2025	Geomean	Turbidity (ntu)	0.1		0.35	Yes
WAPPA	12/30/2025	Geomean	Total Nitrogen	100.00		68.77	No
WAPPA	12/30/2025	Geomean	Total Phosphorous	12.50		13.00	Yes
WAPPA	12/30/2025	Geomean	Nitrate + Nitrite	4.50		6.04	Yes
WAPPA	12/30/2025	Geomean	Orthophosphorous	5.00		7.59	Yes
WAPPA	12/30/2025	Geomean	Ammonia Nitrogen (ug/l	2.5		6.23	Yes
WAPPA	12/30/2025	Geomean	Chlorophyll (ug/l)	0.3		0.19	No
WAPPA	12/30/2025	Geomean	Turbidity (ntu)	0.1		0.25	Yes
Anaehoomalu (A) Bay	12/30/2025	Regression	Total Nitrogen	-40.35	9.26		Yes
Anaehoomalu (A) Bay	12/30/2025	Regression	Total Phosphorous	-2.86	2.09		Yes
Anaehoomalu (A) Bay	12/30/2025	Regression	Nitrate + Nitrite	-31.92	-18.83		Yes
Anaehoomalu (A) Bay	12/30/2025	Regression	Orthophosphorous	-3.22	0.93		Yes
Anaehoomalu (A) Bay	12/30/2025	Geomean	Ammonia Nitrogen (ug/l	2.5		9.22	Yes
Anaehoomalu (A) Bay	12/30/2025	Geomean	Chlorophyll (ug/l)	0.3		0.68	Yes
Anaehoomalu (A) Bay	12/30/2025	Geomean	Turbidity (ntu)	0.1		0.41	Yes

Appendix 12.

Summary of visual censuses of red shrimp or opae‘ula (Halocaridina rubra) in 0.1 m^2 quadrats placed in anchialine pools at Waikoloa for the 30th December 2025 survey.

Site	Site Name	Time	Shrimp Census		Comments
W-11	Pond 155	9:48:00 AM	0	$0.1m^2$	No shrimp, No fish
W-18	Maintenance	11:19:00 AM	0	$0.1m^2$	rubra: /$0.1m^2$ lohena: 0
W-21	Pond 48	10:06:00 AM	0	$0.1m^2$	rubra: 85/$0.1m^2$
W-22	Pond 188	9:55:00 AM	0	$0.1m^2$	No shrimp, fish present
W-20	Unnamed	12:11:00 PM	0	$0.1m^2$	No shrimp, fish present
W-3	Best Efforts	10:29:00 AM	96	$0.1m^2$	

Table 1 - Summary of Water Quality Parameters at Makalawena, North Kona – December 23, 2025
Table 2 - Calulated Geomeans are reported for each ocean transect and for the totality of all ocean samples.

This report summarizes the water quality parameters measured at four out of six designated sampling control sites at Makalawena, North Kona, on December 23, 2025. Samples were collected from the anchialine pools (Sites MAK-1, 2, and 3) and the Shoreline Ocean Site (MAK-4, MAK-5 and MAK-6)
Also report are the calculated Geomean for all Ocean Samples
ND = Below limits of detection.
* Note Ocean salinity results less than 32 parts per thousand are indicated in bold and underlined.

Table 1

Station Group Name	Well Number (Point ID)	Station Name (Point Name)	Date Sampled	Field Data					General Chemistry								
				Dissolved Oxygen	Field-PH	Temperature	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphorus
				%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Anchialine Ponds	**MAK-1**	**Pond 1**	12/23/2025	104.9	8.3	23.2	0.22	ND	0.02	602.91	133.73	13.54	25008.9	93.96	1.46	696.87	135.18
Anchialine Ponds	**MAK-2**	**Pond 2**	12/23/2025	104.1	8.42	23.4	0.23	0.6	0.04	665.87	139.88	11.52	23527.9	94.44	13.83	760.91	153.71
Anchialine Ponds	**MAK-3**	**Pond 3**	12/23/2025	100.8	8.28	23.6	0.17	1.33	0	652.94	151.25	10.92	23599.4	115.25	21.32	769.53	172.56
Ocean Samples	**MAK-4**	**MAK - Shoreline**	12/23/2025	107	7.85	24.7	0.18	6.28	1.06	165.92	54.73	<u>**25.6**</u>	9387.8	106.94	2.84	279.14	57.57
Ocean Samples	**MAK-5**	**MAK - 100m**	12/23/2025	116.6	8.19	26.1	0.19	2.87	0.33	20.28	13.84	33.34	1276.25	55.95	2.36	79.1	16.2
Ocean Samples	**MAK-6**	**MAK - 200m**	12/23/2025	116.5	8.23	26.2	0.16	5.66	0.29	21.23	12	33.28	1227.51	52.72	3.14	79.61	15.14

Table 2

Site Group Name		Date Sampled	Field Data					General Chemistry								
			Dissolved Oxygen	Field-PH	Temperatu re	Turbidity	Ammonia	Chl	Nitrate + Nitrite	Phosphate	Salinity	Silicate	TON	TOP	Total Dissolved Nitrogen	Total Dissolved Phosphoru s
			%	SU	C	ntu	ug/L	ug/L	ug/L	ug/L	0/00	ug/L	ug/L	ug/L	ug/L	ug/L
Geomean	Anchialine Ponds	12/23/2025	103.25	8.33	23.40	0.20	0.89	0.03	639.99	141.44	11.94	24035.85	100.75	7.55	741.71	153.06
Geomean	Makalawena Ocean Transect	12/23/2025	113.28	8.09	25.66	0.18	4.67	0.47	41.49	20.87	30.51	2450.05	68.07	2.76	120.69	24.17

Summary of compliance of annual Makalawena control site data from three marine sites sampled on 23 December 2025 from surface marine sites with the Department of Health West Hawai'i regional water quality standards. Data presented in ug/l unless otherwise noted.
The presence of one ore more sites on a particular transect with salinity of less than equal to 32 parts per thousand requires exceedance analysis using a regression approach (HAR 11-54). These results showed the Makalawena transect showed depressed salinity, requiring the regression approach.

Regression analysis was performed to evaluate compliance in accordance with HAR 11-54. The dataset consisted of three sampling locations, with limited variability in salinity between offshore stations.

While a regression relationship was established, the limited number of data points and clustering of salinity values resulted in negligible residual error, and standard statistical metrics (e.g., p-values, standard error, and confidence intervals) are not meaningful for this dataset.

Accordingly, the regression slope and intercept were used to estimate concentrations at the applicable salinity threshold, consistent with HAR 11-54 methodology.

Station Group Name	**Date Sampled**	**Analysis Method**	**Parameter**	**DOH Not To Exceed The Absolute Value**	**Calculated 95% Upper Limit Or Value**	**Geomean Results**	**Exceeds Standard?**
Makalawena Ocean Transect	12/23/2025	Regression	Total Nitrogen	-40.35	-8.50		Yes
Makalawena Ocean Transect	12/23/2025	Regression	Total Phosphorous	-2.86	17.67		Yes
Makalawena Ocean Transect	12/23/2025	Regression	Nitrate + Nitrite	-31.92	-15.83		Yes
Makalawena Ocean Transect	12/23/2025	Regression	Orthophosphorous	-3.22	30.67		Yes
Makalawena Ocean Transect	12/23/2025	Geomean	Ammonia Nitrogen (ug/l)	2.5		4.67	Yes
Makalawena Ocean Transect	12/23/2025	Geomean	Chlorophyll (ug/l)	0.3		0.47	Yes
Makalawena Ocean Transect	12/23/2025	Geomean	Turbidity (ntu)	0.1		0.18	Yes

Summary of non-compliance (shown with an "X", blank = in compliance) in seven parameters (Nitrate-N, Ammonia-N, Total-N, Ortho-P, Total-P, Turbidity and Chlorophyll-a) measured at three marine transect sites (Waiulua Bay, WAPPA, Anaehoomalu Bay) at Waikoloa and once annually at the Makalawena control site since the imposition of the new Hawai'i State Regional Water Quality Standards for West Hawai'i in July 2000.
Please Note: N/A* = Unable to conduct ocean sampling due to high surf

Year	Quarter	Location	Total Dissolved Nitrogen ug/L	Total Dissolved Phosphorus ug/L	Nitrate + Nitrite ug/L	Phosphate ug/L	Ammonia ug/L	Chl ug/L	Turbidity ntu
2000	3	Waiulua	X				X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay	X	X	X	X	X		X
	4	Waiulua				X	X		X
		WAPPA		X					
		Anae Bay		X	X	X	X		X
		Makalawena	X	X	X	X	X	X	X
2001	1	Waiulua	X	X	X	X	X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay		X		X	X		X
	2	Waiulua	X	X				X	X
		WAPPA	X	X		X		X	X
		Anae Bay	X	X		X		X	X
	3	Waiulua	X	X		X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	4	Waiulua			X		X	X	X
		WAPPA	X		X	X	X	X	X
		Anae Bay	X		X	X	X	X	X
		Makalawena	X	X					X
2002	1	Waiulua		X	X	X	X		X
		WAPPA		X		X	X		X
		Anae Bay	X	X		X	X		X
	2	Waiulua		X			X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay				X	X		X
	3	Waiulua	X	X	X	X	X	X	X
		WAPPA	X				X	X	X
		Anae Bay		X		X	X	X	X
	4	Waiulua	X		X	X	X		X
		WAPPA	X		X	X	X		X
		Anae Bay	X		X	X	X		X
		Makalawena	X		X				X
2003	1	Waiulua		X	X	X	X	X	X
		WAPPA	X				X	X	X
		Anae Bay		X		X	X	X	X
	2	Waiulua	X	X		X	X		X
		WAPPA	X	X		X	X		X
		Anae Bay	X			X	X		X
	3	Waiulua	X	X	X	X	X		X
		WAPPA	X			X	X		X
		Anae Bay	X			X	X		X
	4	Waiulua					X		X
		WAPPA			X	X	X		X
		Anae Bay		X	X	X	X		X
		Makalawena	X				X		X
2004	1	Waiulua		X	X	X			X
		WAPPA	X		X	X			X
		Anae Bay			X	X			X
	2	Waiulua		X	X	X	X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay					X	X	X
	3	Waiulua	X	X	X	X	X	X	X
		WAPPA	X		X		X	X	X
		Anae Bay	X		X		X	X	X
	4	Waiulua			X		X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena	X			X	X	X	X
2005	1	Waiulua		X		X	X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay		X		X	X		X
	2	Waiulua	X	X	X	X	X	X	X
		WAPPA					X	X	X
		Anae Bay	X				X	X	X
	3	Waiulua	X	X	X	X	X	X	X
		WAPPA				X	X	X	X
		Anae Bay		X	X	X	X	X	X
	4	Waiulua					X	X	X
		WAPPA	X				X	X	X
		Anae Bay	X		X	X	X	X	X
		Makalawena	X			X	X	X	X
2006	1	Waiulua			X			X	X
		WAPPA						X	X
		Anae Bay	X	X	X	X		X	X
	2	Waiulua					X		X
		WAPPA	X		X	X	X		X
		Anae Bay	X	X		X	X		X
	3	Waiulua		X		X	X	X	X
		WAPPA					X	X	X
		Anae Bay					X	X	X
	4	Waiulua	X	X	X	X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena	X			X	X	X	X

Year	Quarter	Location	Total Dissolved Nitrogen	Total Dissolved Phosphorus	Nitrate + Nitrite	Phosphate	Ammonia	Chl	Turbidity
2007	1	Waiulua					X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay					X		X
	2	Waiulua	X	X	X	X	X		X
		WAPPA	X	X			X		X
		Anae Bay	X	X	X		X		X
	3	Waiulua		X			X		X
		WAPPA	X		X	X	X		X
		Anae Bay	X	X	X	X	X		X
	4	Waiulua		X	X	X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X			X	X	X
		Makalawena		X	X		X	X	X
2008	1	Waiulua	X	X	X	X	X	X	X
		WAPPA		X		X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	2	Waiulua		X	X	X	X		X
		WAPPA	X		X	X	X		X
		Anae Bay	X		X	X	X		X
	3	Waiulua		X	X	X	X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay	X	X	X		X		X
	4	Waiulua		X	X		X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X		X	X	X	X
		Makalawena	X	X		X	X	X	X
2009	1	Waiulua					X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X			X	X	X	X
	2	Waiulua					X	X	X
		WAPPA					X	X	X
		Anae Bay	X	X	X	X	X		X
	3	Waiulua		X		X	X	X	X
		WAPPA		X			X	X	X
		Anae Bay	X	X	X	X	X	X	X
	4	Waiulua			N/A*				
		WAPPA			N/A*				
		Anae Bay			N/A*				
		Makalawena			N/A*				
2010	1	Waiulua			N/A*				
		WAPPA			N/A*				
		Anae Bay			N/A*				
	2	Waiulua					X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X	X	X	X	X	X
	3	Waiulua					X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X		X	X	X	X
	4	Waiulua		X		X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena	X	X			X		X
2011	1	Waiulua	X	X			X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X	X	X	X	X	X
	2	Waiulua	X	X	X	X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	3	Waiulua		X		X	X		X
		WAPPA	X	X		X	X		X
		Anae Bay	X	X	X	X	X		X
	4	Waiulua		X		X	X	X	X
		WAPPA	X				X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena		X		X	X		X
2012	1	Waiulua					X	X	X
		WAPPA	X	X		X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	2	Waiulua		X		X	X	X	X
		WAPPA	X	X		X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	3	Waiulua		X		X	X	X	X
		WAPPA	X	X		X	X	X	X
		Anae Bay	X	X		X	X	X	X
	4	Waiulua		X			X		X
		WAPPA	X	X		X	X		X
		Anae Bay	X	X	X	X	X		X
		Makalawena	X	X		X	X		X
2013	1	Waiulua		X		X	X	X	X
		WAPPA			N/A*				
		Anae Bay	X	X	X	X	X	X	X
	2	Waiulua					X		X
		WAPPA	X	X		X	X		X
		Anae Bay	X	X		X	X		X
	3	Waiulua		X		X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	4	Waiulua		X		X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena			N/A*				

Year	Quarter	Location	Total Dissolved Nitrogen	Total Dissolved Phosphorus	Nitrate + Nitrite	Phosphate	Ammonia	Chl	Turbidity
2014	1	Waiulua		X		X	X		X
		WAPPA	X	X	X	X	X		X
		Anae Bay	X	X	X	X	X		X
	2	Waiulua					X	X	X
		WAPPA	X	X		X	X	X	X
		Anae Bay					X	X	X
	3	Waiulua	X	X	X	X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay					X	X	X
	4	Waiulua		X			X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena	X	X		X	X		X
2015	1	Waiulua					X	X	X
		WAPPA		X		X	X	X	X
		Anae Bay		X		X	X	X	X
	2	Waiulua		X		X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X			X	X	X
	3	Waiulua		X	X	X	X	X	X
		WAPPA			X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
	4	Waiulua		X		X	X	X	X
		WAPPA	X	X	X	X	X	X	X
		Anae Bay		X			X	X	X
		Makalawena	X		X	X	X	X	X
2016	1	Waiulua		X		X	X		X
		WAPPA		X		X	X		X
		Anae Bay		X		X	X		X
	2	Waiulua					X	X	X
		WAPPA		X			X	X	X
		Anae Bay					X	X	X
	3	Waiulua		X	X	X			X
		WAPPA							X
		Anae Bay							X
	4	Waiulua		X		X	X		X
		WAPPA							X
		Anae Bay							X
		Makalawena		X		X	X	X	X
2017	1	Waiulua	X	X		X	X	X	X
		WAPPA		X			X	X	X
		Anae Bay					X	X	X
	2	Waiulua		X		X		X	X
		WAPPA		X				X	X
		Anae Bay		X				X	X
	3	Waiulua		X		X	X		X
		WAPPA		X		X	X		X
		Anae Bay					X		X
	4	Waiulua			N/A*				
		WAPPA			N/A*				
		Anae Bay			N/A*				
		Makalawena		X	X	X	X		X
2018	1	Waiulua	X	X		X	X	X	X
		WAPPA		X			X	X	X
		Anae Bay					X	X	X
	2	Waiulua		X		X		X	X
		WAPPA		X				X	X
		Anae Bay		X				X	X
	3	Waiulua			N/A*				
		WAPPA			N/A*				
		Anae Bay			N/A*				
	4	Waiulua		X		X	X		X
		WAPPA		X		X	X		X
		Anae Bay					X		X
		Makalawena	X	X	X	X			
2019	2	Waiulua		X		X	X	X	X
		WAPPA	X		X		X	X	X
		A Bay		X		X	X	X	X
	3	Waiulua					X		
		WAPPA		X		X	X		X
		A Bay	X	X		X	X		X
	4	Waiulua	X	X	X	X	X		X
		WAPPA		X		X	X		X
		A Bay	X	X	X	X	X		X
		Makalawena	X	X		X		X	X

Year	Quarter	Location	Total Dissolved Nitrogen	Total Dissolved Phosphorus	Nitrate + Nitrite	Phosphate	Ammonia	Chl	Turbidity
		Waiulua	X		X			X	X
	1	WAPPA		X		X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
		Waiulua	X		X		X	X	X
	2	WAPPA						X	X
		Anae Bay	X	X	X	X		X	X
2020		Waiulua	X		X		X	X	X
	3	WAPPA		X	X	X		X	X
		Anae Bay	X	X	X	X		X	X
		Waiulua	X	X	X	X	X		X
	4	WAPPA			X	X		X	X
		Anae Bay	X	X	X	X	X	X	X
		Makalawena		X	X		X	X	X
		Waiulua	X		X		X		X
	1	WAPPA	X		X		X		X
		Anae Bay	X	X	X	X	X	X	X
		Waiulua	X					X	X
	2	WAPPA	X		X	X	X	X	X
		Anae Bay	X	X	X	X	X	X	X
2021		Waiulua	X				X	X	X
	3	WAPPA	X		X	X	X	X	X
		Anae Bay	X		X		X	X	X
		Waiulua	X				X	X	X
	4	WAPPA	X		X		X		X
		Anae Bay	X		X		X	X	X
		Makalawena	X	X	X	X	X	X	X
		Waiulua	X		X		X	X	X
	1	WAPPA	X	X	X	X	X	X	X
		Anaehoomalu Bay	X		X	X	X	X	X
		Waiulua	X		X		X		X
	2	WAPPA	X		X		X		X
		Anaehoomalu Bay	X	X	X	X	X	X	X
2022		Waiulua	X		X		X	X	X
	3	WAPPA	X		X		X	X	X
		Anaehoomalu Bay	X		X	X	X	X	X
		Waiulua	X	X	X		X	X	X
	4	WAPPA	X		X	X	X	X	X
		Anaehoomalu Bay	X	X	X	X	X	X	X
		Makalawena	X		X	X	X	X	X
		Waiulua				X	X		X
	1	WAPPA	X	X	X	X	X	X	X
		Anaehoomalu Bay		X			X	X	
		Waiulua		X	X			X	X
	2	WAPPA	X	X		X		X	X
		Anaehoomalu Bay	X	X		X		X	
2023		Waiulua	X	X	X			X	X
	3	WAPPA	X	X	X	X	X	X	
		Anaehoomalu Bay	X	X		X	X	X	X
		Waiulua		X				X	X
	4	WAPPA	X	X		X		X	X
		Anaehoomalu Bay		X				X	X
		Makalawena	X	X	X		X	X	X
		Waiulua	X	X	X	X	X		X
	1	WAPPA	X		X		X		X
		Anaehoomalu Bay	X	X	X	X	X		X
		Waiulua	X			X	X		X
	2	WAPPA	X	X	X	X	X	X	X
		Anaehoomalu Bay	X		X	X	X	X	X
2024		Waiulua				X	X	X	X
	3	WAPPA	X	X	X	X	X		X
		Anaehoomalu Bay	X	X	X	X	X	X	X
		Waiulua	X		X	X	X		X
	4	WAPPA	X		X	X	X		X
		Anaehoomalu Bay	X	X	X	X	X	X	X
		Makalawena	N/A*	N/A*	N/A*	N/A*	X	X	X
		Waiulua	X		X		X	X	X
	1	WAPPA	X	X	X	X	X	X	X
		Anaehoomalu Bay	X	X	X	X	X	X	X
		Waiulua	X				X		X
	2	WAPPA		X	X	X	X		X
		Anaehoomalu Bay	X	X	X	X	X		X
2025		Waiulua	X	X	X	X	X		X
	3	WAPPA					X		X
		Anaehoomalu Bay					X		X
		Waiulua	X	X	X	X	X		X
	4	WAPPA		X	X	X	X		X
		Anaehoomalu Bay	X	X	X	X	X	X	X
		Makalawena	X	X	X	X	X	X	X

Waikoloa Summary	Number of Sampling Events	291						
	Number Non-compliant	166	191	151	196	255	181	285
	Percent Non-compliant	57.0%	65.6%	51.9%	67.4%	87.6%	62.2%	97.9%
Waikoloa Total Exceedance Percentage		70.0%						
Makalawena-Awakee Summary	Number of Sampling Events	25						
	Number Non-compliant	18	16	11	16	20	15	23
	Percent Non-compliant	72.0%	64.0%	44.0%	64.0%	80.0%	60.0%	92.0%
Makalawena Total Exceedance Percentage		68.0%						
Waikoloa Summary	Number of Monitoring Events	98						

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Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-1
Matrix: water

PAL Sample ID: P252604-01
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 108 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 100 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-2
Matrix: water

PAL Sample ID: P252604-02
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 122 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 96 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

Kara Greer, Project Manager

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Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-3
Matrix: water

PAL Sample ID: P252604-03
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 112 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 96 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

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Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-4
Matrix: water

PAL Sample ID: P252604-04
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 118 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 100 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-5
Matrix: water

PAL Sample ID: P252604-05
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 108 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 100 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

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Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-6
Matrix: water

PAL Sample ID: P252604-06
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 113 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 100 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

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Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-7 (Shoreline)
Matrix: water

PAL Sample ID: P252604-07
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 113 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 97 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

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Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-12 (W-11)
Matrix: water

PAL Sample ID: P252604-08
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 110 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 98 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

Kara Greer, Project Manager

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Matrix SCIENCES | PAL PACIFIC AGRICULTURAL LABORATORY

Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-11 (MAK-2)
Matrix: water

PAL Sample ID: P252604-09
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 122 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 101 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-13 (W-3)
Matrix: water

PAL Sample ID: P252604-10
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 116 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 98 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

Kara Greer, Project Manager

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-8 (Kua Pond)
Matrix: water

PAL Sample ID: P252604-11
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 122 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 102 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

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Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-9
Matrix: water

PAL Sample ID: P252604-12
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 118 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 102 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Analytical Report

Client Sample ID: K-10 Shoreline
Matrix: water

PAL Sample ID: P252604-13
Sample Date: 12/23/25
Received Date: 12/26/25

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: LC-MS/MS					
1/02/26	1/3/26	AMPA	ND	20 ug/L	
1/02/26	1/3/26	Glyphosate	ND	10 ug/L	
Method: Modified EPA 8270D (GC-MS/MS)					
12/30/25	1/5/26	Permethrin	ND	0.12 ug/L	
12/30/25	1/5/26	Pyriproxyfen	ND	0.060 ug/L	

Surrogate Recovery: 109 %
Surrogate Recovery Range: 60-141
(TPP-d15 used as Surrogate)

Extraction Date	Analysis Date	Analyte	Amount Detected	Limit of Quantitation	Notes
Method: Modified EPA 8321B (LC-MS/MS)					
12/30/25	12/31/25	Carbaryl	ND	0.060 ug/L	

Surrogate Recovery: 100 %
Surrogate Recovery Range: 69-120
(TPP-d15 used as Surrogate)

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager

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Waimea Water Services
65-1206 Mamalahoa Highway 1-206
Kamuela, HI 96743

Report Number: P252604
Report Date: January 12, 2026
Client Project ID: Waikoba/Kukio

Quality Assurance

Method Blank Data **Matrix:** water

Extraction Date	Analysis Date	Batch QC Sample #	Analyte	% Recovery	Expected % Recovery	Notes
12/30/25	12/31/25	25L3002-BLK1	Carbaryl	Not Detected	< 0.060 ug/L	
12/30/25	1/5/26	25L3002-BLK1	Permethrin	Not Detected	< 0.12 ug/L	
12/30/25	1/5/26	25L3002-BLK1	Pyriproxyfen	Not Detected	< 0.060 ug/L	

Method Blank Data **Matrix:** water

Extraction Date	Analysis Date	Batch QC Sample #	Analyte	% Recovery	Expected % Recovery	Notes
1/2/26	1/3/26	26A0203-BLK1	AMPA	Not Detected	< 20 ug/L	
1/2/26	1/3/26	26A0203-BLK1	Glyphosate	Not Detected	< 10 ug/L	

Blank Spike Data **Matrix:** water

Extraction Date	Analysis Date	Batch QC Sample #	Analyte	% Recovery	Expected % Recovery	Notes
12/30/25	12/31/25	25L3002-BS1	Carbaryl	93	80-109	
12/30/25	12/31/25	25L3002-BSD1	Carbaryl	97	80-109	
12/30/25	1/5/26	25L3002-BS1	Permethrin	107	62-146	
12/30/25	1/5/26	25L3002-BSD1	Permethrin	107	62-146	
12/30/25	1/5/26	25L3002-BS1	Pyriproxyfen	107	50-149	
12/30/25	1/5/26	25L3002-BSD1	Pyriproxyfen	108	50-149	

Blank Spike Data **Matrix:** water

Extraction Date	Analysis Date	Batch QC Sample #	Analyte	% Recovery	Expected % Recovery	Notes
1/2/26	1/3/26	26A0203-BS1	AMPA	90	60-140	
1/2/26	1/3/26	26A0203-BSD1	AMPA	92	60-140	
1/2/26	1/3/26	26A0203-BS1	Glyphosate	83	60-140	
1/2/26	1/3/26	26A0203-BSD1	Glyphosate	84	60-140	

This analytical report complies with the ISO/IEC 17025:2017 Quality Standard.

Kara Greer, Project Manager