

MARINE WATER QUALITY MONITORING
MAKENA RESORT, MAKENA, MAUI
WATER CHEMISTRY
REPORT 1-2009

Prepared for

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I. PURPOSE

The Makena Resort fronts approximately 5.4 miles of coastline of southeastern Maui, extending from Papanui Stream (Nahuna Point) on the north and Pu`u Olai (Ahihi Bay) on the south. Within the Resort are two 18-hole golf courses (North and South Courses), as well as a hotel, sewage treatment plant and private residences. No part of the project involves direct alteration of the shoreline or nearshore marine environments.

Evaluations of other golf courses and other forms of resort development located near the ocean in the Hawaiian Islands reveal that there is detectable input to the coastal ocean of materials used for fertilization of turfgrass and landscaping (Dollar and Atkinson 1992). However, few, if any, effects that have been documented have been found to be detrimental to the marine ecosystem. Thus, there is no *a priori* reason to suspect that the construction and responsible operation of the golf courses and other components of the Makena Resort will cause any harmful changes to the marine environment. Nevertheless, in the interest of assuring maintenance of environmental quality, and as a means of ensuring that proper procedures are set forth, a condition of the Land Use Commission District Boundary Amendment for the project was the implementation of an ongoing marine monitoring program off the Makena Resort Development. The primary goals of the program are twofold: 1) to assess the degree that materials used on land to enhance turf growth and landscaping, as well as other nutrient subsidies, leach to groundwater and subsequently reach the ocean, and 2) to determine the fate of these materials within the nearshore zone. In terms of determining fate, the question that is addressed is if the materials that originate from Resort activities disperse with little or no effect, or do they cause changes in water quality sufficient to alter marine biological community structure?

The rationale of the monitoring program is to conduct repetitive evaluations of water chemistry at the same locations at regular time intervals (twice per year). This strategy allows for determination of variations in effects from the Makena Resort in both space (at different locations along the shoreline) and time. These studies also fulfill condition No. 10, Declaration of Conditions pertaining to the Amendment of the District Boundary, as required by the Land Use Commission, dated April 17, 1998. The following report presents the results of the twenty-third increment in the monitoring program, and contains data from water chemistry sampling conducted on June 20, 2009.

II. ANALYTICAL METHODS

Three survey sites directly downslope from the Makena Resort have been selected as sampling locations. A fourth site, located offshore of an area with minimal land-based development, particularly golf course operations, was selected as a control. During the June 2007 survey, another sampling location was added near the southern boundary of Maluaka Bay. It is anticipated that this station will remain part of the sampling protocol permanently. Figure 1 is a map showing the shoreline and topographical features of the Makena area, and the location of the North and South Golf Courses. All survey sites are depicted as transects perpendicular to the shoreline extending from the shoreline out to what is considered open coastal ocean (i.e., beyond the effects of activities on land). Survey Site 1 is located near the northern boundary of the project

site off Nahuna Point; Survey Site 2 bisects Makena Bay near Makena Landing. Site 3 bisects the middle of the South course on the north side of Maluaka Point. Site 3A is on the southern corner of Maluaka Bay. Site 4, which is considered the Control site, is located near the northern boundary of the 'Ahihi-Kina`u natural area reserve north of the 1790 lava flow and approximately 1-2 miles south of the existing Makena Golf courses (Figure 1). The control site was located off a shoreline area with minimal land uses (i.e., residences near the shoreline and upslope ranchlands) rather than off the completely uninhabited 1790 lava flow. This location was selected as the most appropriate control site, as it is the farthest location from the Makena Resort with the same geophysical structural of the land area. The completely different geological structure of the lava flow off the natural reserve likely results in very different groundwater dynamics compared to the land area where the Makena Resort is located, hence making the lava flow an unsuitable control site.

In July of 2002, Site 3 was relocated from a location at the southern boundary of the project offshore of Oneloa Beach to the location directly off the Makena Golf Course, as described above. The relocation of Site 3 was deemed necessary as the original location consistently showed virtually no input of groundwater to the ocean. Such lack of groundwater discharge resulted in little potential for evaluating effects from the project. The new location of Site 3 is directly downslope from both the portion of the golf course nearest to the ocean, several newly constructed private residences, and a 3-acre recently restored wetland area. As a result, the new location represents an area that reflects the maximum influence on nearshore water quality from a variety of land uses and natural habitat.

All fieldwork for the present survey was conducted on June 19 - 20, 2009. Environmental conditions during sample collection consisted of mild winds (8-10 knots), sunny skies, and very little swell. Virtually no rainfall was measured in the Makena area within the previous month and drought conditions prevailed.

Water samples were collected at stations along transects that extend from the highest wash of waves to between 125-200 meters (m) offshore, depending on the site. Such a sampling scheme is designed to span the greatest range of salinity with respect to freshwater efflux at the shoreline. Sampling was more concentrated in the nearshore zone because this area is most likely to show the effects of land-based activities. With the exception of the two stations closest to the shoreline (0 and 2 m offshore), samples were collected at two depths; a surface sample was collected within approximately 10 centimeters (cm) of the sea surface, and a bottom sample was collected within one m of the sea floor.

Water samples from the shoreline to a distance of 10 m offshore were collected in triple-rinsed 1-liter polyethylene bottles by swimmers working from the shoreline. A digital refractometer was used to pinpoint the location of maximum groundwater flux to the ocean shoreline origin of each transect site. Water samples beyond 10 m from the shoreline were collected from a small boat using a 1.8-liter Niskin-type oceanographic sampling bottle. This bottle was lowered to the desired depth in an open position where spring-loaded endcaps were triggered to close by a messenger released from the surface. Upon recovery, each sample was placed on ice until further processing in Honolulu. Water samples were also collected from eight golf course irrigation wells

(No's 1, 2, 3, 4, 5, 6, 10 and 11) and one irrigation lake on the same day as the ocean sampling.

Water quality parameters evaluated included the 10 specific criteria designated for open coastal waters in Chapter 11-54, Section 06 (Open Coastal waters) of the State of Hawaii Department of Health Water Quality Standards. These criteria include: total nitrogen (TN) which is defined as inorganic nitrogen [nitrate + nitrite nitrogen ($\text{NO}_3^- + \text{NO}_2^-$), ammonium (NH_4^+)], plus total organic nitrogen (TON), total phosphorus (TP) which is defined as inorganic phosphorus (PO_4^{3-}) plus total organic phosphorus, chlorophyll *a* (Chl *a*), turbidity, temperature, pH and salinity. In addition, orthophosphate phosphorus (PO_4^{3-}) and silica (Si) were reported because these constituents are sensitive indicators of biological activity and the degree of groundwater mixing, respectively.

Analyses for $\text{NO}_3^- + \text{NO}_2^-$ (hereafter termed NO_3^-), NH_4^+ and PO_4^{3-} , were performed on filtered samples using a Technicon autoanalyzer according to standard methods for seawater analysis (Strickland and Parsons 1968, Grasshoff 1983). TN and TP were analyzed in a similar fashion on unfiltered samples following digestion. Total organic nitrogen (TON) and Total organic phosphorus (TOP) were calculated as the difference between TN and inorganic N, and TP and inorganic P, respectively. Limits of detection for the dissolved nutrients are $0.01 \mu\text{M}$ ($0.14 \mu\text{g/L}$) for NO_3^- and NH_4^+ , $0.01 \mu\text{M}$ ($0.31 \mu\text{g/L}$) for PO_4^{3-} , $0.1 \mu\text{M}$ ($1.4 \mu\text{g/L}$) for TN and $0.1 \mu\text{M}$ ($3.1 \mu\text{g/L}$) for TP.

Chl *a* was measured by filtering 300 ml of water through glass fiber filters; pigments on filters were extracted in 90% acetone in the dark at -5°C for 12-24 hours, and the fluorescence before and after acidification of the extract was measured with a Turner Designs fluorometer (level of detection $0.01 \mu\text{g/L}$). Salinity was determined using an AGE Model 2100 laboratory salinometer with a precision of 0.003‰.

In situ field measurements included water temperature, pH, dissolved oxygen and salinity which were acquired using an RBR Model XR-420 CTD calibrated to factory specifications. The CTD has a readability of 0.001°C , 0.001 pH units, 0.001% oxygen saturation, and 0.001 parts per thousand (‰) salinity. Shoreline salinity was measured in the field using an Atago PAL-06S digital refractometer.

Nutrient, turbidity, Chl *a* and salinity analyses were conducted by Marine Analytical Specialists located in Honolulu, Hawaii. This laboratory possesses acceptable ratings from EPA-compliant proficiency and quality control testing.

III. RESULTS and DISCUSSION

A. General Overview

Table 1 shows results of all marine water chemical analyses for samples collected off Makena on June 20, 2009 with nutrient concentrations reported in micromolar units (μM). Table 2 shows

similar results with nutrient concentrations presented in units of micrograms per liter ($\mu\text{g/L}$). Tables 3 and 4 show geometric means of ocean samples for 23 surveys at Sites 1, 2 and 4, 14 surveys at Site 3, and 5 surveys from Site 3-A, with nutrient concentrations shown in μM and $\mu\text{g/L}$, respectively. Table 5 shows water chemistry measurements (in units of μM and $\mu\text{g/L}$) for samples collected from irrigation wells and one irrigation lake located on the Makena Resort Golf Courses. Concentrations of twelve chemical constituents in surface and deep-water samples from the June 2009 sampling are plotted as functions of distance from the shoreline in Figures 2 and 3. Mean concentrations (\pm standard error) of twelve chemical constituents in surface and deep water samples as functions of distance from the shoreline at Sites 1-4 collected since 1995 are plotted in Figures 4-15. In addition, data from the most recent sampling in June 2009 are also plotted on Figures 4-15.

During the June 2009 sampling, nearshore concentrations of dissolved Si, NO_3^- and TN on all five transects were elevated up to three orders of magnitude compared to samples collected at the sampling stations farthest from shore (Figure 2, Tables 1 and 2). The horizontal gradients of nutrients were steepest on transect Sites 3-A and 2 where NO_3^- at the shoreline ($186 \mu\text{M}$ and $37 \mu\text{M}$, respectively) decreased by more than three orders of magnitude between the shoreline and 150 m offshore ($0.08 \mu\text{M}$ and $0.06 \mu\text{M}$, respectively). At transect Sites 1, 3, and 4, peak values of NO_3^- at the shoreline were between 9 and $43 \mu\text{M}$, with values at the most offshore stations ranging from 0.08 to $0.85 \mu\text{M}$. (Figure 2, Table 1). Salinity displayed mirror images of the patterns for nutrients, with lowest salinity at the shoreline of Sites 3-A and 2 (10.9 and 25.9‰, respectively), with rapidly increasing values with increasing distance from shore to near oceanic values (34.9‰) at the ends of the transects (Figure 3, Table 1). Distinct horizontal gradients extended to a distance of 100 - 150 m from the shoreline at all five transect sites (Tables 1 and 2).

Horizontal gradients in the surface concentrations of phosphate phosphorus (PO_4^{3-}) and TP were also evident at Sites 2 and 3-A with the highest values in the samples collected near the shoreline, and progressively lower concentrations with increasing distance from shore. While there were distinct gradients in the concentrations of PO_4^{3-} , the magnitude of the range in values was far less than for Si, NO_3^- and TN (Figure 2, Tables 1 and 2) and the gradient extended out only to a distance of 5 - 10 m from the shoreline.

With no streams in the sampling area, nor sheet flow drainage preceding sampling, the pattern of elevated Si, NO_3^- , PO_4^{3-} and TN with corresponding reduced salinity indicates groundwater entering the ocean near the shoreline. Low salinity groundwater, which contains high concentrations of Si, NO_3^- , TN and PO_4^{3-} (see values for well waters in Table 5), percolates to the ocean near the shoreline, resulting in a distinct zone of mixing in the nearshore region. The zone of mixing is discernible by distinct decreasing gradients of nutrients and increasing gradients of salinity with distance from shoreline. During periods of low tide when sea conditions are calm, the zone of mixing between groundwater and ocean water is most pronounced. The June 2009 sampling was conducted at low tide (+0.1 ft) with calm winds, resulting in a marked zone of mixing extending approximately 150 m from shore. Past monitoring surveys at Makena Resort conducted during periods of high tide and strong winds (e.g. December 2005) showed substantially smaller horizontal gradients than the present survey. Comparing the results of surveys

conducted during different sea conditions clearly indicates that tidal state, as well as wind and wave energy, greatly affect groundwater mixing in the nearshore zone.

Dissolved nutrient constituents that are not associated with groundwater input (NH_4^+ , TON, TOP) showed varying results with respect to distance from the shoreline (Figure 2). Concentrations of NH_4^+ in the surface waters were slightly elevated near the shoreline compared to offshore region (Figure 2). The highest concentrations of NH_4^+ were recorded in the shoreline samples at Sites 1 and 4 ($3.4 \mu\text{M}$ and $1.2 \mu\text{M}$, respectively), while concentrations of NH_4^+ at the shoreline origins of the other transect sites fell between 0.31 and $0.69 \mu\text{M}$ (Table 1). Concentrations of TOP and TON were nearly constant along the length of each transect, showing no indications of consistent horizontal gradients (Tables 1 and 2).

Turbidity was highest near the shoreline at all five transect sites with Sites 1 and 4 showing higher concentrations compared to Sites 2, 3-A and 4 (Table 1, Figure 3). In previous surveys, turbidity has generally been highest on Transect 2 compared to the other sites. Transect 2 bisects Makena Bay, which is semi-enclosed embayment with a silt/sand bottom rather than the predominantly "hard" reef or sand bottoms that occur at the other transect sites. In addition, it has been observed that during flash floods originating in the ranch lands upslope of the Makena Resort, terrigenous sediment may flow to the ocean in Makena Bay. As a result of wave-induced resuspension of the naturally occurring silt/sand substratum, as well as terrigenous runoff which may be partially retained within the embayment, turbidity has often been elevated at Transect 2 relative to the other transect sites. It is important to note that in surveys conducted since July 2002, water clarity in Makena Bay has improved greatly compared to preceding surveys in 2001 which reflected conditions following substantial input of terrigenous materials from a flash-flood that occurred in October 1999. Since that time, a large retention basin has been constructed on the upper slopes of Makena Resort in the watershed that flows into Makena Bay.

Patterns in the concentrations of Chl *a* showed higher values near the shoreline compared to offshore values at all sites during June 2009 (Figure 3). Site 2 had a distinctly higher shoreline value ($2.58 \mu\text{g/L}$) compared to the other sites (Table 1 and Figure 3).

Surface water temperature ranged between 25.0°C and 26.6°C during the June 2009 survey with the lowest measurement in the shoreline sample at Site 3-A (Tables 1 and 2). At Sites 3-A and 4, temperatures were lowest at the shoreline and steadily increased with distance offshore while at Sites 1 and 2, temperature decreased with distance offshore (Table 1 and Figure 3). At Site 3 temperature remained nearly constant along the entire length of the transect varying by only $0.1 - 0.2^\circ\text{C}$.

In many areas of the Hawaiian Islands, input of low salinity groundwater to the nearshore ocean creates a distinct buoyant surface lens that can persist for some distance offshore. Buoyant surface layers are generally found in areas where turbulent processes (primarily wave action) are insufficient to completely mix the water column in the nearshore zone. Figures 2 -15 and Tables 1 and 2 show concentrations of water chemistry constituents with respect to vertical stratification. During the June 2009 survey, vertical stratification was evident for Si, NO_3^- , TN and salinity along all transects with the most pronounced gradients.

With respect to the other constituents of water chemistry, variations between surface and deep samples were generally small and showed no apparent trend with distance offshore (Figures 2-15).

B. Temporal Comparison of Monitoring Results

Figures 4-15 show mean concentrations (\pm standard error) of water chemistry constituents from surface and deep samples at Transect Sites 1-4 from the twenty-three monitoring surveys conducted from 1995 to 2008. In addition, the results of the most recent survey in June 2009 are also shown on each plot. Because Site 3-A was not added to the sampling regime until June 2007, data from this site is not yet included in Figures 4-15.

With a few exceptions, surface concentrations of most constituents during the June 2009 survey were within the mean ranges of past surveys (Figure 7-15). Deviations from the means were most notable at Site 3 where the June 2009 data for Si and NO_3^- were higher than the mean at all sites along the transect (Figure 10). Concentrations of Si were also higher than the means within 5 m of the shoreline at Site 2 (Figure 7). Concentrations of NH_4^+ and turbidity were also higher during the most recent survey compared to the surface mean values at Sites 1 and 4 (Figures 6 and 15). For all sites, temperature in June 2009 was approximately 0.5°C higher than the mean values (Figures 6, 9, 12 and 15). These variations can be a result of sampling during a period of particularly low mixing of groundwater and ocean water in the nearshore zone, or may reflect an increase in nutrient subsidies to groundwater as a result of activities on land.

C. Conservative Mixing Analysis

A useful treatment of water chemistry data for interpreting the extent of material input from land is application of a hydrographic mixing model. In the simplest form, such a model consists of plotting the concentration of a dissolved chemical species as a function of salinity. Comparison of the curves produced by such plots with conservative mixing lines provides an indication of the origin and fate of the material in question (Officer 1979, Dollar and Atkinson 1992, Smith and Atkinson 1993).

Figure 16 shows plots of concentrations of four chemical constituents (Si, NO_3^- , PO_4^{3-} , and NH_4^+) as functions of salinity for samples collected in June 2009. Figures 17 and 18 show the same type of plot with data pooled by transect site for a composite of all past surveys, as well as for the most recent survey. Each graph also shows four conservative mixing lines that are constructed by connecting the end member concentrations of open ocean water with irrigation well No. 4 located on the upper North Course of the Makena Resort (representative of groundwater upslope of the Makena Resort).

If the parameter in question displays purely conservative behavior (no input or removal from any process other than physical mixing), data points should fall on, or very near, the conservative mixing line. If, however, external material is added to the system through processes such as leaching of fertilizer nutrients to groundwater, data points will fall above the mixing line. If

material is being removed from the system by processes such as uptake by biotic metabolic processes, data points will fall below the mixing line.

Dissolved Si represents a check on the model as this material is present in high concentration in groundwater, but is not a major component of fertilizer. In addition, Si is not utilized rapidly within the nearshore environment by biological processes. It can be seen in Figure 16 that when concentrations of Si are plotted as functions of salinity, all but four data points fall on the conservative mixing line created by connecting endpoint concentrations from water collected from the upslope irrigation well and the open ocean. Such good agreement indicates that marine waters at the five transect sites are primarily a mixture of groundwater flowing beneath the project and ocean water. The four points that fall below the mixing line are from shoreline samples at Sites 1, 2, and 3A. Over the course of monitoring, data points from Site 1 have consistently been below the Si mixing lines (Figure 17). These results indicate that with the exception of Transect 1, groundwater endmembers from upslope Well No. 4 provides a valid representation of groundwater that enters the ocean following flow through the Makena development. Over the course of monitoring since 1995, the relationship between salinity and Si has remained nearly constant (Figure 17).

NO_3^- is the form of nitrogen most common in fertilizer mixes that are used for enhancing turf growth. When the concentrations of NO_3^- are plotted as functions of salinity, data from different transect prescribes distinctly different patterns (Figure 16). Data points from Transects 2 (Makena Bay) and 4 (Control transect) lie on the well water and ocean water conservative mixing line. The position of these two data arrays indicates that the source of NO_3^- entering the ocean at these sites contains little or no subsidies from activities on land. Inspection of the long-term mixing data (Figure 17) indicates that with the exception of two data points, all of the values of NO_3^- from Control Site 4 fall on, or very near, the conservative mixing line. Such a result validates that Site 4 is indeed a good water quality "control" area.

Conversely, data points from the nearshore samples at Transects 1, 3, and 3-A all fall well above the conservative mixing line, indicating various subsidies of NO_3^- to the ocean from sources on land. Data points for Sites 3 and 3-A are similar in slope, and are slightly steeper in slope than data points from Site 1 (Figure 16). Such relationships indicate subsidies of NO_3^- at Transect sites 1, 3 and 3-A are likely a result of leaching of golf course fertilizers to the groundwater lens. In addition to the golf courses, however, residences near the shoreline at Site 1 include landscaping and lawns, while residences and a wetland lie directly inshore from Site 3.

Transect Site 1 has also been used as a monitoring station for a similar evaluation of the effects of the Wailea Golf Courses on water chemistry that commenced in 1989. The lowest concentrations of NO_3^- relative to salinity at Transect site 1 occurred during the initial two years of study, with subsequent higher concentrations since 1992. Hence, there appears to have been an increase of NO_3^- in nearshore waters since 1992 that was not occurring in 1989-1991. Completion of the Wailea Gold Course occurred in December 1993, while completion of the Makena North Course occurred in November 1993. As the southern region of the Wailea Course and the northern part of the Makena Course abut each other in the makai-mauka direction landward of ocean Transect 1, the increased concentrations of NO_3^- evident in Figure 16 may be a result of leaching of

fertilizer materials from the combined golf courses to groundwater that enters the ocean in the sampling area.

Mixing analyses also indicate an ongoing input of NO_3^- at the shoreline of Stations 3 and 3A located off the existing Makena Golf Course, as well as several new residences that have been constructed adjacent to the Golf Course (Figures 16 and 17). Such subsidies have been noted in past surveys, and it can be seen in Figure 17 that the magnitude of the slope of data points in the December 2008 survey is distinctly lower than in previous surveys. Hence, these data indicate that the subsidies of NO_3^- are not progressively increasing. In June 2008, renovation of the golf course fairways directly adjacent to the ocean began which included the complete removal of all turf and re-shaping of the fairways. Application of fertilizer was also curtailed and is not expected to be resumed for over one year. Future monitoring will clarify if the trend of NO_3^- input to the ocean is indeed decreasing.

While the data reveal a long-term subsidy to the concentration of NO_3^- in groundwater and the nearshore zone at several of the sampling sites, the concentrations of NO_3^- fall in clearly linear relationship as functions of salinity. The linearity of the data array indicates that there is no detectable uptake of this material by the marine environment. Such lack of uptake indicates that the nutrients are not being removed from the water column by metabolic reactions that could change the composition of the marine environment. Rather, the nutrient subsidies are diluted to background oceanic levels by physical processes of wind and wave mixing. As a result, the increased nutrients do not appear to have the potential to cause alteration in biological community composition or function.

Similar situations have also been observed in other locales in the Hawaiian islands where nutrient subsidies from golf course leaching result in excess NO_3^- in the nearshore zone. At Keauhou Bay on the Big Island, it was shown that owing to the distinct vertical stratification in the nearshore zone, the excess nutrients never come into contact with benthic communities, thereby limiting the potential for increased uptake by benthic algae. In addition, the residence time of the high nutrient water was short enough within the embayment to preclude phytoplankton blooms. As a result, while NO_3^- concentrations doubled as a result of golf course leaching for a period of at least several years, there was no detectable negative effect to the marine environment (Dollar and Atkinson 1992). Owing to the unrestricted nature of circulation and mixing off the Makena project (no confined embayments) it is reasonable to assume that the excess NO_3^- subsidies that are apparent in the present study will not result in alteration to biological communities.

Indeed, surveys of the nearshore marine habitats off of Makena reveal a generally healthy coral reef that does not appear to exhibit any negative effects from nutrient loading, particularly in the form of abundant algal biomass (Marine Research Consultants 2006). In addition to the lack of negative impacts to offshore coral communities, inspection of the entire shoreline fronting the Makena Resort revealed that there are no areas where excessive algal growth is presently occurring.

The other form of dissolved inorganic nitrogen, NH_4^+ , does not show a linear pattern of distribution with respect to salinity for either the June 2009 survey (Figure 16) or the entire monitoring program (Figure 18). Some samples with near oceanic salinity also displayed the highest concentrations of NH_4^+ . The lack of a correlation between salinity and concentration of

NH_4^+ suggests that this form of nitrogen is not present in the marine environment as a result of mixing from groundwater sources. Rather, NH_4^+ is generated by natural biotic activity in the ocean waters off Makena. However, during the June 2009 survey, the highest measurements for NH_4^+ occurred in low salinity nearshore water from Sites 1 and 3-A.

PO_4^{3-} is also a major component of fertilizer, but is usually not found to leach to groundwater to the extent of NO_3^- , owing to a high absorptive affinity of phosphorus in soils. During June 2009, data points with salinities less than 32.5‰ fall below the mixing line. Other data points representing PO_4^{3-} vs. salinity do not show consistent linearity with respect to the conservative mixing line and cluster around the endpoint. Thus, the elevated NO_3^- , which is likely a result of golf course and residential landscaping, is not reflected in similar subsidies of PO_4^{3-} .

D. Time Course Mixing Analyses

While it is possible to evaluate temporal changes from repetitive surveys conducted over time in terms of concentrations of water chemistry constituents (See Section C), a more informative and accurate method of evaluating changes over time is to utilize the results of scaling nutrient concentrations to salinity. As discussed above, the simple hydrographic mixing model consisting of plotting concentrations of nutrient constituents versus salinity eliminates the ambiguity associated with comparing only the concentrations of samples collected during multiple samplings at different stages of tide and weather conditions. Figures 19 and 20 show plots of Si and NO_3^- , respectively, as functions of salinity collected during each year of sampling (1995-2009). Also shown in Figures 19 and 20 are straight lines that represent the least squares linear regression fitted through concentrations of Si and NO_3^- as functions of salinity at each monitoring site for each year. Tables 6-8 show the numerical values of the Y-intercepts, slopes, and respective upper and lower 95% confidence limits of linear regressions fitted through the data points for Si, NO_3^- , and PO_4^{3-} as functions of salinity for each year of monitoring. The magnitude of the contribution of nutrients originating from land based activities to groundwater will be reflected in both the steepness of the slope and the magnitude of the Y-intercept of the regression line fitted through the concentrations scaled to salinity (the Y-intercept can be interpreted as the concentration that would occur at a salinity of zero if the distribution of data points is linear). This relationship is valid because with increasing contributions from land, nutrient concentrations in any given parcel of water will increase with no corresponding change in salinity. Hence, if the contribution from land to groundwater nutrient composition is increasing over time, there would be progressive increases in the absolute value of the slopes, as well as the Y-intercepts of the regression lines fitted through each set of annual nutrient concentrations when plotted as functions of salinity. Conversely, if the contributions to groundwater from land are decreasing, there will be decreases in the absolute values of the slopes and Y-intercepts.

Plots of the values of the slopes (Figure 21) and Y-intercepts (Figure 22) of regression lines fitted through concentrations of Si, NO_3^- and PO_4^{3-} scaled to salinity during each survey year provide an indication of the changes that have been occurring over time in the nearshore ocean off the Makena Resort. As stated above, Si provides the best case for evaluating the effectiveness of the method, as Si is present in high concentration in groundwater but is not a component of fertilizers. NO_3^- and PO_4^{3-} are the forms of nitrogen and phosphorus, respectively, found in high

concentrations in groundwater relative to ocean water, and are the major nutrient constituents found in fertilizers.

Examination of Figures 21 and 22, as well as Tables 6-8 reveal that none of the slopes or Y-intercepts of Si , NO_3^- and PO_4^{3-} from 1995 to 2009 at any of the transect sites exhibit any indication of progressively increasing or decreasing values over the course of monitoring. The term "REGSLOPE" in Tables 6-8 denotes the values of the slopes and 95% confidence limits of linear regressions of the values of the yearly slopes and Y-intercepts as a function of time. For all sites, the upper and lower 95% confidence limits of the REGSLOPE coefficients are not significantly different than zero, indicating that there is no statistically significant increase or decrease in the salinity-scaled concentrations of Si , NO_3^- and PO_4^{3-} over the course of the monitoring program (Tables 6-8).

For all three nutrients, there is little variation in either slopes or Y-intercepts during any year at Site 1, located off the "5 Graves" area downslope from the juncture of the Wailea and Makena Resorts (Figures 21 and 22). Such lack of variation indicates relatively consistent concentrations of Si , NO_3^- and PO_4^{3-} in groundwater entering the ocean over the fourteen years of monitoring. Sites 2 (Makena Landing) and 4 ('Ahihi-Kina'u) also show relative constant trends with time with the exception of 2001 which is marked by large spikes in Si and PO_4^{3-} . Such a fluctuation is not present for NO_3^- in 2001. Sampling in 2001 was conducted during a period of rough winter sea conditions marked by vigorous mixing of the water column. As a result, there was very weak linear relationship between nutrient concentrations and salinity.

At Site 3, located directly downslope for the point of the Makena Golf Course closest to the ocean, there is a trend of decreasing NO_3^- between 2002 and 2004, an increasing trend from 2004 to 2007, followed by another downturn in 2008 - 2009 (Figures 21 and 22). As a result of these reversing trends, there is no overall significant change over the seven-year period of monitoring. The multiple reversing trend may reflect changes in land use, such as variation in fertilizer application or construction-related activities in 2002-2004 versus 2004-2007. In June of 2008, the golf course fronting the ocean in this area was shut down for re-alignment and re-planting. Underground retention/filtration systems were also constructed to mitigate adverse affects of stormwater runoff. At the time of this survey, new turf grass had been applied but the course remained closed and the filtration systems were not yet operational.

F. Compliance with DOH Standards

Tables 1 and 2 also show samples that exceed DOH water quality standards for open coastal waters under "wet" and "dry" conditions. These criteria are applied depending upon whether the area is likely to receive less than (dry) or greater than (wet) 3 million gallons of groundwater and/or surface water input per mile per day. As it is not possible to accurately estimate groundwater and surface water discharge, both wet and dry standards are considered. DOH standards include specific criteria for three situations; criteria that are not to be exceeded during either 10% or 2% of the time, and criteria that are not to be exceeded by the geometric mean of samples. With twenty-three samplings collected to date, comparison of the 10% or 2% of the time

criteria for any sample is not statistically meaningful. However, comparing sample concentrations to these criteria provide an indication of whether water quality is near the stated specific criteria.

Boxed values in Tables 1 and 2 show instances where measurements exceed the DOH standards under dry conditions, while boxed and shaded values show instances where measurements exceed DOH standards under wet conditions.

Results from the June 2009 survey indicated several measurements of NO_3^- , NH_4^+ and TN along all five transect sites exceeded the 10% DOH criteria under wet or dry conditions (Tables 1 and 2). Most of the instances where the DOH criteria for NO_3^- and TN was exceeded were from samples collected within 50 m of the shoreline. One measurement of TP, two of turbidity and three measurements of Chl *a* exceeded the 10% DOH criteria under dry conditions. Under "wet" criteria, one measurement of TP and three measurements of Chl *a* exceeded the DOH criteria while no measurements of turbidity exceeded the standard. It is of interest to note that at Transect Site 4, which is considered the control station beyond the influence of the Makena Resort, exceedance of DOH criteria occurred for NO_3^- , NH_4^+ , TN, turbidity and Chl *a*.

Tables 3 and 4 show geometric means of samples collected at the same locations during the twenty-three increments of the monitoring program at Sites 1, 2 and 4. Geometric means of samples collected over fourteen increments of sampling at Site 3 and three increments of sampling at Site 3-A are also shown. These tables also specify the samples that exceed the DOH geometric mean limits for open coastal waters under "dry" (boxed) and "wet" (boxed and shaded) conditions. For NO_3^- , NH_4^+ , and TN numerous dry and wet standards were exceeded on all transects. Five samples of TP and sixteen samples of turbidity exceeded standards. All but two samples exceed the geometric mean standards for Chl *a*.

Site 4 is considered a control transect, in that it is not located offshore of a resort, golf course or dense residential development. It can be seen in Tables 3 and 4, however, that the number of samples that exceed geometric mean criteria at Site 4 are comparable to the other three sites, all of which are located downslope from the Makena Resort. Hence, Resort activities, including golf courses cannot be attributed as the sole (or even major) factor causing water quality to exceed geometric mean standards.

Several comments can be made regarding the present DOH water quality standards and how they apply to the monitoring program at the Makena Resort. As noted above, the category of water quality standards that are applicable for the Makena Monitoring program are "Open Coastal Waters." As the name implies, these standards apply to "open" waters that can be reasonably defined as "waters beyond the direct influence of land." In order to evaluate the effects of land uses on the nearshore ocean off Makena, the selected sampling regime collects water within a zone that extends from the shoreline to the open coastal ocean. As a result, sampling takes place within the region of ocean that is directly influenced by land. If the monitoring protocol were changed to include only those sampling locations beyond 50-100 m from shore (i.e., open coastal waters), which is completely valid with respect to meeting DOH regulatory compliance, virtually none of the factors discussed above relating to the effects of activities on land to the nearshore ocean would not be observed.

Initial steps have been taken by DOH to rectify this situation. During revision of the Department of Health water quality standards in 2004, a unique set of monitoring criteria was added for the West Coast of the Island of Hawaii (i.e., "Kona standards"). The rationale for these unique standards was the recognition that existing numerical "standards" represent offshore coastal waters that are beyond the natural confluence of land and the nearshore ocean. As a result, the West Hawaii standards recognize that groundwater entering the ocean at the shoreline contains substantially elevated nutrients relative to open coastal waters. As a result, the Kona criteria provide the potential to meet water quality standards with elevated nutrient concentrations resulting from natural sources of groundwater input. As the same processes of groundwater discharge to the coastal ocean have been documented in Maui, it is hopeful that similar new provisions of the water quality standards will soon be applicable to the South Maui area.

III. SUMMARY

- The twenty-third phase of water chemistry monitoring of the nearshore ocean off the Makena Resort was carried out on June 20, 2009. Sixty-two ocean water samples were collected on four transects spaced along the project ocean frontage and on one control transect. Site 1 was located at the northern boundary of the project, Site 2 was located near the central part of the Makena North Golf Course in the center of Makena Bay, Site 3-A (initiated during the June 2007 survey) was located near the southern boundary of Maluaka Bay, Site 3 was downslope from the part of Makena South Golf Course that comes closest to the shoreline, and Control Site 4 was located to the south of Makena Resort near the northern boundary of the 'Ahihi-Kina'u Natural Area Reserve. Sampling transects extended from the shoreline out to the open coastal ocean. Water samples were analyzed for chemical criteria specified by DOH water quality standards, as well as several additional criteria. In addition, water samples were collected from eight irrigation wells and an irrigation lake.
- Water chemistry constituents that occur in high concentration in groundwater (Si , NO_3^- and TN) displayed distinct horizontal gradients with high concentrations nearest to shore and decreasing concentrations moving seaward. Groundwater input (based on salinity) was greatest at Sites 1, 2 and 3-A, but was also evident at the other two sites. As Site 4 was not located in the vicinity of the Makena Resort, it is apparent that groundwater input is not solely a function of Resort land usage.
- Vertical stratification of the water column was also evident on all transects during June 2009, with many surface samples displaying higher nutrient and lower salinities than the corresponding bottom samples. The strong vertical and horizontal patterns of distribution indicate that physical mixing processes generated by tide, wind, waves and currents were insufficient to completely mix the water column throughout the sampling area during the time of the monitoring survey.
- $\text{Chl } a$ was elevated near the shoreline compared to offshore samples with Site 2 having distinctly higher values. Turbidity was elevated in the shoreline samples at all five sites and was higher in magnitude at Sites 1 and 4 compared to the other sites. Site 2, located at the point

where sediment-laden storm water runoff entered the ocean following a flash flood in October 1999 did not display elevated turbidity during the present survey.

- Other organic water chemistry constituents that do not occur in high concentrations in groundwater (NH_4^+ , TON, TOP) did not show any distinctive patterns with respect to horizontal gradients. Concentrations of NH_4^+ , however, were elevated in the shoreline samples at four of the five sites.
- Scaling nutrient concentrations to salinity indicates that there were measurable subsidies of NO_3^- to groundwater that enters the nearshore ocean at three Transect sites. Results of the June 2009 monitoring indicated that these subsidies were greatest in magnitude at Sites 3A and 3, followed by Site 1. No subsidies of NO_3^- were apparent at Site 2 (Makena Landing) or Site 4 ('Ahihi-Kina'u). These subsidies, which are likely a result of land uses involving fertilizers, substantially increase the concentration of NO_3^- with respect to salinity in groundwater flowing to the ocean compared to natural groundwater. The area shoreward of Site 1 includes the juncture of the southern part of the Wailea Gold Course and the northern part of the Makena North Course, as well as residential development. Sites 3 and 3A are directly downslope from the Makena South Course in an area where the golf course extends to the shoreline. In addition, private residences are near completion upslope of Transect 3, and it is possible that a cesspool remains from a house that was recently torn down. Hence, the subsidies of NO_3^- noted at these sites may result from a combination of sources.
- Linear regression statistics of nutrient concentration plotted as functions of salinity are useful for evaluating changes to water quality over time. When the regression values of nutrient concentrations versus salinity are plotted as a function of time, there are no statistically significant increases or decreases over the fourteen years of monitoring at any of the survey sites. The lack of increase in these slopes and intercepts indicate that there has been no consistent change in nutrient input from land to groundwater that enters the ocean from 1995 to 2009 (2002 to 2009 at Site 2). At Site 3 off the Makena Resort South Golf Course, there was a progressive decrease in NO_3^- input between 2002 and 2004, followed by an increase between 2004 and 2007, and another decrease in 2008-2009. Further monitoring at this site will be of interest to note the future direction of the oscillating trends noted in the last seven years.
- Comparing water chemistry parameters to DOH standards revealed that several measurements of NO_3^- , NH_4^+ and TN, and a few of TP, turbidity and Chl *a* exceeded the DOH "not to exceed more than 10% of the time" criteria for dry and wet conditions of open coastal waters. It is apparent that the concentrations of NO_3^- in nearshore marine waters that contains a mixture of seawater and natural groundwater may exceed DOH criteria with no subsidies from human activities on land. Numerous values of NO_3^- , NH_4^+ , TN, turbidity and Chl *a* exceeded specified limits for geometric means. Such exceedances occurred at all survey sites, including the control site that was far from any golf course influence. The consistent exceedance of water quality standards is in large part a consequence of the standards not accounting for the natural effects of groundwater discharge to the nearshore ocean and resultant zones of mixing.

- As in past surveys, there is a subsidy of dissolved inorganic nutrients (e.g., NO_3^- and sometimes to a lesser extent PO_4^{3-}) to groundwater that enters the nearshore ocean at sampling sites downslope from parts of the Makena Resort. Without question, such input is a consequence of various land use activities. However, none of these inputs have increased significantly over time, although there is an indication of the beginning of a declining trend in the most recent data. Monitoring of coral reef community structure that is part of the ongoing monitoring, as well as the noted lack of any nuisance algal aggregations in the nearshore area indicate that the nutrient subsidies are not detrimental to marine community structure.
- The next phase of the Makena Resort monitoring program is scheduled for the June of 2010.

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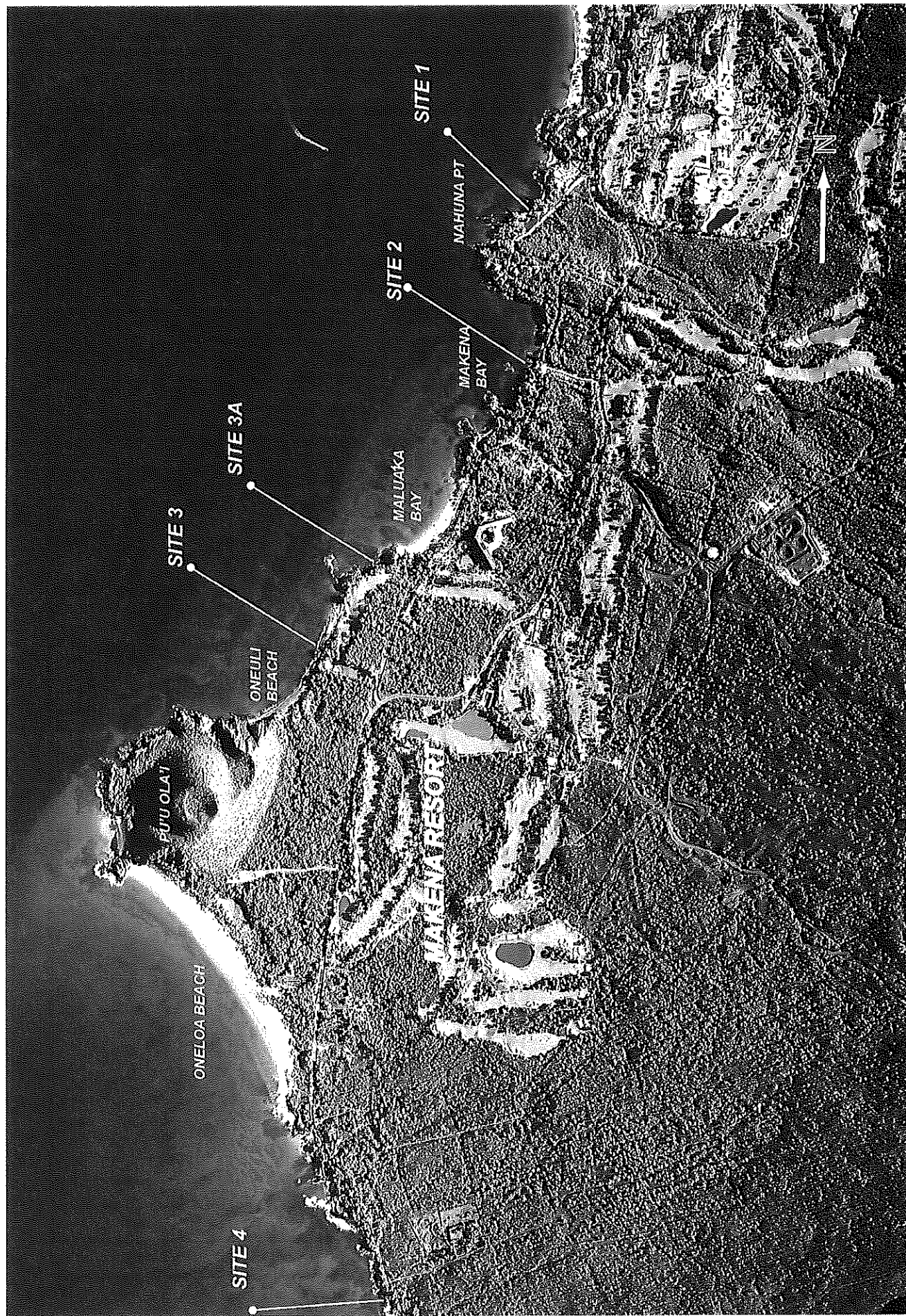


FIGURE 1. Aerial photograph of Makena Resort on southwest coastline of Maui. Also shown are locations of five water sampling transects that extend from the shoreline to 150-200 m from shore. The southern end of the Wailea golf course is visible at right.

TABLE 1. Water chemistry measurements from ocean water samples collected in the vicinity of the Makena Resort on June 20, 2009. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit. Also shown are the State of Hawaii, Department of Health (DOH) "not to exceed more than 10% of the time" and "not to exceed more than 2% of the time" water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH 10% "dry" standards; boxed and shaded values exceed DOH 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	DEPTH (m)	PO ₄ ³⁻ (μM)	NO ₃ ⁻ (μM)	NH ₄ ⁺ (μM)	Si (μM)	TOP (μM)	TON (μM)	TP (μM)	TN (μM)	TURB (NTU)	SALINITY (ppt)	CHL a (μg/L)	TEMP (deg.C)	pH (std.units)	O ₂ % Sat
MAKENA 1	0 S	0.1	0.14	43.05	3.44	86.08	0.33	13.50	0.47	59.99	0.58	28.451	0.69	26.4	8.17	98.4
	2 S	0.1	0.29	26.31	0.76	58.83	0.30	12.37	0.59	39.44	0.38	30.858	0.67	26.4	8.21	98.4
	5 S	0.1	0.11	11.86	0.01	28.74	0.28	10.25	0.39	22.12	0.26	33.148	0.35	26.4	8.20	99.4
	5 D	1.0	0.28	10.14	0.37	25.58	0.27	11.23	0.55	21.74	0.23	33.355	0.39	26.4	8.20	99.3
	10 S	0.1	0.10	8.39	0.16	23.76	0.27	11.19	0.37	19.74	0.25	33.469	0.31	26.4	8.19	100.4
	10 D	1.7	0.20	7.68	0.31	22.05	0.28	9.95	0.48	17.94	0.27	33.577	0.47	26.5	8.19	100.4
	50 S	0.1	0.05	1.51	0.24	6.26	0.29	10.24	0.34	11.99	0.17	34.670	0.17	26.2	8.12	100.8
	50 D	4.4	0.07	0.02	0.03	1.84	0.29	8.83	0.36	8.88	0.17	34.958	0.12	26.0	8.13	107.5
	100 S	0.1	0.07	2.53	0.08	9.28	0.28	9.71	0.35	12.32	0.15	34.513	0.09	25.9	8.11	97.8
	100 D	6.2	BDL	0.04	BDL	1.82	0.33	10.11	0.33	10.15	0.10	34.945	0.13	26.0	8.13	108.4
	150 S	0.1	0.06	0.42	0.11	3.08	0.28	10.47	0.34	11.00	0.12	34.861	0.14	26.2	8.12	96.4
	150 D	11.7	0.08	0.05	0.19	1.62	0.30	9.56	0.38	9.80	0.15	34.958	0.08	26.0	8.13	112.9
MAKENA 2	0 S	0.1	0.49	37.05	0.69	131.58	0.25	11.77	0.74	49.51	0.30	25.919	2.58	26.4	8.18	99.2
	2 S	0.1	0.10	2.61	0.40	26.06	0.31	12.12	0.41	15.13	0.27	32.871	1.29	26.4	8.26	100.2
	5 S	0.1	0.10	2.55	0.25	11.45	0.27	9.97	0.37	12.77	0.41	34.275	0.41	26.3	8.13	100.8
	5 D	1.2	0.26	1.84	0.58	9.44	0.29	11.78	0.55	14.20	0.28	34.437	0.45	26.3	8.12	99.2
	10 S	0.1	0.21	1.57	0.45	8.28	0.27	9.49	0.48	11.51	0.30	34.481	0.28	26.3	8.12	99.3
	10 D	1.5	0.10	1.30	0.32	8.00	0.26	8.64	0.36	10.26	0.36	34.538	0.27	26.2	8.13	98.2
	50 S	0.1	0.02	2.37	0.45	13.54	0.31	9.71	0.33	12.53	0.21	34.090	0.43	26.0	8.11	99.3
	50 D	2.8	0.24	0.01	0.67	2.32	0.27	9.32	0.51	10.00	0.14	34.919	0.22	26.0	8.12	102.5
	100 S	0.1	0.15	0.19	0.49	3.17	0.27	9.03	0.42	9.71	0.13	34.865	0.25	26.1	8.12	99.7
	100 D	4.7	0.14	0.01	0.31	2.24	0.25	8.76	0.39	9.08	0.10	34.955	0.19	26.0	8.14	103.5
	150 S	0.1	0.18	0.21	0.31	3.84	0.26	10.50	0.44	11.02	0.13	34.830	0.18	26.0	8.12	97.6
	150 D	11.4	0.14	BDL	0.35	2.42	0.29	9.77	0.43	10.12	0.12	34.917	0.31	26.0	8.14	103.2
200 S	0.1	0.04	0.06	0.58	2.28	0.33	10.70	0.37	11.34	0.10	34.956	0.18	26.1	8.13	99.8	
200 D	16.0	0.03	0.06	0.48	2.10	0.29	8.94	0.32	9.48	0.09	34.970	0.13	25.9	8.14	102.3	
MAKENA 3-A	0 S	0.1	1.78	187.0	0.45	442.04	0.12	8.96	1.90	196.4	0.17	10.890	0.25	25.0	7.69	96.3
	2 S	0.1	0.98	121.1	0.53	237.49	0.08	8.56	1.06	130.2	0.25	22.904	0.47	25.4	7.82	99.2
	5 S	0.1	0.21	36.28	0.92	75.44	0.26	8.42	0.47	45.62	0.38	31.359	0.25	25.3	8.00	99.8
	5 D	1.0	0.06	14.15	0.38	34.12	0.31	7.56	0.37	22.09	0.21	33.488	0.40	25.7	8.06	98.4
	10 S	0.1	0.06	25.81	0.18	56.81	0.28	7.67	0.34	33.66	0.20	32.290	0.27	25.9	8.04	99.4
	10 D	1.8	0.16	1.95	0.06	8.44	0.26	8.70	0.42	10.71	0.15	34.736	0.20	25.9	8.11	98.2
	50 S	0.1	0.29	15.03	0.32	36.37	0.22	8.41	0.51	23.76	0.32	33.363	0.22	26.0	8.02	99.1
	50 D	4.3	0.20	0.19	0.40	2.72	0.27	9.01	0.47	9.60	0.13	34.932	0.28	26.1	8.11	100.9
	100 S	0.0	0.05	4.99	0.16	15.00	0.24	7.76	0.29	12.91	0.16	34.382	0.17	26.1	8.06	93.6
	100 D	5.0	0.04	0.03	0.41	2.18	0.26	8.52	0.30	8.96	0.12	34.963	0.25	26.1	8.12	102.3
	150 S	0.1	0.07	0.25	0.63	3.70	0.32	8.95	0.39	9.83	0.15	34.902	0.09	26.1	8.12	100.3
	150 D	11.5	0.05	0.03	0.24	2.16	0.25	8.83	0.30	9.10	0.12	34.969	0.09	25.8	8.13	112.5
MAKENA 3	0 S	0.1	0.09	26.22	0.31	31.78	0.28	9.53	0.37	36.06	0.28	33.837	0.35	26.0	8.07	102.4
	2 S	0.1	0.05	17.92	0.49	24.26	0.24	7.68	0.29	26.09	0.22	34.231	0.59	26.0	8.05	101.4
	5 S	0.1	0.03	17.98	BDL	24.75	0.27	9.96	0.30	27.94	0.25	34.208	0.30	26.0	8.04	100.3
	5 D	1.0	0.17	15.32	BDL	21.73	0.30	8.14	0.47	23.46	0.29	34.298	0.29	26.0	8.04	100.3
	10 S	0.1	0.27	26.01	0.07	31.54	0.29	6.83	0.56	32.91	0.29	33.920	0.25	26.1	8.03	100.5
	10 D	1.9	0.06	17.63	0.16	23.39	0.27	9.43	0.33	27.22	0.29	34.224	0.41	26.1	8.03	99.8
	50 S	0.1	0.12	11.26	0.06	15.85	0.29	8.28	0.41	19.60	0.19	34.508	0.23	26.0	8.04	99.4
	50 D	2.3	0.22	2.36	0.17	5.53	0.30	8.38	0.52	10.91	0.16	34.866	0.20	26.1	8.09	97.2
	100 S	0.1	0.09	4.26	0.16	7.74	0.31	8.07	0.40	12.49	0.19	34.804	0.10	26.0	8.07	98.6
	100 D	6.3	0.14	0.19	0.25	2.23	0.31	7.94	0.45	8.38	0.12	34.965	0.12	26.0	8.13	103.9
	150 S	0.1	0.03	0.08	0.03	2.02	0.29	8.76	0.32	8.87	0.11	34.971	0.13	26.1	8.14	98.6
	150 D	9.2	0.03	0.05	0.06	1.91	0.29	9.34	0.32	9.45	0.11	34.983	0.14	25.8	8.14	110.9
MAKENA 4	0 S	0.1	0.18	9.59	1.19	67.55	0.37	10.50	0.55	21.28	0.65	31.860	0.97	25.4	8.06	101.4
	2 S	0.1	0.22	8.51	0.14	60.81	0.30	8.26	0.52	16.91	0.38	32.160	0.43	25.4	8.08	100.4
	5 S	0.1	0.05	4.13	0.20	32.91	0.26	8.79	0.31	13.12	0.20	33.571	0.33	25.4	8.07	100.4
	5 D	1.0	0.21	3.44	0.14	28.98	0.30	7.56	0.51	11.14	0.17	33.757	0.31	25.4	8.07	99.4
	10 S	0.1	0.04	1.05	0.06	12.91	0.28	8.35	0.32	9.46	0.22	34.554	0.27	25.4	8.06	98.2
	10 D	2.0	0.05	1.19	0.06	14.82	0.30	6.72	0.35	7.97	0.22	34.465	0.26	25.4	8.05	98.0
	50 S	0.1	0.07	1.00	0.23	11.46	0.32	7.87	0.39	9.10	0.21	34.642	0.27	25.6	8.06	98.0
	50 D	4.4	0.19	0.58	0.26	8.90	0.28	7.62	0.47	8.46	0.19	34.716	0.22	25.7	8.07	95.4
	100 S	0.1	0.16	0.57	0.49	5.66	0.33	8.63	0.49	9.69	0.16	34.830	0.18	25.6	8.08	98.4
	100 D	6.4	0.04	BDL	0.23	3.41	0.30	7.72	0.34	7.95	0.15	34.926	0.15	25.8	8.10	98.4
	150 S	0.1	0.04	0.85	0.22	10.45	0.27	7.49	0.31	8.56	0.23	34.671	0.14	25.6	8.07	98.5
	150 D	7.7	0.09	0.22	0.17	4.78	0.30	7.43	0.39	7.82	0.17	34.963	0.13	25.8	8.09	102.3
DOH WQS	DRY		10% 2%	0.71 1.43	0.36 0.64				0.96 1.45	12.86 17.86	0.50 1.00	*	0.50 1.00	**	***	****
	WET		10% 2%	1.00 1.78	0.61 1.07				1.29 1.93	17.85 25.00	1.25 2.00	*	0.90 1.75	**	***	****

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

****Dissolved Oxygen not to be below 75% saturation.

TABLE 2. Water chemistry measurements from ocean water samples (in $\mu\text{g/L}$) collected in the vicinity of the Makena Resort on June 20, 2009. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit. Also shown are the State of Hawaii, Department of Health (DOH) "not to exceed more than 10% of the time" and "not to exceed more than 2% of the time" water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH 10% "dry" standards; boxed and shaded values exceed DOH 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	DEPTH (m)	PO ₄ ³⁻ (μ g/L)	NO ₃ ⁻ (μ g/L)	NH ₄ ⁺ (μ g/L)	Si (μ g/L)	TOP (μ g/L)	TON (μ g/L)	TP (μ g/L)	TN (μ g/L)	TURB (NTU)	SALINITY (ppt)	CHL <i>a</i> (μ g/L)	TEMP (deg. C)	pH (std units)	O ₂ (% Sat)
MAKENA 1	0 S	0.1	4.34	602.7	48.18	2419	10.23	189.0	14.57	839.9	0.58	28.451	0.69	26.4	8.17	98.4
	2 S	0.1	8.99	368.3	10.64	1653	9.30	173.2	18.29	552.2	0.38	30.858	0.67	26.4	8.21	98.4
	5 S	0.1	3.41	166.0	0.14	807.6	8.68	143.5	12.09	309.7	0.26	33.148	0.35	26.4	8.20	99.4
	5 D	1.0	8.68	142.0	5.18	718.8	8.37	157.2	17.05	304.4	0.23	33.355	0.39	26.4	8.20	99.3
	10 S	0.1	3.10	117.5	2.24	667.7	8.37	156.7	11.47	276.4	0.25	33.469	0.31	26.4	8.19	100.4
	10 D	1.7	6.20	107.5	4.34	619.6	8.68	139.3	14.88	251.2	0.27	33.577	0.47	26.5	8.19	100.4
	50 S	0.1	1.55	21.14	3.36	175.9	8.99	143.4	10.54	167.9	0.17	34.670	0.17	26.2	8.12	100.8
	50 D	4.4	2.17	0.28	0.42	51.7	8.99	123.6	11.16	124.3	0.17	34.958	0.12	26.0	8.13	107.5
	100 S	0.1	2.17	35.42	1.12	260.8	8.68	135.9	10.85	172.5	0.15	34.513	0.09	25.9	8.11	97.8
	100 D	6.2	BDL	0.56	BDL	51.1	10.23	141.5	10.23	142.1	0.10	34.945	0.13	26.0	8.13	108.4
	150 S	0.1	1.86	5.88	1.54	86.5	8.68	146.6	10.54	154.0	0.12	34.861	0.14	26.2	8.12	96.4
	150 D	11.7	2.48	0.70	2.66	45.5	9.30	133.8	11.78	137.2	0.15	34.958	0.08	26.0	8.13	112.9
MAKENA 2	0 S	0.1	15.19	518.7	9.66	3697	7.75	164.8	22.94	693.1	0.30	25.919	2.58	26.4	8.18	99.2
	2 S	0.1	3.10	36.54	5.60	732.3	9.61	169.7	12.71	211.8	0.27	32.871	1.29	26.4	8.26	100.2
	5 S	0.1	3.10	35.70	3.50	321.7	8.37	139.6	11.47	178.8	0.41	34.275	0.41	26.3	8.13	100.8
	5 D	1.2	8.06	25.76	8.12	265.3	8.99	164.9	17.05	198.8	0.28	34.437	0.45	26.3	8.12	99.2
	10 S	0.1	6.51	21.98	6.30	232.7	8.37	132.9	14.88	161.1	0.30	34.481	0.28	26.3	8.12	99.3
	10 D	1.5	3.10	18.20	4.48	224.8	8.06	121.0	11.16	143.6	0.36	34.538	0.27	26.2	8.13	98.2
	50 S	0.1	0.62	33.18	6.30	380.5	9.61	135.9	10.23	175.4	0.21	34.090	0.43	26.0	8.11	99.3
	50 D	2.8	7.44	0.14	9.38	65.2	8.37	130.5	15.81	140.0	0.14	34.919	0.22	26.0	8.12	102.5
	100 S	0.1	4.65	2.66	6.86	89.1	8.37	126.4	13.02	135.9	0.13	34.865	0.25	26.1	8.12	99.7
	100 D	4.7	4.34	0.14	4.34	62.9	7.75	122.6	12.09	127.1	0.10	34.955	0.19	26.0	8.14	103.5
	150 S	0.1	5.58	2.94	4.34	107.9	8.06	147.0	13.64	154.3	0.13	34.830	0.18	26.0	8.12	97.6
	150 D	11.4	4.34	BDL	4.90	68.0	8.99	136.8	13.33	141.7	0.12	34.917	0.31	26.0	8.14	103.2
200 S	0.1	1.24	0.84	8.12	64.1	10.23	149.8	11.47	158.8	0.10	34.956	0.18	26.1	8.13	99.8	
200 D	16.0	0.93	0.84	6.72	59.0	8.99	125.2	9.92	132.7	0.09	34.970	0.13	25.9	8.14	102.3	
MAKENA 3-A	0 S	0.1	55.18	2618	6.30	12421	3.72	125.4	58.90	2749.3	0.17	10.890	0.25	25.0	7.69	96.3
	2 S	0.1	30.38	1696	7.42	6673	2.48	119.8	32.86	1822.9	0.25	22.904	0.47	25.4	7.82	99.2
	5 S	0.1	6.51	507.9	12.89	2120	8.06	117.9	14.57	638.7	0.38	31.359	0.25	25.3	8.00	99.8
	5 D	1.0	1.86	198.1	5.32	958.8	9.61	105.8	11.47	309.3	0.21	33.488	0.40	25.7	8.06	98.4
	10 S	0.1	1.86	361.3	2.52	1596	8.68	107.4	10.54	471.2	0.20	32.290	0.27	25.9	8.04	99.4
	10 D	1.8	4.96	27.30	0.84	237.2	8.06	121.8	13.02	149.9	0.15	34.736	0.20	25.9	8.11	98.2
	50 S	0.1	8.99	210.4	4.48	1022	6.82	117.7	15.81	332.6	0.32	33.363	0.22	26.0	8.02	99.1
	50 D	4.3	6.20	2.66	5.60	76.4	8.37	126.1	14.57	134.4	0.13	34.932	0.28	26.1	8.11	100.9
	100 S	0.0	1.55	69.86	2.24	421.5	7.44	108.6	8.99	180.7	0.16	34.382	0.17	26.1	8.06	93.6
	100 D	5.0	1.24	0.42	5.74	61.3	8.06	119.3	9.30	125.4	0.12	34.963	0.25	26.1	8.12	102.3
	150 S	0.1	2.17	3.50	8.82	104.0	9.92	125.3	12.09	137.6	0.15	34.902	0.09	26.1	8.12	100.3
	150 D	11.5	1.55	0.42	3.36	60.7	7.75	123.6	9.30	127.4	0.12	34.969	0.09	25.8	8.13	112.5
MAKENA 3	0 S	0.1	2.79	367.1	4.34	893.0	8.68	133.4	11.47	504.8	0.28	33.837	0.35	26.0	8.07	102.4
	2 S	0.1	1.55	250.9	6.86	681.7	7.44	107.5	8.99	365.3	0.22	34.231	0.59	26.0	8.05	101.4
	5 S	0.1	0.93	251.7	BDL	695.5	8.37	139.4	9.30	391.2	0.25	34.208	0.30	26.0	8.04	100.3
	5 D	1.0	5.27	214.5	BDL	610.6	9.30	114.0	14.57	328.4	0.29	34.298	0.29	26.0	8.04	100.3
	10 S	0.1	8.37	364.1	0.98	886.3	8.99	95.6	17.36	460.7	0.29	33.920	0.25	26.1	8.03	100.5
	10 D	1.9	1.86	246.8	2.24	657.3	8.37	132.0	10.23	381.1	0.29	34.224	0.41	26.1	8.03	99.8
	50 S	0.1	3.72	157.6	0.84	445.4	8.99	115.9	12.71	274.4	0.19	34.508	0.23	26.0	8.04	99.4
	50 D	2.3	6.82	33.04	2.38	155.4	9.30	117.3	16.12	152.7	0.16	34.866	0.20	26.1	8.09	97.2
	100 S	0.1	2.79	59.64	2.24	217.5	9.61	113.0	12.40	174.9	0.19	34.804	0.10	26.0	8.07	98.6
	100 D	6.3	4.34	2.66	3.50	62.7	9.61	111.2	13.95	117.3	0.12	34.965	0.12	26.0	8.13	103.9
	150 S	0.1	0.93	1.12	0.42	56.8	8.99	122.6	9.92	124.2	0.11	34.971	0.13	26.1	8.14	98.6
	150 D	9.2	0.93	0.70	0.84	53.7	8.99	130.8	9.92	132.3	0.11	34.983	0.14	25.8	8.14	110.9
MAKENA 4	0 S	0.1	5.58	134.3	16.66	1898	11.47	147.0	17.05	297.9	0.65	31.860	0.97	25.4	8.06	101.4
	2 S	0.1	6.82	119.1	1.96	1709	9.30	115.6	16.12	236.7	0.38	32.160	0.43	25.4	8.08	100.4
	5 S	0.1	1.55	57.82	2.80	924.8	8.06	123.1	9.61	183.7	0.20	33.571	0.33	25.4	8.07	100.4
	5 D	1.0	6.51	48.16	1.96	814.3	9.30	105.8	15.81	156.0	0.17	33.757	0.31	25.4	8.07	99.4
	10 S	0.1	1.24	14.70	0.84	362.8	8.68	116.9	9.92	132.4	0.22	34.554	0.27	25.4	8.06	98.2
	10 D	2.0	1.55	16.66	0.84	416.4	9.30	94.1	10.85	111.6	0.22	34.465	0.26	25.4	8.05	98.0
	50 S	0.1	2.17	14.00	3.22	322.0	9.92	110.2	12.09	127.4	0.21	34.642	0.27	25.6	8.06	98.0
	50 D	4.4	5.89	8.12	3.64	250.1	8.68	106.7	14.57	118.4	0.19	34.716	0.22	25.7	8.07	95.4
	100 S	0.1	4.96	7.98	6.86	159.0	10.23	120.8	15.19	135.7	0.16	34.830	0.18	25.6	8.08	98.4
	100 D	6.4	1.24	BDL	3.22	95.8	9.30	108.1	10.54	111.3	0.15	34.926	0.15	25.8	8.10	98.4
	150 S	0.1	1.24	11.90	3.08	293.6	8.37	104.9	9.61	119.8	0.23	34.671	0.14	25.6	8.07	98.5
	150 D	7.7	2.79	3.08	2.38	134.3	9.30	104.0	12.09	109.5	0.17	34.963	0.13	25.8	8.09	102.3
DOH WQS	DRY		10%	10.00	5.00				30.00	180.00	0.50	*	0.50	**	***	****
			2%	20.00	9.00				45.00	250.00	1.00	*	1.00	**	***	****
	WET		10%	14.00	8.50				40.00	250.00	1.25	*	0.90	**	***	****
			2%	25.00	15.00				60.00	350.00	2.00		1.75	**	***	****

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

****Dissolved Oxygen not to be below 75% saturation.

TABLE 3. Geometric mean data from water chemistry measurements (in μM) off the Makena Resort collected since August 1995 from Sites 1, 2, and 4 (N=23); since June 2002 from Site 3 (N=14) and since June 2007 from Site 3-A (N=5). For geometric mean calculations, detection limits were used in cases where sample was below detection limit. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep. Also shown are State of Hawaii, Department of Health (DOH) geometric mean water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH GM 10% "dry" standards; boxed and shaded values exceed DOH GM 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	PO_4^{3-} (μM)	NO_3^- (μM)	NH_4^+ (μM)	Si (μM)	TOP (μM)	TON (μM)	TP (μM)	TN (μM)	TURB (NTU)	SALINITY (ppt)	CHL a ($\mu\text{g/L}$)	TEMP (deg.C)	pH	O2
MAKENA 1	0 S	0.19	36.85	0.36	60.63	0.24	7.26	0.49	51.40	0.34	28.585	0.91	25.6	8.13	102.5
	2 S	0.14	24.65	0.18	43.68	0.25	8.01	0.42	36.25	0.28	31.243	0.86	25.6	8.16	103.4
	5 S	0.11	9.64	0.13	21.08	0.26	8.11	0.39	21.60	0.23	32.773	0.61	25.7	8.16	104.4
	5 D	0.11	7.76	0.21	17.89	0.27	7.60	0.40	18.58	0.19	33.364	0.53	25.7	8.16	104.8
	10 S	0.09	3.69	0.16	9.98	0.26	7.61	0.36	12.79	0.18	34.179	0.40	25.7	8.16	105.3
	10 D	0.10	2.26	0.20	6.80	0.28	7.60	0.40	10.94	0.17	34.413	0.41	25.7	8.15	104.3
	50 S	0.08	2.52	0.22	7.11	0.27	7.45	0.36	11.37	0.15	34.405	0.31	25.7	8.14	100.3
	50 D	0.08	0.30	0.14	2.54	0.28	7.46	0.37	8.16	0.12	34.785	0.28	25.6	8.14	98.6
	100 S	0.08	1.08	0.16	4.84	0.27	6.87	0.37	9.81	0.12	34.529	0.26	25.7	8.13	97.6
	100 D	0.07	0.10	0.09	2.07	0.28	7.45	0.36	7.81	0.09	34.832	0.23	25.6	8.15	97.0
	150 S	0.08	0.30	0.16	3.00	0.27	7.41	0.36	8.69	0.12	34.721	0.21	25.8	8.14	96.7
	150 D	0.08	0.07	0.13	1.82	0.27	7.22	0.37	7.55	0.10	34.837	0.18	25.6	8.15	97.3
MAKENA 2	0 S	0.20	4.17	0.41	22.74	0.32	8.59	0.56	14.48	0.89	33.339	0.91	25.7	8.13	97.3
	2 S	0.18	3.66	0.29	19.49	0.32	8.17	0.53	13.17	0.64	33.558	0.88	25.8	8.14	98.6
	5 S	0.17	3.03	0.31	14.88	0.29	7.40	0.48	11.54	0.46	34.021	0.68	25.7	8.14	98.3
	5 D	0.18	2.76	0.38	14.12	0.31	7.65	0.51	11.82	0.44	34.086	0.86	25.7	8.13	97.7
	10 S	0.13	1.67	0.24	9.61	0.30	5.70	0.45	9.54	0.32	34.368	0.47	25.7	8.14	98.2
	10 D	0.12	1.06	0.27	7.95	0.30	7.34	0.45	9.35	0.27	34.487	0.54	25.7	8.14	97.2
	50 S	0.10	1.17	0.30	7.49	0.32	7.81	0.45	9.82	0.24	34.443	0.37	25.6	8.13	96.6
	50 D	0.11	0.24	0.24	3.26	0.31	7.81	0.44	8.54	0.18	34.776	0.41	25.6	8.14	96.2
	100 S	0.09	0.47	0.22	4.14	0.29	7.50	0.40	8.51	0.16	34.634	0.30	25.7	8.13	96.8
	100 D	0.08	0.15	0.24	2.36	0.29	7.36	0.39	7.97	0.12	34.809	0.29	25.6	8.15	95.9
	150 S	0.09	0.23	0.25	3.07	0.29	7.62	0.39	8.29	0.13	34.759	0.25	25.7	8.14	96.1
	150 D	0.08	0.10	0.16	2.02	0.29	7.76	0.39	8.17	0.10	34.828	0.25	25.6	8.15	96.5
	200 S	0.07	0.13	0.18	2.31	0.29	7.47	0.38	8.06	0.11	34.828	0.28	25.8	8.15	97.4
	200 D	0.07	0.05	0.21	1.71	0.29	7.95	0.38	8.31	0.09	34.859	0.27	25.7	8.16	96.4
MAKENA 3-A	0 S	1.22	170.9	0.85	296.6	0.26	11.19	1.54	185.4	0.18	16.696	0.31	25.1	7.81	94.0
	2 S	0.65	115.3	0.94	193.5	0.24	7.20	1.09	127.2	0.18	23.608	0.49	25.3	7.85	95.0
	5 S	0.22	31.06	0.39	60.72	0.34	12.20	0.64	61.96	0.22	29.480	0.45	25.4	7.95	95.4
	5 D	0.12	14.54	0.50	32.18	0.32	9.89	0.48	30.13	0.17	32.685	0.47	25.5	8.02	95.5
	10 S	0.07	5.85	0.33	16.13	0.30	9.30	0.40	19.58	0.11	33.731	0.25	25.6	8.05	95.8
	10 D	0.06	1.08	0.28	4.43	0.28	7.46	0.37	9.68	0.12	34.761	0.29	25.5	8.08	98.3
	50 S	0.07	1.88	0.48	8.05	0.27	8.97	0.40	14.36	0.12	34.381	0.17	26.0	8.09	97.9
	50 D	0.05	0.10	0.54	2.99	0.29	9.03	0.37	9.77	0.10	34.782	0.18	25.7	8.10	100.0
	100 S	0.07	1.11	0.12	5.93	0.27	7.80	0.36	10.41	0.09	34.659	0.18	26.0	8.08	96.7
	100 D	0.10	0.03	0.51	2.11	0.29	8.33	0.41	8.97	0.07	34.917	0.16	25.6	8.11	99.5
	150 S	0.04	0.20	0.20	3.60	0.31	8.78	0.36	10.62	0.11	34.766	0.15	25.9	8.10	97.4
	150 D	0.04	0.01	0.45	1.46	0.29	8.22	0.34	8.75	0.09	34.934	0.19	25.6	8.11	100.8
MAKENA 3	0 S	0.12	7.40	0.41	17.51	0.27	6.28	0.47	22.70	0.27	33.742	0.57	25.7	8.13	101.2
	2 S	0.14	12.65	0.31	23.61	0.27	6.77	0.48	27.35	0.28	33.759	0.61	25.8	8.11	101.3
	5 S	0.11	7.93	0.22	15.35	0.27	8.23	0.44	21.09	0.20	34.099	0.36	25.8	8.11	101.3
	5 D	0.13	5.21	0.24	11.85	0.28	7.15	0.44	16.95	0.19	34.335	0.43	25.7	8.11	100.3
	10 S	0.09	4.05	0.27	9.25	0.29	7.66	0.41	15.24	0.16	34.417	0.27	25.7	8.12	99.4
	10 D	0.08	2.16	0.23	6.50	0.30	7.88	0.40	12.61	0.14	34.629	0.29	25.6	8.12	99.4
	50 S	0.08	1.53	0.21	5.34	0.28	7.77	0.38	10.98	0.13	34.650	0.23	25.7	8.11	94.8
	50 D	0.08	0.37	0.19	2.83	0.29	7.97	0.39	8.96	0.09	34.809	0.23	25.6	8.13	93.0
	100 S	0.07	0.50	0.27	3.13	0.29	7.53	0.38	8.79	0.11	34.777	0.17	25.7	8.12	95.4
	100 D	0.06	0.11	0.27	1.89	0.29	7.11	0.37	7.71	0.08	34.831	0.18	25.6	8.13	95.0
	150 S	0.05	0.17	0.16	2.25	0.29	7.00	0.36	7.74	0.10	34.795	0.15	25.7	8.15	95.7
	150 D	0.06	0.08	0.12	1.78	0.29	6.98	0.36	7.36	0.09	34.857	0.17	25.6	8.16	96.8
MAKENA 4	0 S	0.19	36.85	0.36	60.63	0.24	7.26	0.49	51.40	0.34	28.585	0.91	25.6	8.13	99.5
	2 S	0.14	24.65	0.18	43.68	0.25	8.01	0.42	36.25	0.28	31.243	0.86	25.6	8.16	101.3
	5 S	0.11	9.64	0.13	21.08	0.26	8.11	0.39	21.60	0.23	32.773	0.61	25.7	8.16	102.9
	5 D	0.11	7.76	0.21	17.89	0.27	7.60	0.40	18.58	0.19	33.364	0.53	25.7	8.16	103.0
	10 S	0.09	3.69	0.16	9.98	0.26	7.61	0.36	12.79	0.18	34.179	0.40	25.7	8.16	100.6
	10 D	0.10	2.26	0.20	6.80	0.28	7.60	0.40	10.94	0.17	34.413	0.41	25.7	8.15	100.6
	50 S	0.08	2.52	0.22	7.11	0.27	7.45	0.36	11.37	0.15	34.405	0.31	25.7	8.14	94.2
	50 D	0.08	0.30	0.14	2.54	0.28	7.46	0.37	8.16	0.12	34.785	0.28	25.6	8.14	93.7
	100 S	0.08	1.08	0.16	4.84	0.27	6.87	0.37	9.81	0.12	34.529	0.26	25.7	8.13	93.9
	100 D	0.07	0.10	0.09	2.07	0.28	7.45	0.36	7.81	0.09	34.832	0.23	25.6	8.15	92.5
	150 S	0.08	0.30	0.16	3.00	0.27	7.41	0.36	8.69	0.12	34.721	0.21	25.8	8.14	95.6
	150 D	0.08	0.07	0.13	1.82	0.27	7.22	0.37	7.55	0.10	34.837	0.18	25.6	8.15	94.2
DOH WQS		DRY	0.25	0.14				0.52	7.86	0.20		0.15			
GEOMETRIC MEAN		WET	0.36	0.25				0.64	10.71	0.50	*	0.30	**	***	

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

TABLE 4. Geometric mean data (in $\mu\text{g/L}$) from water chemistry measurements (in μM) off the Makena Resort collected since August 1995 for Sites 1, 2, and 4 (N=23); since June 2002 from Site 3 (N=14) and since June 2007 from Site 3-A (N=5). For geometric mean calculations, detection limits were used in cases where sample was below detection limit. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep. Also shown are State of Hawaii, Department of Health (DOH) geometric mean water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH GM 10% "dry" standards; boxed and shaded values exceed DOH GM 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	PO ₄ ³⁻ ($\mu\text{g/L}$)	NO ₃ ⁻ ($\mu\text{g/L}$)	NH ₄ ⁺ ($\mu\text{g/L}$)	Si ($\mu\text{g/L}$)	TOP ($\mu\text{g/L}$)	TON ($\mu\text{g/L}$)	TP ($\mu\text{g/L}$)	TN ($\mu\text{g/L}$)	TURB (NTU)	SALINITY (ppt)	CHL a ($\mu\text{g/L}$)	TEMP (deg.C)	pH	O ₂
MAKENA 1	0 S	5.80	516.1	5.00	1703	7.40	101.6	15.10	719.9	0.34	28.585	0.91	25.6	8.13	102.5
	2 S	4.30	345.2	2.50	1227	7.70	112.1	13.00	507.7	0.28	31.243	0.86	25.6	8.16	103.4
	5 S	3.40	135.0	1.80	592.1	8.00	113.5	12.00	302.5	0.23	32.773	0.61	25.7	8.16	104.4
	5 D	3.40	108.6	2.90	502.5	8.30	106.4	12.30	260.2	0.19	33.364	0.53	25.7	8.16	104.8
	10 S	2.70	51.60	2.20	280.3	8.00	106.5	11.10	179.1	0.18	34.179	0.40	25.7	8.16	105.3
	10 D	3.00	31.60	2.80	191.0	8.60	106.4	12.30	153.2	0.17	34.413	0.41	25.7	8.15	104.3
	50 S	2.40	35.20	3.00	199.7	8.30	104.3	11.10	159.2	0.15	34.405	0.31	25.7	8.14	100.3
	50 D	2.40	4.20	1.90	71.35	8.60	104.4	11.40	114.2	0.12	34.785	0.28	25.6	8.14	98.6
	100 S	2.40	15.10	2.20	136.0	8.30	96.20	11.40	137.3	0.12	34.529	0.26	25.7	8.13	97.6
	100 D	2.10	1.40	1.20	58.15	8.60	104.3	11.10	109.3	0.09	34.832	0.23	25.6	8.15	97.0
	150 S	2.40	4.20	2.20	84.27	8.30	103.7	11.10	121.7	0.12	34.721	0.21	25.8	8.14	96.7
	150 D	2.40	0.90	1.80	51.12	8.30	101.1	11.40	105.7	0.10	34.837	0.18	25.6	8.15	97.3
MAKENA 2	0 S	6.10	58.40	5.70	638.8	9.90	120.3	17.30	202.8	0.89	33.339	0.91	25.7	8.13	97.3
	2 S	5.50	51.20	4.00	547.5	9.90	114.4	16.40	184.4	0.64	33.558	0.88	25.8	8.14	98.6
	5 S	5.20	42.40	4.30	418.0	8.90	103.6	14.80	161.6	0.46	34.021	0.68	25.7	8.14	98.3
	5 D	5.50	38.60	5.30	396.6	9.60	107.1	15.70	165.5	0.44	34.086	0.86	25.7	8.13	97.7
	10 S	4.00	23.30	3.30	269.9	9.20	79.80	13.90	133.6	0.32	34.368	0.47	25.7	8.14	98.2
	10 D	3.70	14.80	3.70	223.3	9.20	102.8	13.90	130.9	0.27	34.487	0.54	25.7	8.14	97.2
	50 S	3.00	16.30	4.20	210.4	9.90	109.3	13.90	137.5	0.24	34.443	0.37	25.6	8.13	96.6
	50 D	3.40	3.30	3.30	91.57	9.60	109.3	13.60	119.6	0.18	34.776	0.41	25.6	8.14	96.2
	100 S	2.70	6.50	3.00	116.3	8.90	105.0	12.30	119.1	0.16	34.634	0.30	25.7	8.13	96.8
	100 D	2.40	2.10	3.30	66.29	8.90	103.0	12.00	111.6	0.12	34.809	0.29	25.6	8.15	95.9
	150 S	2.70	3.20	3.50	86.24	8.90	106.7	12.00	116.1	0.13	34.759	0.25	25.7	8.14	96.1
	150 D	2.40	1.40	2.20	56.74	8.90	108.6	12.00	114.4	0.10	34.828	0.25	25.6	8.15	96.5
	200 S	2.10	1.80	2.50	64.89	8.90	104.6	11.70	112.8	0.11	34.828	0.28	25.8	8.15	97.4
	200 D	2.10	0.70	2.90	48.03	8.90	111.3	11.70	116.3	0.09	34.859	0.27	25.7	8.16	96.4
MAKENA 3-A	0 S	37.70	2393	11.90	8332	8.00	156.7	47.60	2596	0.18	16.696	0.31	25.1	7.81	94.0
	2 S	20.10	1615	13.10	5435	7.40	100.8	33.70	1781	0.18	23.608	0.49	25.3	7.85	95.0
	5 S	6.80	435.0	5.40	1706	10.50	170.8	19.80	867.8	0.22	29.480	0.45	25.4	7.95	95.4
	5 D	3.70	203.6	7.00	903.9	9.90	138.5	14.80	422.0	0.17	32.685	0.47	25.5	8.02	95.5
	10 S	2.10	81.90	4.60	453.1	9.20	130.2	12.30	274.2	0.11	33.731	0.25	25.6	8.05	95.8
	10 D	1.80	15.10	3.90	124.4	8.60	104.4	11.40	135.5	0.12	34.761	0.29	25.5	8.08	98.3
	50 S	2.10	26.30	6.70	226.1	8.30	125.6	12.30	201.1	0.12	34.381	0.17	26.0	8.09	97.9
	50 D	1.50	1.40	7.50	83.99	8.90	126.4	11.40	136.8	0.10	34.782	0.18	25.7	8.1	100.0
	100 S	2.10	15.50	1.60	166.6	8.30	109.2	11.10	145.8	0.09	34.659	0.18	26.0	8.08	96.7
	100 D	3.00	0.40	7.10	59.27	8.90	116.6	12.60	125.6	0.07	34.917	0.16	25.6	8.11	99.5
	150 S	1.20	2.80	2.80	101.1	9.60	122.9	11.10	148.7	0.11	34.766	0.15	25.9	8.1	97.4
	150 D	1.20	0.10	6.30	41.01	8.90	115.1	10.50	122.5	0.09	34.934	0.19	25.6	8.11	100.8
MAKENA 3	0 S	3.70	103.6	5.70	491.9	8.30	87.90	14.50	317.9	0.27	33.742	0.57	25.7	8.13	101.2
	2 S	4.30	177.1	4.30	663.2	8.30	94.80	14.80	383.0	0.28	33.759	0.61	25.8	8.11	101.3
	5 S	3.40	111.0	3.00	431.2	8.30	115.2	13.60	295.3	0.20	34.099	0.36	25.8	8.11	101.3
	5 D	4.00	72.90	3.30	332.9	8.60	100.1	13.60	237.4	0.19	34.335	0.43	25.7	8.11	100.3
	10 S	2.70	56.70	3.70	259.8	8.90	107.2	12.60	213.4	0.16	34.417	0.27	25.7	8.12	99.4
	10 D	2.40	30.20	3.20	182.6	9.20	110.3	12.30	176.6	0.14	34.629	0.29	25.6	8.12	99.4
	50 S	2.40	21.40	2.90	150.0	8.60	108.8	11.70	153.7	0.13	34.650	0.23	25.7	8.11	94.8
	50 D	2.40	5.10	2.60	79.49	8.90	111.6	12.00	125.4	0.09	34.809	0.23	25.6	8.13	93.0
	100 S	2.10	7.00	3.70	87.92	8.90	105.4	11.70	123.1	0.11	34.777	0.17	25.7	8.12	95.4
	100 D	1.80	1.50	3.70	53.09	8.90	99.50	11.40	107.9	0.08	34.831	0.18	25.6	8.13	95.0
	150 S	1.50	2.30	2.20	63.20	8.90	98.00	11.10	108.4	0.10	34.795	0.15	25.7	8.15	95.7
	150 D	1.80	1.10	1.60	50.00	8.90	97.70	11.10	103.0	0.09	34.857	0.17	25.6	8.16	96.8
MAKENA 4	0 S	5.80	516.1	5.00	1703	7.40	101.6	15.10	719.9	0.34	28.585	0.91	25.6	8.13	99.5
	2 S	4.30	345.2	2.50	1227	7.70	112.1	13.00	507.7	0.28	31.243	0.86	25.6	8.16	101.3
	5 S	3.40	135.0	1.80	592.1	8.00	113.5	12.00	302.5	0.23	32.773	0.61	25.7	8.16	102.9
	5 D	3.40	108.6	2.90	502.5	8.30	106.4	12.30	260.2	0.19	33.364	0.53	25.7	8.16	103.0
	10 S	2.70	51.60	2.20	280.3	8.00	106.5	11.10	179.1	0.18	34.179	0.40	25.7	8.16	100.6
	10 D	3.00	31.60	2.80	191.0	8.60	106.4	12.30	153.2	0.17	34.413	0.41	25.7	8.15	100.6
	50 S	2.40	35.20	3.00	199.7	8.30	104.3	11.10	159.2	0.15	34.405	0.31	25.7	8.14	94.2
	50 D	2.40	4.20	1.90	71.35	8.60	104.4	11.40	114.2	0.12	34.785	0.28	25.6	8.14	93.7
	100 S	2.40	15.10	2.20	136.0	8.30	96.20	11.40	137.3	0.12	34.529	0.26	25.7	8.13	93.9
	100 D	2.10	1.40	1.20	58.15	8.60	104.3	11.10	109.3	0.09	34.832	0.23	25.6	8.15	92.5
	150 S	2.40	4.20	2.20	84.27	8.30	103.7	11.10	121.7	0.12	34.721	0.21	25.8	8.14	95.6
	150 D	2.40	0.90	1.80	51.12	8.30	101.1	11.40	105.7	0.10	34.837	0.18	25.6	8.15	94.2
DOH WQS		DRY	3.50	2.00				16.00	110.00	0.20	*	0.15	**	***	
GEOMETRIC MEAN		WET	5.00	3.50				20.00	150.00	0.50		0.30			

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

*** pH shall not deviate more than 0.5 units from a value of 8.1.

TABLE 5. Water chemistry measurements in μM and $\mu\text{g/L}$ (shaded) from irrigation wells and an irrigation lake collected in the vicinity of the Makena Resort on June 19, 2009. For sampling site locations, see Figure 1.

WELL	PO_4^{3-} (μM)	PO_4^{3-} ($\mu\text{g/L}$)	NO_3^- (μM)	NO_3^- ($\mu\text{g/L}$)	NH_4^+ (μM)	NH_4^+ ($\mu\text{g/L}$)	Si (μM)	Si ($\mu\text{g/L}$)	TOP (μM)	TOP ($\mu\text{g/L}$)	TON (μM)	TON ($\mu\text{g/L}$)	TP (μM)	TP ($\mu\text{g/L}$)	TN (μM)	TN ($\mu\text{g/L}$)	SALINITY (ppt)
1	2.20	68.20	126.0	1764	2.20	30.80	520.7	14632	0.55	17.05	13.60	190.40	2.75	85.25	141.8	1985	1.355
2	2.90	89.90	129.1	1807	2.95	41.30	693.1	19475	0.35	10.85	8.85	123.90	3.25	100.75	140.9	1973	1.751
3	2.95	91.45	130.7	1829	3.45	48.30	709.6	19938	0.15	4.65	8.80	123.20	3.10	96.10	142.9	2001	2.044
4	2.90	89.90	118.6	1660	3.80	53.20	645.8	18146	0.15	4.65	7.70	107.80	3.05	94.55	130.1	1821	1.970
5	2.65	82.15	156.1	2185	2.30	32.20	560.1	15737	0.15	4.65	3.45	48.30	2.80	86.80	161.9	2266	1.565
6	2.35	72.85	160.9	2253	4.30	60.20	544.9	15312	0.30	9.30	4.70	65.80	2.65	82.15	169.9	2379	1.528
10	2.75	85.25	145.7	2040	1.95	27.30	618.3	17373	0.25	7.75	2.15	30.10	3.00	93.00	149.8	2097	2.100
11	1.65	51.15	107.0	1498	5.25	73.50	574.4	16139	0.55	17.05	8.70	121.80	2.20	68.20	121.0	1693	1.965
ILLIO	0.45	13.95	43.8	612.5	15.15	212.10	547.6	15386	2.20	68.20	56.45	790.30	2.65	82.15	115.4	1614.9	1.752

TABLE 6. Linear regression statistics (y-intercept and slope) of concentrations of silica as functions of salinity from four ocean transect sites off of the Mokena Resort collected during monitoring surveys from 1995 to June 2009 (Transect Site 3 has been monitored since 2002; Transect Site 3A since 2007). Also shown are standard errors and upper and lower 95% confidence limits around the y-intercepts and slopes. REGSLOPE* indicates regression statistics for slope of yearly coefficients as a function of time. For location of transect sites, see Figure 1.

SILICA - Y-INTERCEPT

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	522.34	12.18	491.03	553.66
1996	629.56	11.05	605.49	653.64
1997	504.17	2.83	496.89	511.46
1998	484.14	2.44	477.86	490.41
1999	479.11	9.89	457.55	500.66
2000	528.68	5.87	513.58	543.77
2001	625.85	10.91	597.82	653.88
2002	502.98	8.68	480.66	525.30
2003	625.85	10.91	597.82	653.88
2004	546.00	8.33	527.84	564.16
2005	466.59	11.09	442.42	490.75
2006	487.68	24.60	434.08	541.28
2007	491.19	34.99	414.95	567.42
2008	371.80	16.96	334.85	408.75
2009	457.28	10.01	431.54	483.02
REGSLOPE	-7.34	3.84	-15.65	0.96

SITE 2				
1995	468.41	85.54	248.51	688.30
1996	549.09	177.83	164.91	933.28
1997	567.57	9.71	543.80	591.33
1998	563.20	37.23	472.10	654.30
1999	466.74	95.75	261.37	672.11
2000	770.15	27.32	703.31	837.00
2001	1254.31	74.17	1072.82	1435.81
2002	577.53	29.40	505.60	649.46
2003	505.05	20.10	461.94	548.15
2004	565.31	93.71	364.33	766.29
2005	339.08	33.78	266.64	411.52
2006	553.48	62.93	418.51	688.45
2007	443.05	17.15	406.27	479.84
2008	402.41	73.66	244.42	560.41
2009	501.76	9.02	479.69	523.82
REGSLOPE	-10.18	12.92	-38.09	17.73

SITE 3A				
2007	714.10	5.58	701.94	726.27
2008	805.12	9.00	785.52	824.73
2009	646.37	7.80	626.32	666.43
REGSLOPE	-33.87	72.10	-950.01	882.28

SITE 3				
2002	931.92	27.54	861.13	1002.71
2003	984.76	41.58	894.16	1075.35
2004	632.75	127.62	354.68	910.82
2005	704.38	52.31	590.40	818.35
2006	928.22	64.18	788.40	1068.05
2007	722.80	15.07	689.97	755.63
2008	1058.06	48.59	952.18	1163.94
2009	943.91	40.06	840.94	1046.89
REGSLOPE	11.24	25.27	-50.59	73.08

SITE 4				
1995	710.45	8.83	687.74	733.15
1996	917.33	13.38	888.18	946.47
1997	776.74	3.53	767.66	785.82
1998	841.35	6.75	824.00	858.70
1999	823.63	24.78	769.63	877.62
2000	946.97	12.51	914.80	979.14
2001	1403.91	260.13	735.22	2072.61
2002	767.85	4.37	756.63	779.08
2003	854.37	29.88	789.26	919.48
2004	843.49	37.55	761.67	925.31
2005	703.97	14.00	673.47	734.46
2006	735.05	14.01	704.53	765.57
2007	710.11	7.14	694.56	725.66
2008	712.32	18.22	672.63	752.01
2009	715.30	7.99	694.75	735.84
REGSLOPE	-10.96	10.55	-33.76	11.83

SILICA - SLOPE

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	-15.08	0.38	-16.05	-14.12
1996	-18.05	0.32	-18.75	-17.34
1997	-14.43	0.08	-14.65	-14.21
1998	-13.83	0.07	-14.02	-13.64
1999	-13.63	0.29	-14.27	-12.99
2000	-15.08	0.18	-15.54	-14.62
2001	-17.76	0.32	-18.57	-16.94
2002	-14.38	0.26	-15.05	-13.72
2003	-17.76	0.32	-18.57	-16.94
2004	-15.68	0.25	-16.23	-15.14
2005	-13.31	0.33	-14.02	-12.61
2006	-13.88	0.76	-15.53	-12.23
2007	-14.11	1.14	-16.59	-11.62
2008	-10.46	0.52	-11.59	-9.33
2009	-12.98	0.30	-13.76	-12.20
REGSLOPE	0.22	0.11	-0.02	0.46

SITE 2				
1995	-13.47	2.51	-19.93	-7.00
1996	-15.62	5.15	-26.75	-4.49
1997	-16.26	0.29	-16.96	-15.56
1998	-16.11	1.08	-18.76	-13.45
1999	-13.21	2.78	-19.18	-7.23
2000	-22.06	0.80	-24.02	-20.11
2001	-35.68	2.12	-40.87	-30.49
2002	-16.54	0.86	-18.64	-14.44
2003	-14.37	0.59	-15.63	-13.11
2004	-16.23	2.73	-22.09	-10.38
2005	-9.61	0.98	-11.70	-7.52
2006	-15.82	1.83	-19.75	-11.89
2007	-12.54	0.51	-13.64	-11.45
2008	-11.41	2.14	-15.99	-6.83
2009	-14.32	0.27	-14.98	-13.66
REGSLOPE	0.30	0.37	-0.50	1.09

SITE 3A				
2007	-20.35	0.19	-20.75	-19.94
2008	-22.96	0.28	-23.57	-22.36
2009	-18.28	0.26	-18.96	-17.61
REGSLOPE	1.03	2.11	-25.74	27.80

SITE 3				
2002	-26.75	0.81	-28.83	-24.68
2003	-28.10	1.21	-30.73	-25.47
2004	-18.19	3.69	-26.24	-10.14
2005	-20.11	1.51	-23.40	-16.83
2006	-26.56	1.89	-30.67	-22.46
2007	-20.60	0.44	-21.56	-19.63
2008	-30.22	1.41	-33.29	-27.14
2009	-26.90	1.17	-29.90	-23.91
REGSLOPE	-0.30	0.72	-2.07	1.46

SITE 4				
1995	-20.55	0.27	-21.25	-19.85
1996	-26.23	0.40	-27.10	-25.37
1997	-22.27	0.11	-22.55	-21.99
1998	-24.07	0.20	-24.58	-23.56
1999	-23.50	0.73	-25.10	-21.90
2000	-27.12	0.37	-28.08	-26.16
2001	-39.92	7.42	-58.99	-20.86
2002	-21.99	0.13	-22.34	-21.65
2003	-24.36	0.91	-26.34	-22.39
2004	-24.27	1.10	-26.66	-21.88
2005	-20.11	0.41	-21.00	-19.22
2006	-20.96	0.41	-21.86	-20.06
2007	-20.27	0.23	-20.77	-19.78
2008	-20.33	0.53	-21.49	-19.17
2009	-20.34	0.24	-20.95	-19.73
REGSLOPE	0.32	0.30	-0.32	0.97

TABLE 7. Linear regression statistics (y-intercept and slope) of concentrations of nitrate as functions of salinity from four ocean transect sites off of the Makena Resort collected during monitoring surveys from 1995 to June 2009 (Transect Site 3 has been monitored since 2002; Transect Site 3A since 2007). Also shown are standard errors and upper and lower 95% confidence limits around the y-intercepts and slopes. "REGSLOPE" indicates regression statistics for slope of yearly coefficients as a function of time. For location of transect sites, see Figure 1.

NITRATE -Y-INTERCEPT

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	326.50	7.10	308.25	344.75
1996	336.49	4.62	326.41	346.56
1997	406.96	1.93	402.00	411.93
1998	268.90	1.55	264.91	272.89
1999	225.24	5.32	213.66	236.83
2000	309.77	3.36	301.14	318.41
2001	336.53	9.69	311.61	361.44
2002	278.21	17.43	233.40	323.03
2003	421.29	7.81	404.28	438.30
2004	442.33	4.89	431.68	452.99
2005	296.36	7.44	280.16	312.56
2006	361.76	7.20	346.08	377.45
2007	305.06	15.88	270.45	339.67
2008	330.95	7.18	315.29	346.60
2009	231.91	3.07	224.01	239.81
REGSLOPE	-0.96	3.94	-9.48	7.55

SITE 2				
1995	119.87	12.03	88.95	150.79
1996	106.36	18.44	66.53	146.19
1997	193.75	5.64	179.95	207.55
1998	166.93	5.33	153.89	179.97
1999	116.21	14.04	86.10	146.32
2000	142.07	2.83	135.13	149.01
2001	154.93	7.65	136.21	173.64
2002	180.82	58.78	36.98	324.66
2003	163.36	6.31	149.82	176.91
2004	145.36	10.55	122.74	167.99
2005	102.66	9.11	83.13	122.19
2006	124.74	4.89	114.26	135.22
2007	134.27	3.25	127.30	141.24
2008	108.01	12.87	80.41	135.61
2009	142.21	9.04	120.08	164.34
REGSLOPE	-1.16	1.70	-4.83	2.51

SITE 3A				
2007	354.33	49.92	245.56	463.11
2008	448.07	7.75	431.19	464.95
2009	283.99	14.63	246.38	321.60
REGSLOPE	-35.17	74.43	-980.84	910.50

SITE 3				
2002	847.45	52.35	712.88	982.01
2003	693.24	39.54	607.10	779.38
2004	463.72	90.73	266.04	661.40
2005	535.53	47.19	432.72	638.34
2006	856.96	48.22	751.91	962.02
2007	1233.34	18.23	1193.63	1273.06
2008	899.91	41.92	808.57	991.25
2009	827.18	19.10	778.08	876.29
REGSLOPE	41.93	35.88	-45.86	129.72

SITE 4				
1995	111.38	6.47	94.74	128.02
1996	118.34	1.63	114.79	121.89
1997	122.56	1.29	119.25	125.88
1998	112.77	1.87	107.97	117.57
1999	109.13	3.30	101.94	116.33
2000	118.51	0.75	116.58	120.43
2001	100.93	54.85	-40.08	241.94
2002	118.91	3.25	110.56	127.25
2003	113.78	2.76	107.77	119.79
2004	134.97	4.64	124.86	145.07
2005	114.59	4.47	104.85	124.33
2006	119.85	1.76	116.03	123.68
2007	269.24	10.13	247.16	291.32
2008	62.93	4.05	54.11	71.74
2009	107.17	1.51	103.30	111.04
REGSLOPE	1.65	2.66	-4.10	7.40

NITRATE - SLOPE

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	-9.49	0.22	-10.05	-8.92
1996	-9.67	0.14	-9.97	-9.38
1997	-11.70	0.06	-11.85	-11.55
1998	-7.72	0.05	-7.84	-7.60
1999	-6.44	0.16	-6.79	-6.10
2000	-8.91	0.10	-9.17	-8.65
2001	-9.60	0.28	-10.32	-8.88
2002	-7.99	0.52	-9.31	-6.66
2003	-12.09	0.23	-12.60	-11.58
2004	-12.74	0.15	-13.06	-12.42
2005	-8.48	0.22	-8.96	-8.01
2006	-10.40	0.22	-10.89	-9.92
2007	-8.73	0.52	-9.86	-7.60
2008	-9.52	0.22	-10.00	-9.05
2009	-6.65	0.09	-6.89	-6.41
REGSLOPE	0.03	0.11	-0.22	0.28

SITE 2				
1995	-3.47	0.35	-4.38	-2.56
1996	-3.05	0.53	-4.20	-1.89
1997	-5.57	0.17	-5.97	-5.16
1998	-4.79	0.16	-5.17	-4.41
1999	-3.31	0.41	-4.19	-2.43
2000	-4.08	0.08	-4.29	-3.88
2001	-4.41	0.22	-4.95	-3.88
2002	-5.19	1.72	-9.40	-0.99
2003	-4.68	0.18	-5.07	-4.28
2004	-4.19	0.31	-4.84	-3.53
2005	-2.94	0.26	-3.50	-2.37
2006	-3.57	0.14	-3.88	-3.27
2007	-3.85	0.10	-4.06	-3.64
2008	-3.09	0.37	-3.89	-2.29
2009	-4.10	0.27	-4.76	-3.43
REGSLOPE	0.03	0.05	-0.07	0.14

SITE 3A				
2007	-9.57	1.67	-13.20	-5.93
2008	-12.81	0.24	-13.33	-12.29
2009	-7.98	0.49	-9.25	-6.72
REGSLOPE	0.79	2.33	-28.80	30.38

SITE 3				
2002	-24.49	1.53	-28.43	-20.56
2003	-19.86	1.15	-22.36	-17.35
2004	-13.37	2.63	-19.09	-7.64
2005	-15.33	1.36	-18.29	-12.37
2006	-24.61	1.42	-27.70	-21.52
2007	-35.51	0.54	-36.68	-34.34
2008	-25.78	1.22	-28.43	-23.12
2009	-23.65	0.56	-25.08	-22.22
REGSLOPE	-1.18	1.04	-3.72	1.36

SITE 4				
1995	-3.26	0.20	-3.77	-2.75
1996	-3.40	0.05	-3.50	-3.29
1997	-3.53	0.04	-3.63	-3.43
1998	-3.24	0.05	-3.38	-3.10
1999	-3.13	0.10	-3.34	-2.92
2000	-3.40	0.02	-3.46	-3.34
2001	-2.87	1.56	-6.89	1.15
2002	-3.44	0.10	-3.70	-3.19
2003	-3.28	0.08	-3.46	-3.09
2004	-3.89	0.14	-4.18	-3.59
2005	-3.29	0.13	-3.57	-3.00
2006	-3.43	0.05	-3.54	-3.31
2007	-7.87	0.32	-8.58	-7.17
2008	-1.79	0.12	-2.05	-1.54
2009	-3.07	0.04	-3.18	-2.95
REGSLOPE	-0.05	0.08	-0.22	0.12

TABLE 8. Linear regression statistics (y-intercept and slope) of concentrations of orthophosphate phosphorus as functions of salinity from four ocean transect sites off of the Makena Resort collected during monitoring surveys from 1995 to December 2008 (Transect site 3 has been monitored since 2002; Trastect Site 3A since 2007). Also shown are standard errors and upper and lower 95% confidence limits around the y-intercepts and slopes. For location of transect sites, see Figure 1.

PHOSPHATE -Y-INTERCEPT

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	1.04	0.14	0.68	1.39
1996	1.78	0.12	1.52	2.03
1997	1.40	0.12	1.10	1.69
1998	1.10	0.06	0.95	1.25
1999	1.07	0.12	0.80	1.34
2000	0.89	0.12	0.59	1.19
2001	2.16	0.76	0.22	4.11
2002	1.12	0.68	-0.64	2.88
2003	0.48	0.19	0.06	0.90
2004	2.71	0.17	2.33	3.08
2005	-0.02	0.14	-0.34	0.29
2006	1.36	0.13	1.08	1.65
2007	1.07	0.20	0.64	1.50
2008	0.89	0.13	0.61	1.16
2009	0.87	0.38	-0.12	1.85
REGSLOPE	-0.03	0.04	-0.12	0.06

SITE 2				
1995	0.15	0.63	-1.46	1.76
1996	2.03	1.59	-1.41	5.48
1997	3.70	0.25	3.10	4.31
1998	3.55	1.44	0.03	7.07
1999	3.68	5.55	-8.22	15.58
2000	12.78	1.18	9.89	15.66
2001	30.73	3.12	23.09	38.37
2002	6.67	1.68	2.57	10.77
2003	3.57	0.31	2.90	4.24
2004	5.76	0.53	4.62	6.91
2005	-0.95	2.96	-7.31	5.40
2006	1.88	0.57	0.67	3.10
2007	0.22	0.26	-0.34	0.78
2008	1.50	1.14	-0.95	3.95
2009	1.54	0.34	0.71	2.38
REGSLOPE	-0.26	0.48	-1.30	0.78

SITE 3A				
2007	2.39	0.24	1.86	2.93
2008	4.43	0.49	3.36	5.50
2009	2.60	0.15	2.21	2.99
REGSLOPE	0.10	1.12	-14.08	14.29

SITE 3				
2002	4.62	2.31	-1.31	10.55
2003	7.38	0.99	5.24	9.53
2004	7.40	0.78	5.70	9.10
2005	3.17	0.53	2.03	4.32
2006	7.32	1.16	4.80	9.84
2007	4.46	0.46	3.47	5.45
2008	4.01	1.13	1.56	6.47
2009	3.12	2.67	-3.74	9.99
REGSLOPE	-0.38	0.27	-1.05	0.29

SITE 4				
1995	2.44	0.15	2.04	2.84
1996	3.08	0.13	2.79	3.37
1997	2.95	0.09	2.71	3.19
1998	3.50	0.46	2.32	4.67
1999	3.26	0.14	2.96	3.55
2000	3.29	0.20	2.77	3.82
2001	-19.16	22.66	-77.41	39.09
2002	3.98	0.15	3.60	4.35
2003	4.13	1.29	1.33	6.93
2004	4.75	0.79	3.04	6.47
2005	2.12	0.38	1.28	2.95
2006	2.15	0.40	1.28	3.02
2007	2.65	0.09	2.46	2.83
2008	2.98	0.67	1.52	4.44
2009	1.51	0.65	-0.16	3.19
REGSLOPE	0.03	0.36	-0.75	0.81

PHOSPHATE - SLOPE

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	-0.03	0.00	-0.04	-0.02
1996	-0.05	0.00	-0.06	-0.04
1997	-0.04	0.00	-0.05	-0.03
1998	-0.03	0.00	-0.03	-0.02
1999	-0.03	0.00	-0.03	-0.02
2000	-0.02	0.00	-0.03	-0.01
2001	-0.06	0.02	-0.12	0.00
2002	-0.03	0.02	-0.08	0.02
2003	-0.01	0.01	-0.02	0.00
2004	-0.08	0.01	-0.09	-0.06
2005	0.00	0.00	-0.01	0.01
2006	-0.04	0.00	-0.04	-0.03
2007	-0.03	0.01	-0.04	-0.02
2008	-0.02	0.00	-0.03	-0.02
2009	-0.02	0.01	-0.05	0.01
REGSLOPE	0.00	0.00	0.00	0.00

SITE 2				
1995	0.00	0.02	-0.05	0.04
1996	-0.06	0.05	-0.16	0.04
1997	-0.10	0.01	-0.12	-0.09
1998	-0.10	0.04	-0.20	0.00
1999	-0.10	0.16	-0.44	0.25
2000	-0.36	0.03	-0.45	-0.28
2001	-0.87	0.09	-1.09	-0.65
2002	-0.19	0.05	-0.31	-0.07
2003	-0.10	0.01	-0.12	-0.08
2004	-0.16	0.02	-0.20	-0.13
2005	0.03	0.09	-0.15	0.21
2006	-0.05	0.02	-0.09	-0.02
2007	0.00	0.01	-0.02	0.01
2008	-0.04	0.03	-0.11	0.03
2009	-0.04	0.01	-0.07	-0.02
REGSLOPE	0.01	0.01	-0.02	0.04

SITE 3A				
2007	-0.07	0.01	-0.09	-0.05
2008	-0.13	0.02	-0.16	-0.09
2009	-0.07	0.01	-0.09	-0.06
REGSLOPE	0.00	0.03	-0.41	0.40

SITE 3				
2002	-0.13	0.07	-0.30	0.04
2003	-0.21	0.03	-0.27	-0.15
2004	-0.21	0.02	-0.26	-0.16
2005	-0.09	0.02	-0.12	-0.06
2006	-0.21	0.03	-0.28	-0.13
2007	-0.13	0.01	-0.16	-0.10
2008	-0.11	0.03	-0.18	-0.04
2009	-0.09	0.08	-0.29	0.11
REGSLOPE	0.01	0.01	-0.01	0.03

SITE 4				
1995	-0.07	0.00	-0.08	-0.06
1996	-0.09	0.00	-0.09	-0.08
1997	-0.08	0.00	-0.09	-0.07
1998	-0.10	0.01	-0.13	-0.06
1999	-0.09	0.00	-0.10	-0.08
2000	-0.09	0.01	-0.10	-0.07
2001	0.55	0.65	-1.11	2.21
2002	-0.11	0.00	-0.12	-0.10
2003	-0.11	0.04	-0.19	-0.02
2004	-0.13	0.02	-0.18	-0.08
2005	-0.06	0.01	-0.08	-0.03
2006	-0.06	0.01	-0.08	-0.03
2007	-0.07	0.00	-0.08	-0.07
2008	-0.08	0.02	-0.13	-0.04
2009	-0.04	0.02	-0.09	0.01
REGSLOPE	0.00	0.01	-0.02	0.02

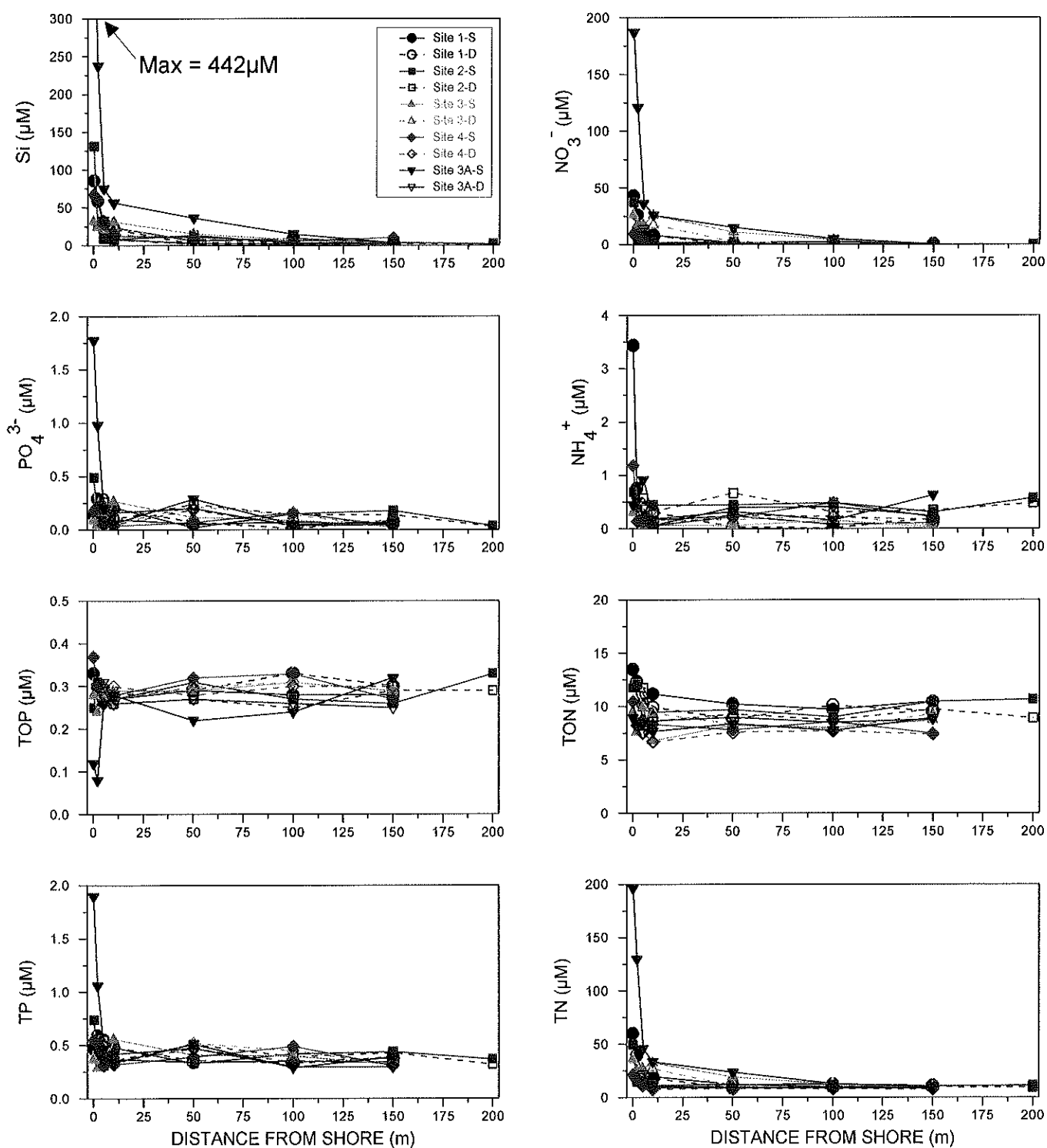


FIGURE 2. Plots of dissolved nutrients in surface (S) and deep (D) samples collected on June 20, 2009 as a function of distance from the shoreline in the vicinity of Makena Resort. For site locations, see Figure 1.

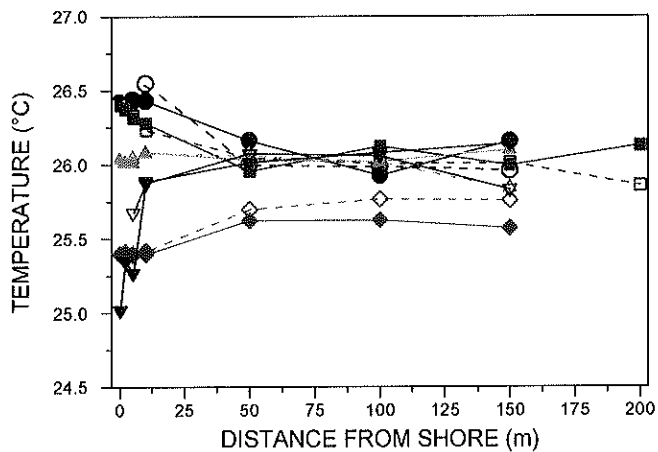
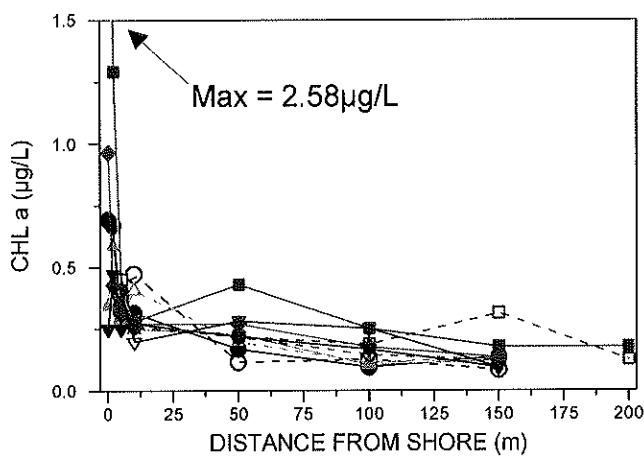
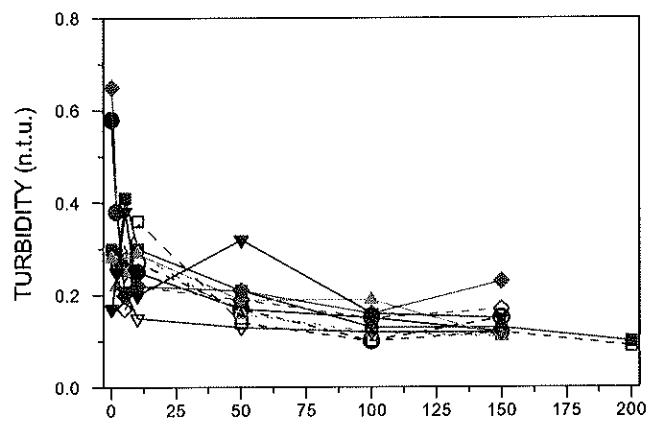
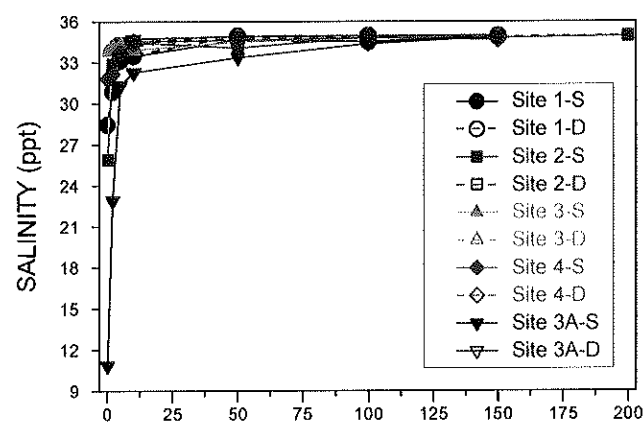


FIGURE 3. Plots of water chemistry constituents in surface (S) and deep (D) samples collected on June 20, 2009 as a function of distance from the shoreline in the vicinity of Makena Resort. For site locations, see Figure 1.

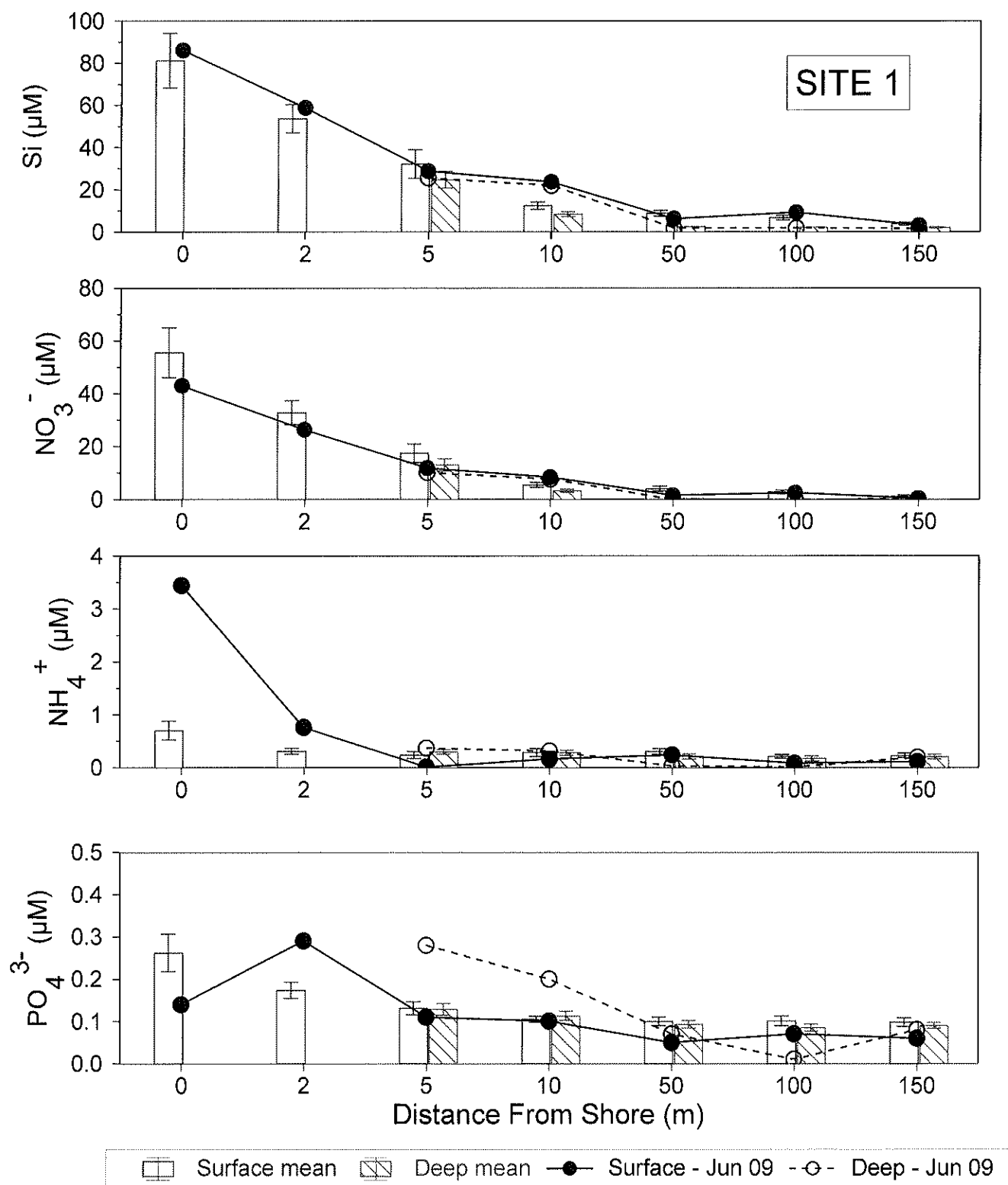


FIGURE 4. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 1, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

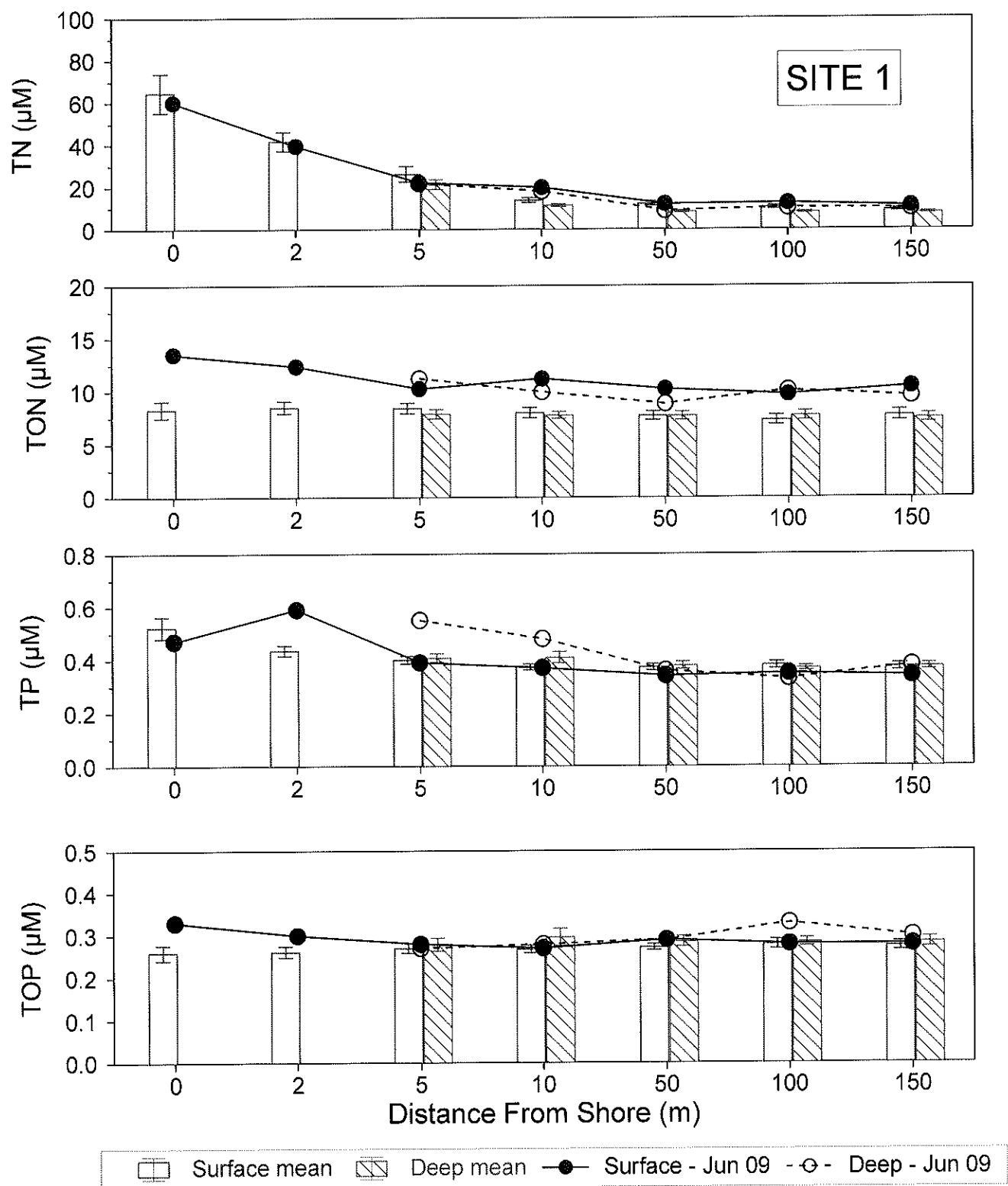


FIGURE 5. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 1, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

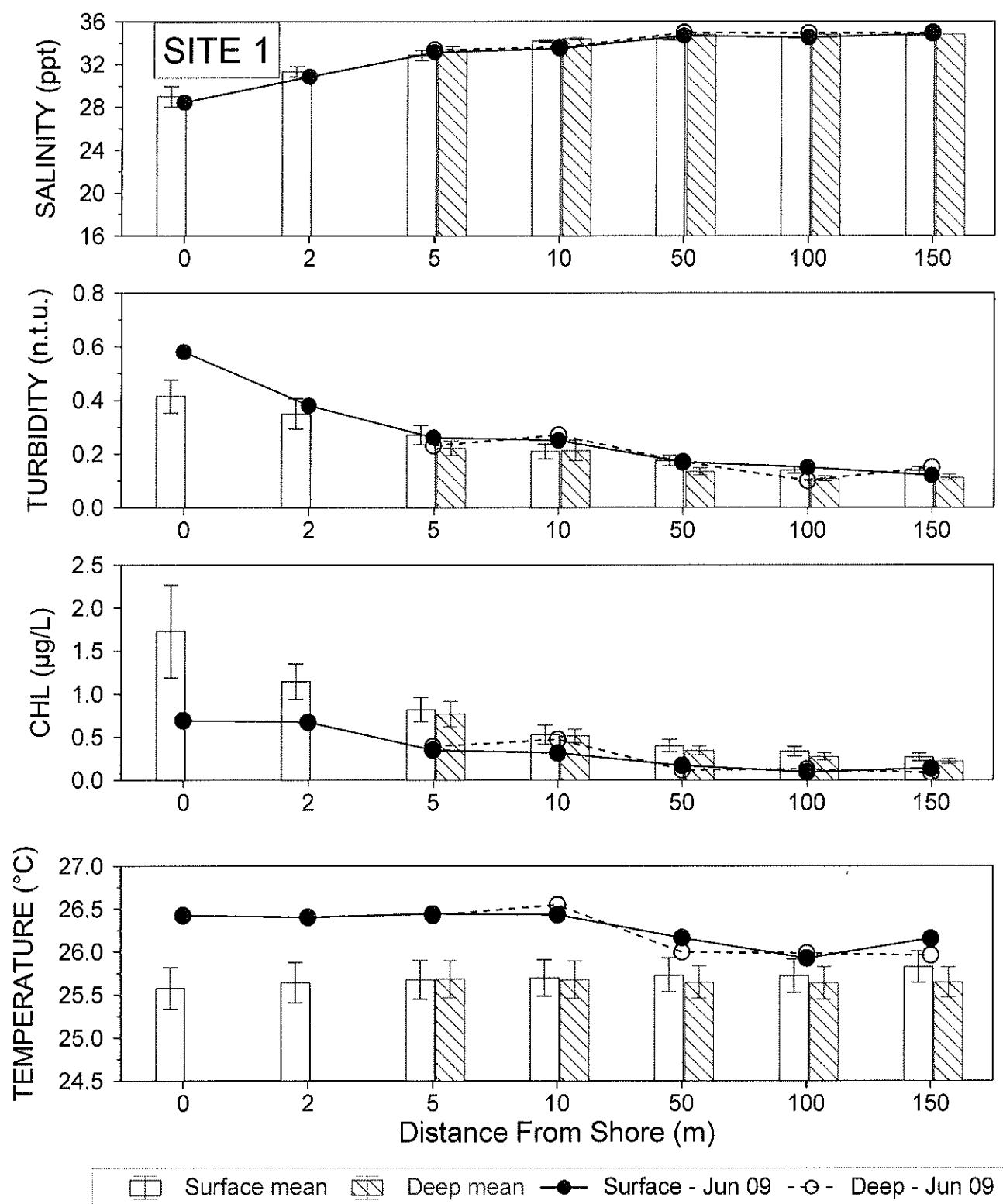


FIGURE 6. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 1, offshore of the Makena Resort. Data points and connected lines from samples collected during the most survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

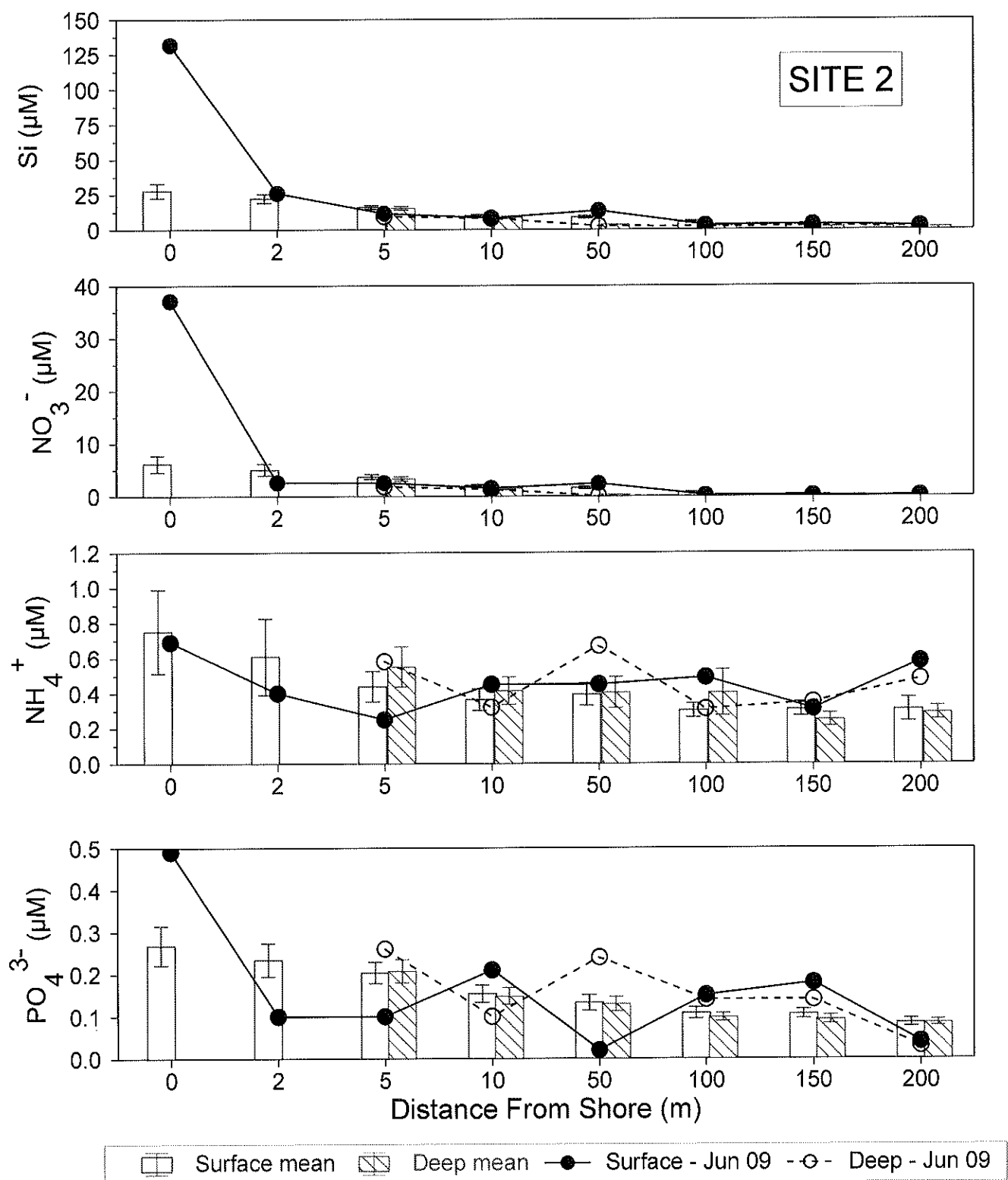


FIGURE 7. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 2, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

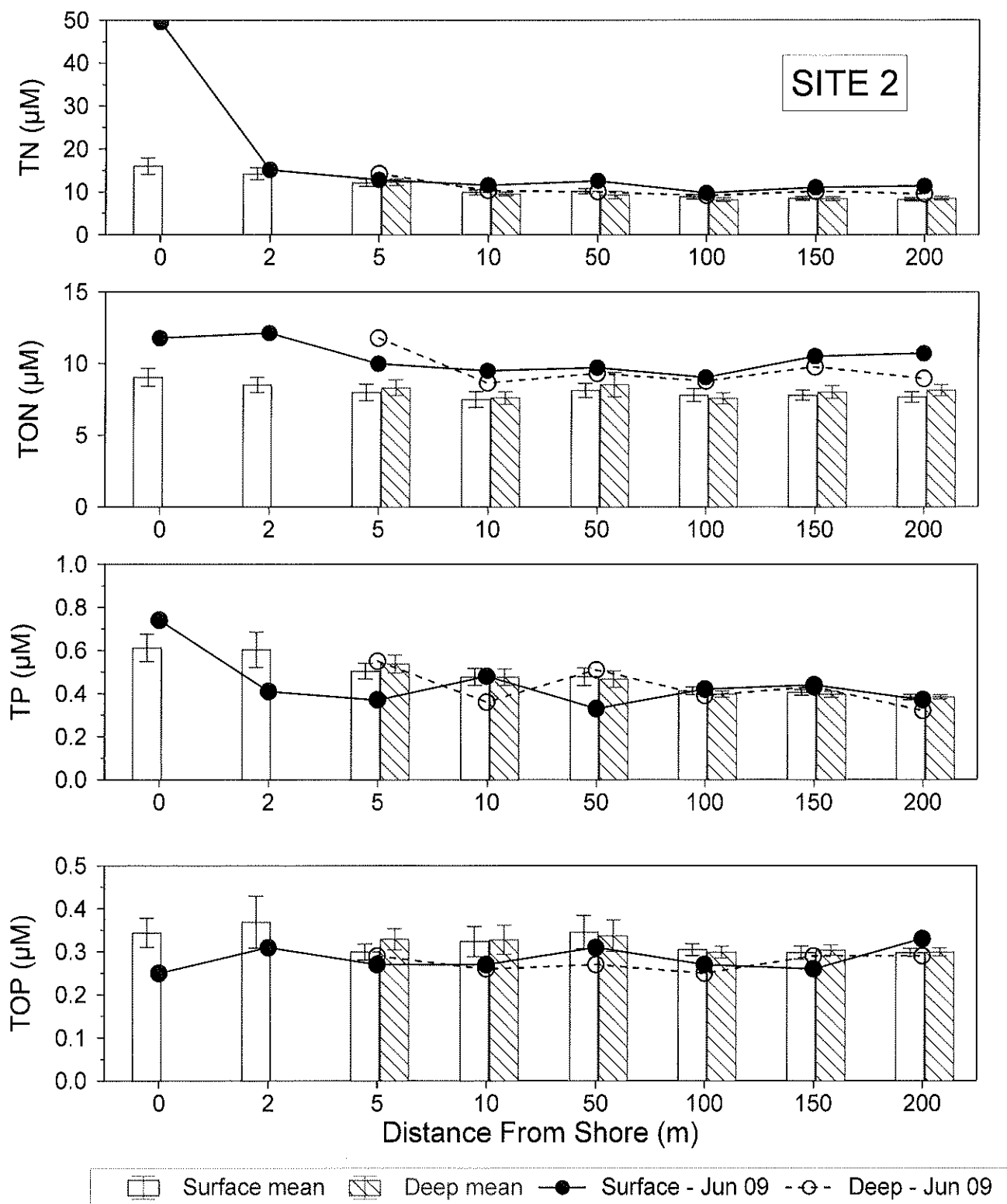


FIGURE 8. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 2, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

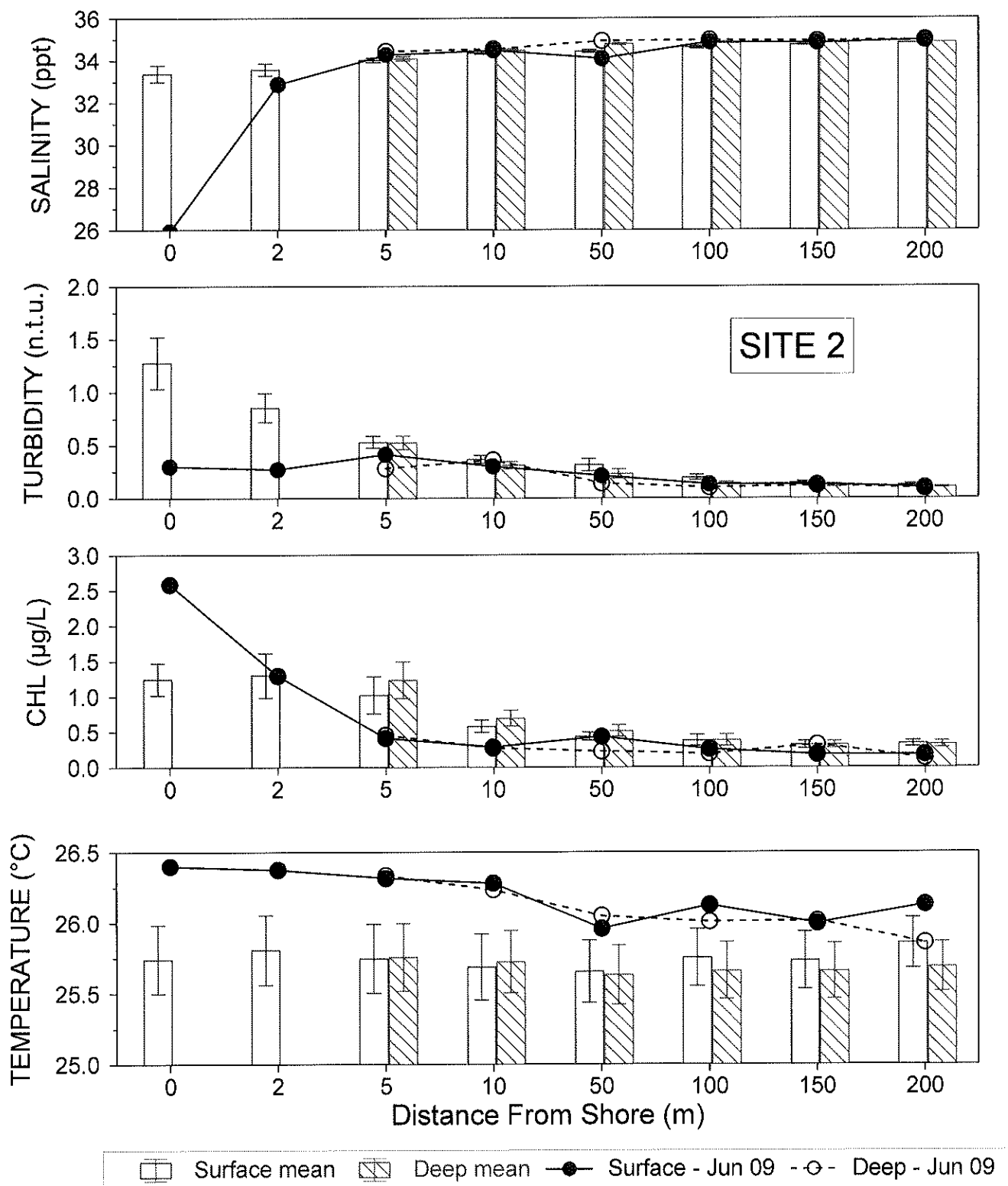


FIGURE 9. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 2, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

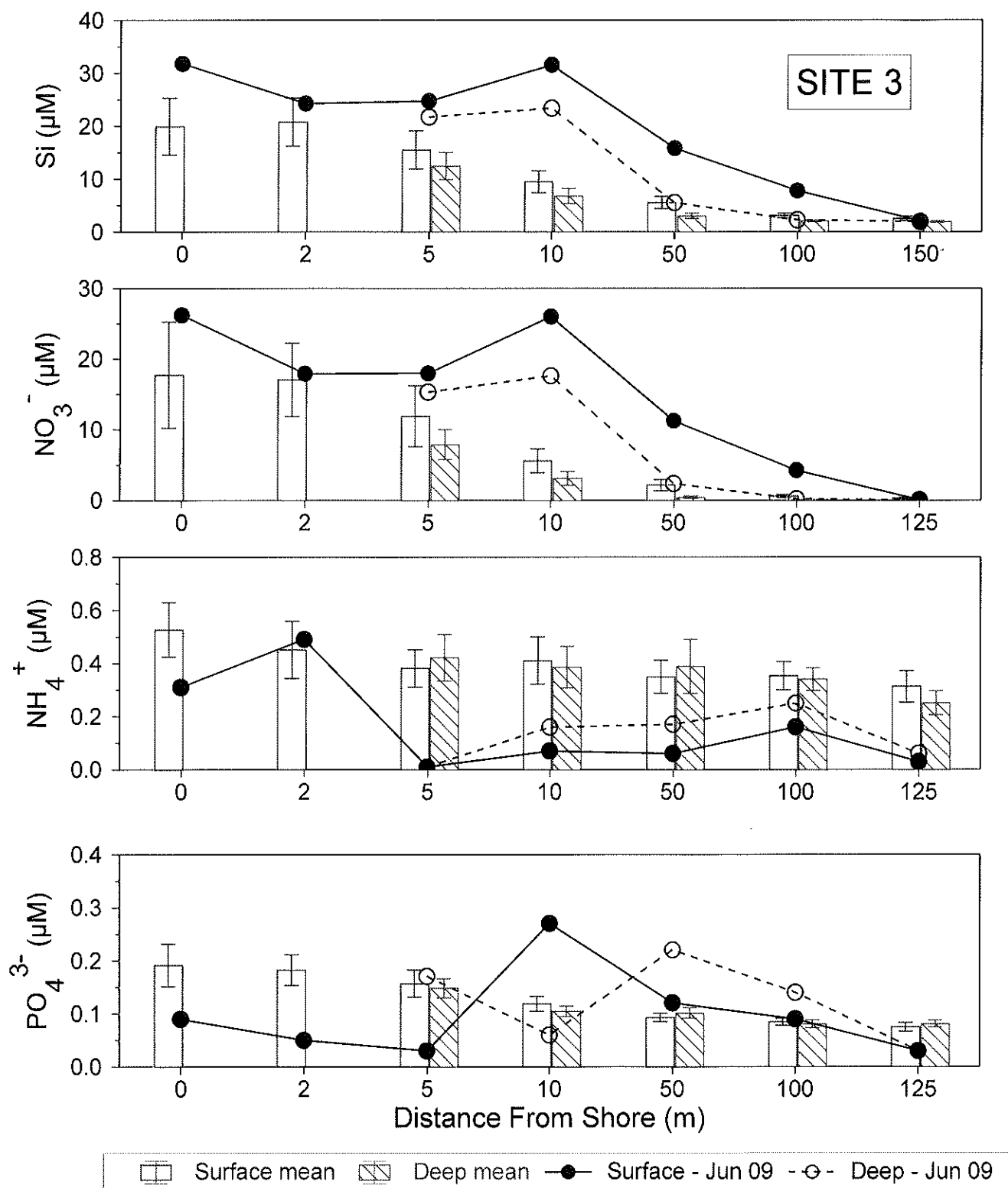


FIGURE 10. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

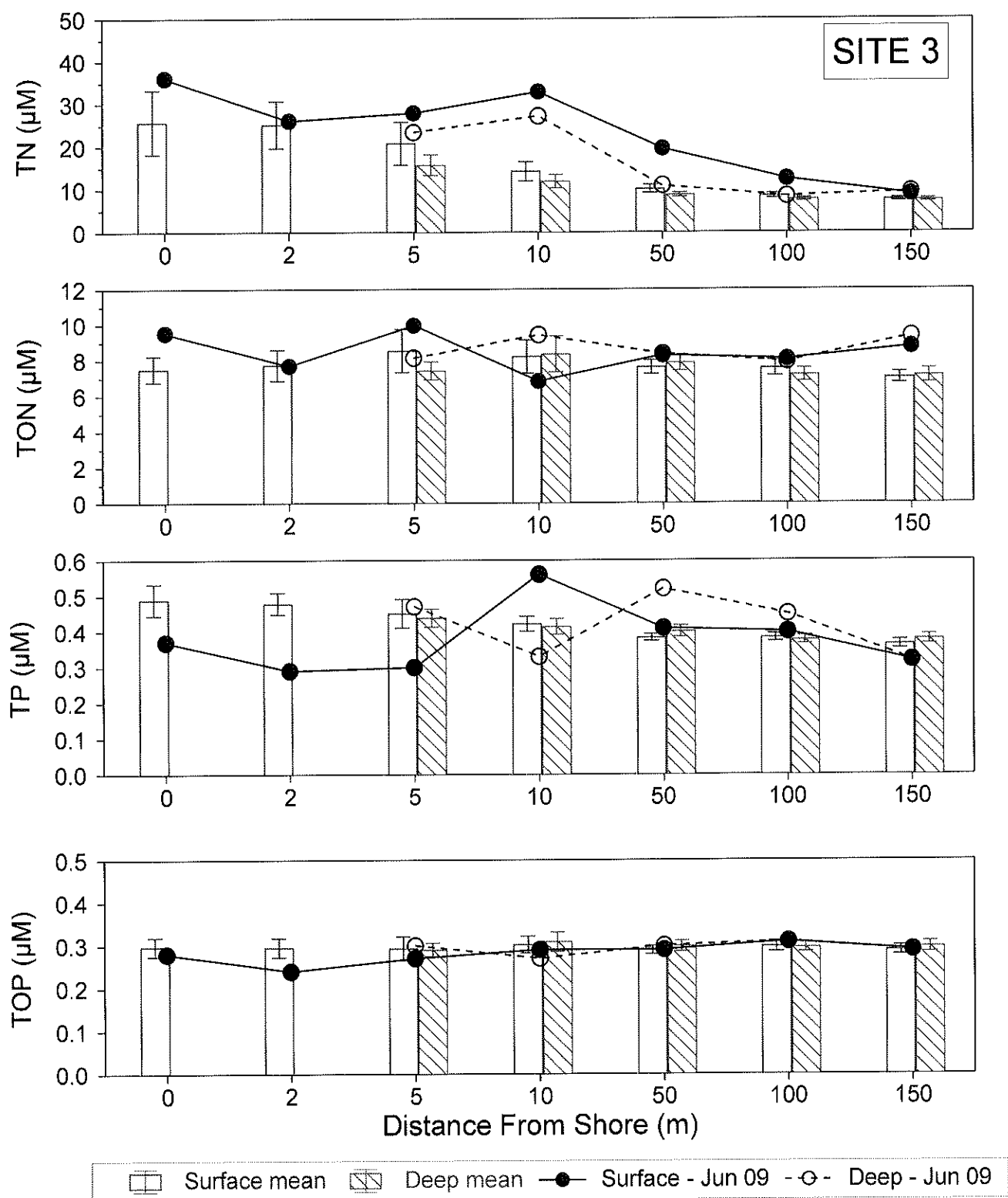


FIGURE 11. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

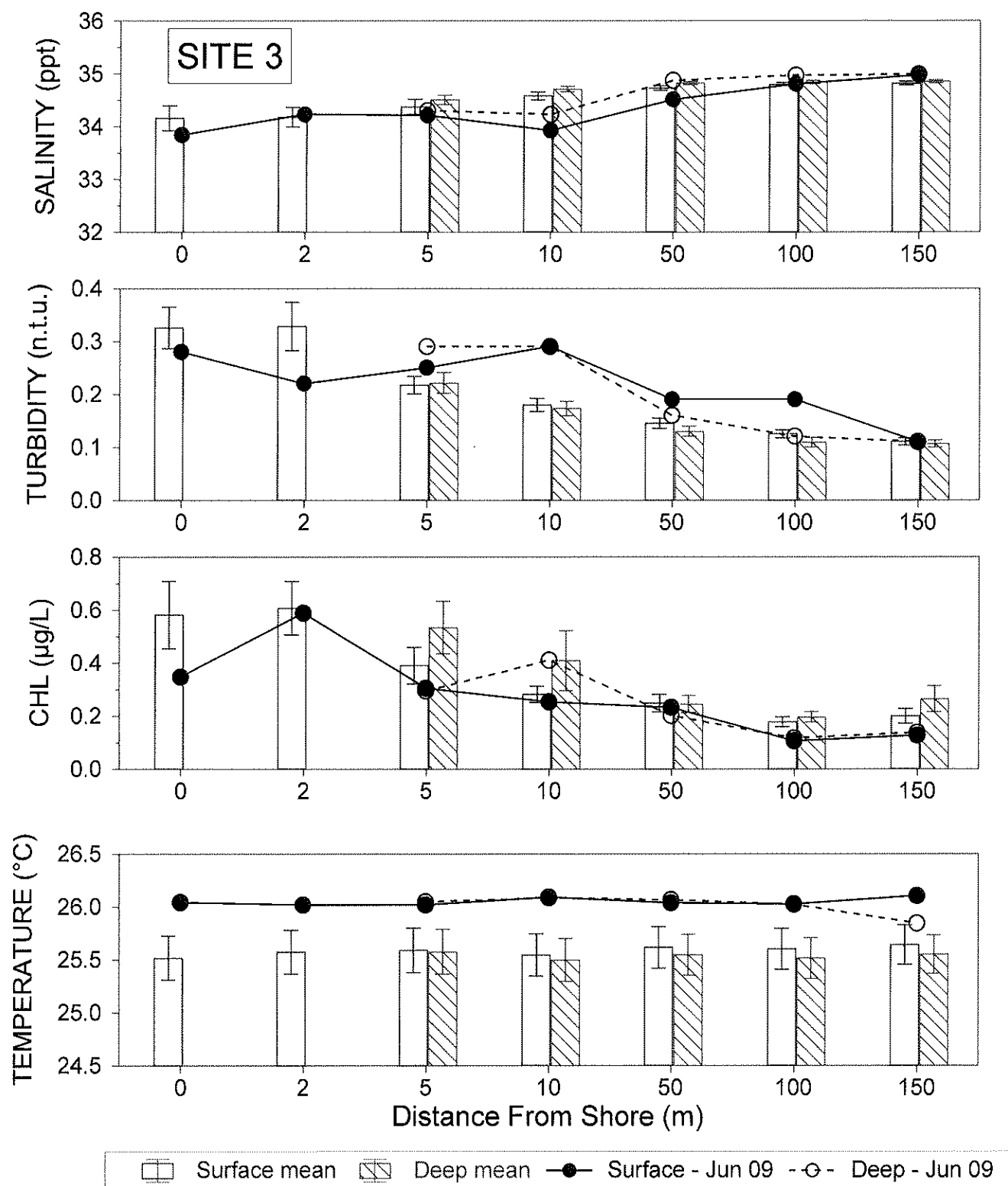


FIGURE 12. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 ($N=23$). Error bars represent standard error of the mean. For site location, see Figure 1.

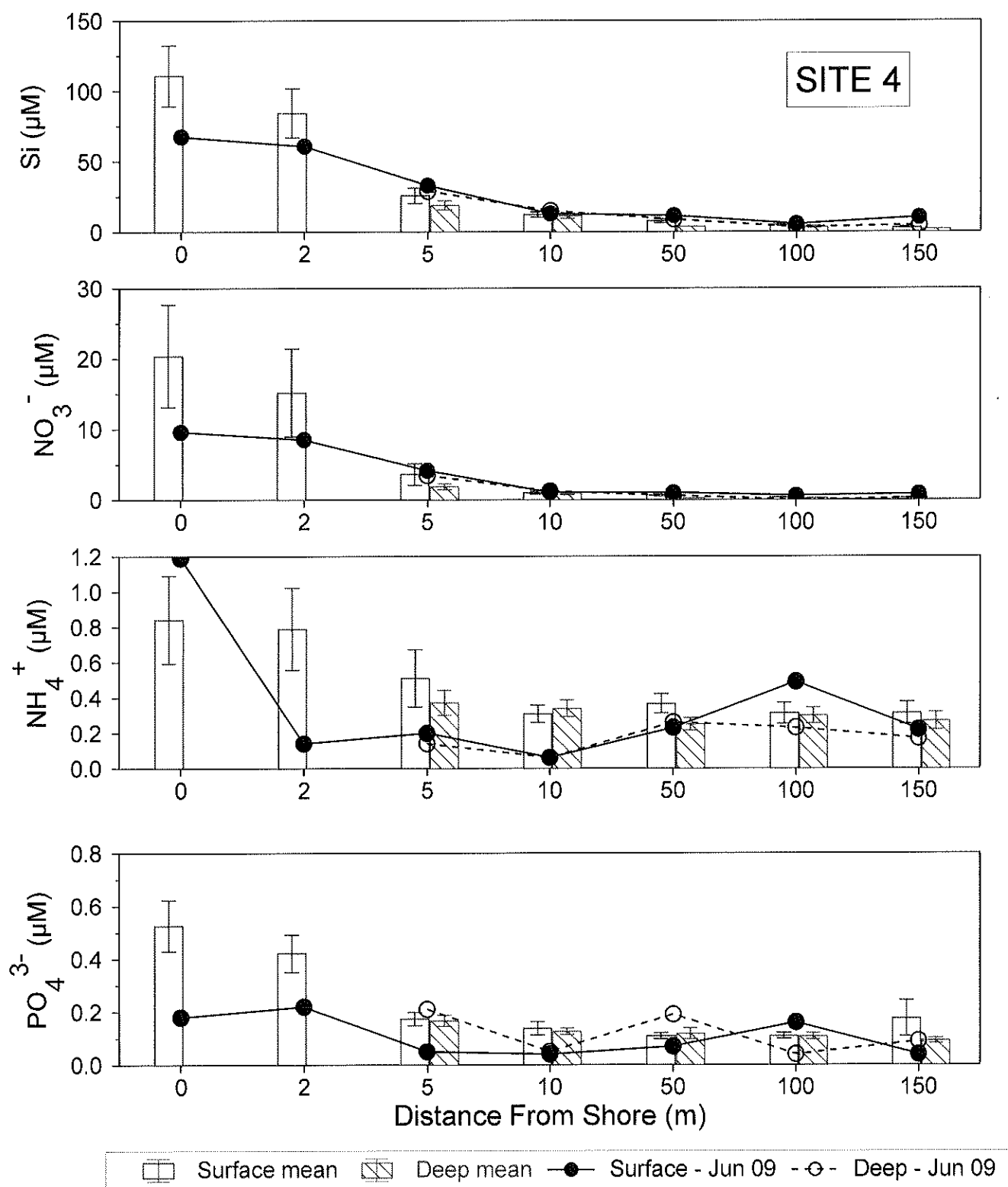


FIGURE 13. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 4, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

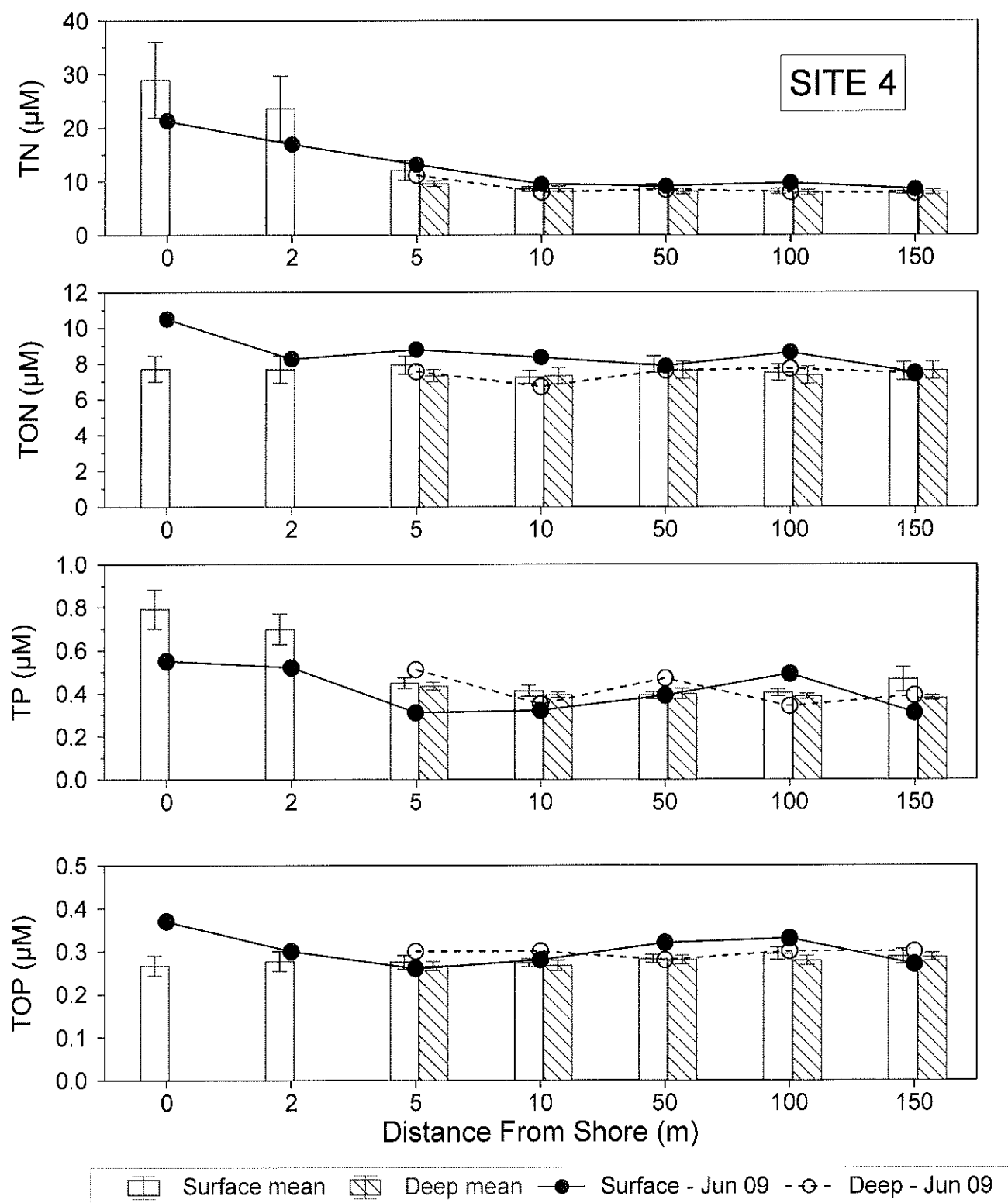


FIGURE 14. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 4, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

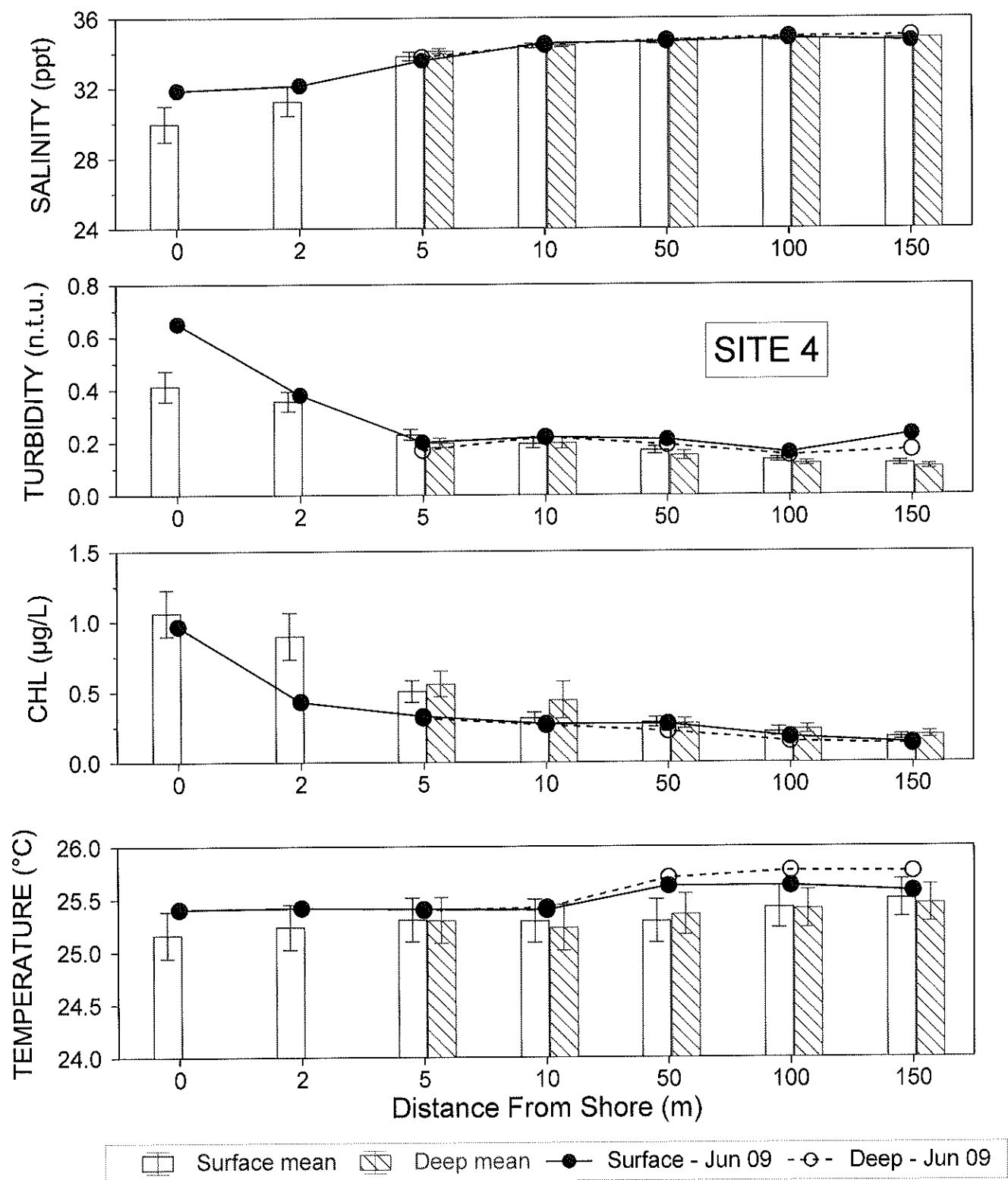


FIGURE 15. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 4, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=23). Error bars represent standard error of the mean. For site location, see Figure 1.

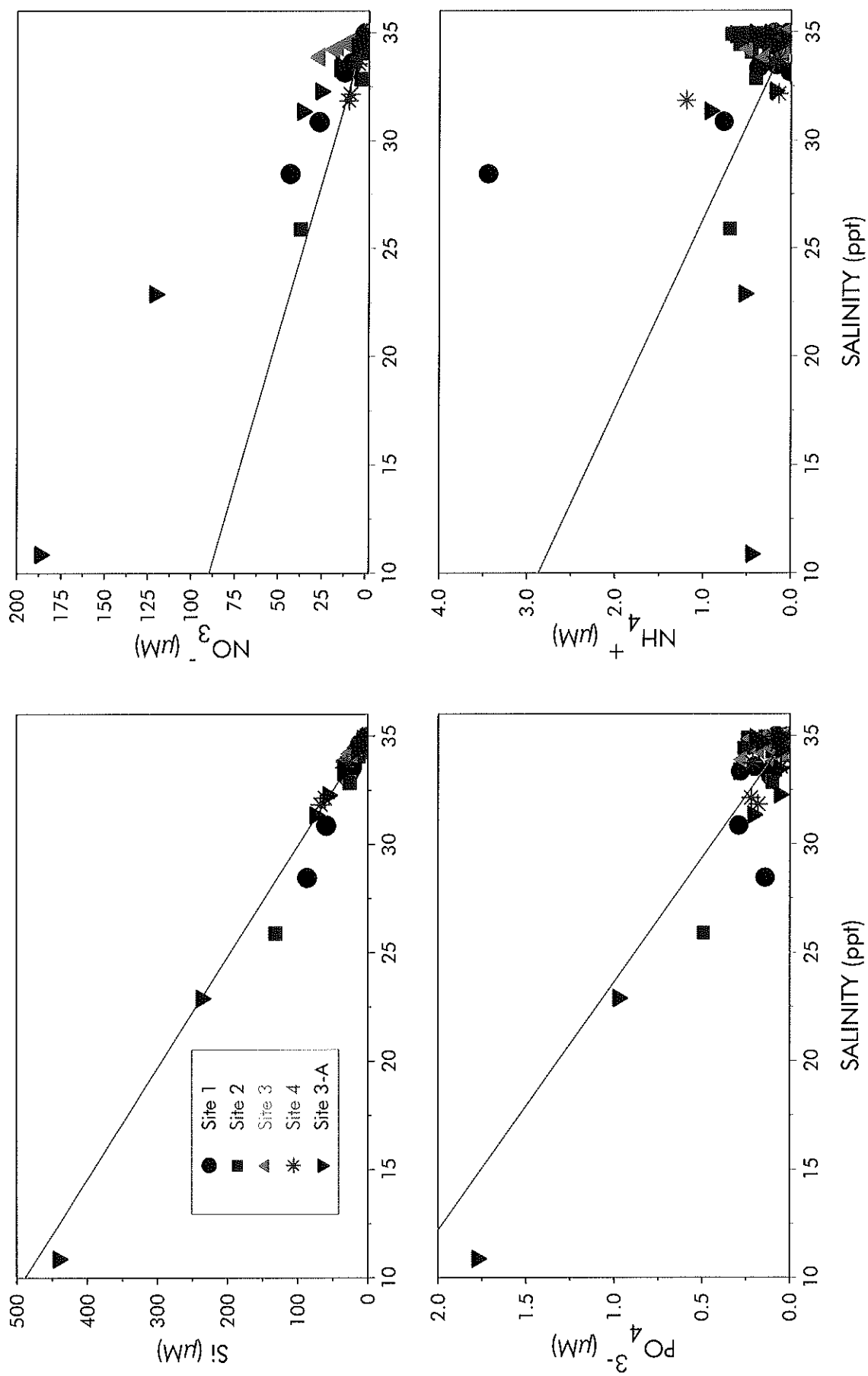


FIGURE 16. Mixing diagram showing concentration of dissolved nutrients from samples collected offshore of the Makena Resort on June 20, 2009 as functions of salinity. Solid red line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from an irrigation well upslope of the Makena Golf Courses. For sampling site locations, see Figure 1.

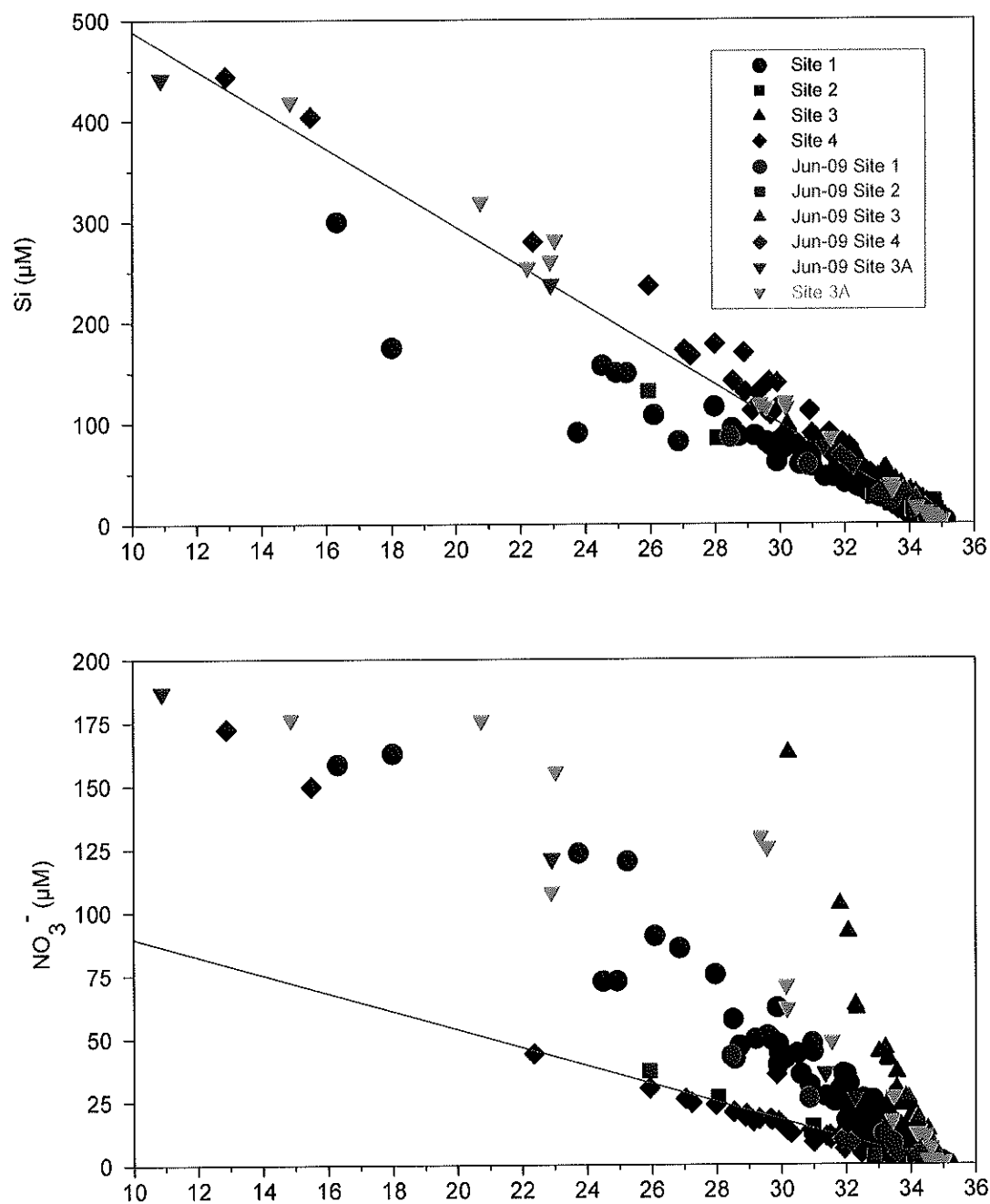


FIGURE 17. Silicate and nitrate, plotted as a function of salinity for surface samples collected since August 1995 at four sites offshore of the Makena Golf Course. Black symbols represent combined data from surveys conducted between August 1995 and December 2008. Green symbols represent data from surveys at Site 3A commencing in June 2007. Red symbols are data from most recent survey. Solid red line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from golf course irrigation well #4. For sampling site locations, see Figure 1.

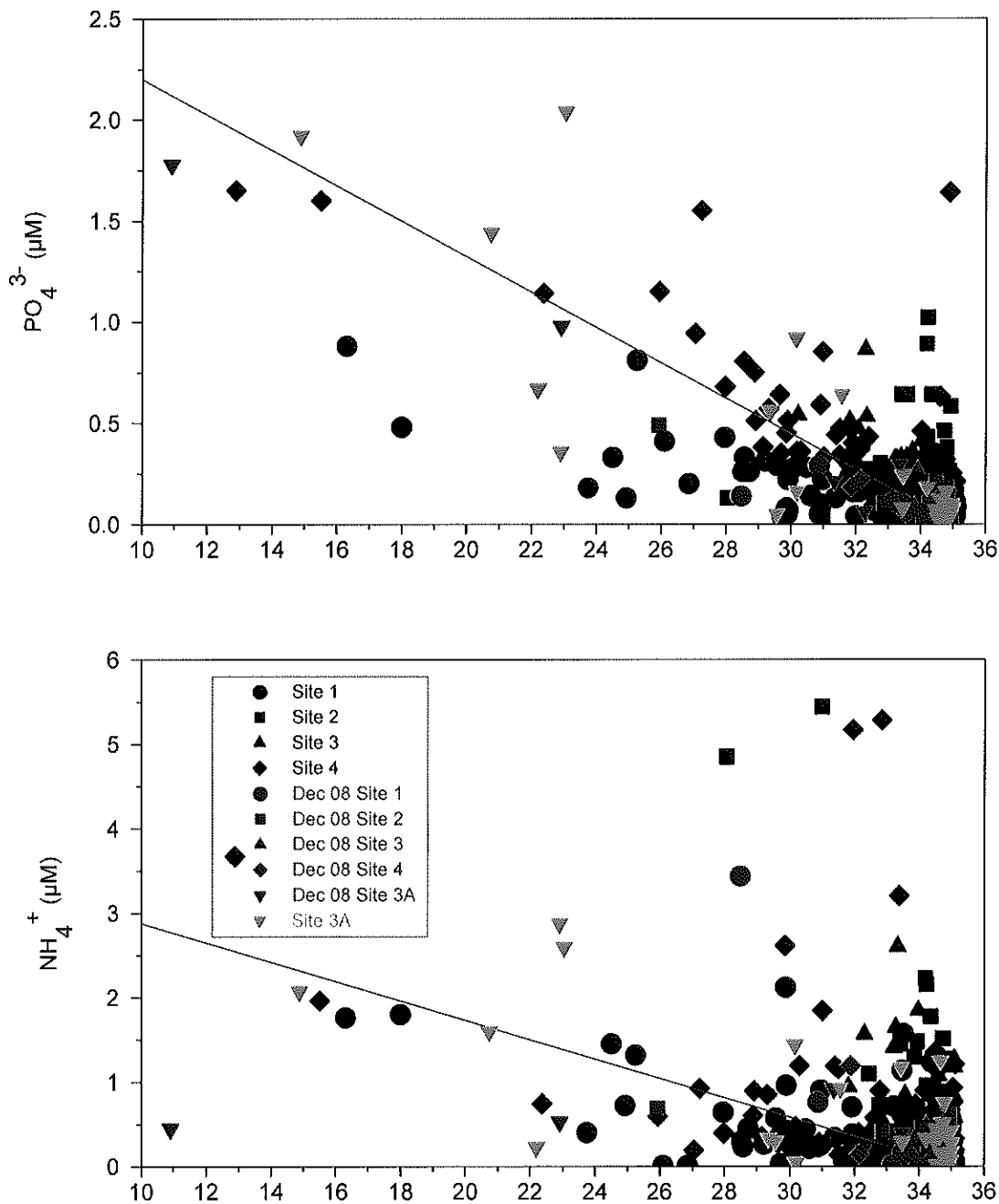


FIGURE 18. Phosphate and ammonium, plotted as a function of salinity for surface samples collected since August 1995 at four sites offshore of the Makena Golf Course. Black symbols represent combined data from surveys conducted between August 1995 and December 2008. Green symbols represent data from surveys at Site 3A commencing in June 2007. Red symbols are data from the most recent survey. Solid red line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from golf course irrigation well #4. For sampling site locations, see Figure 1.

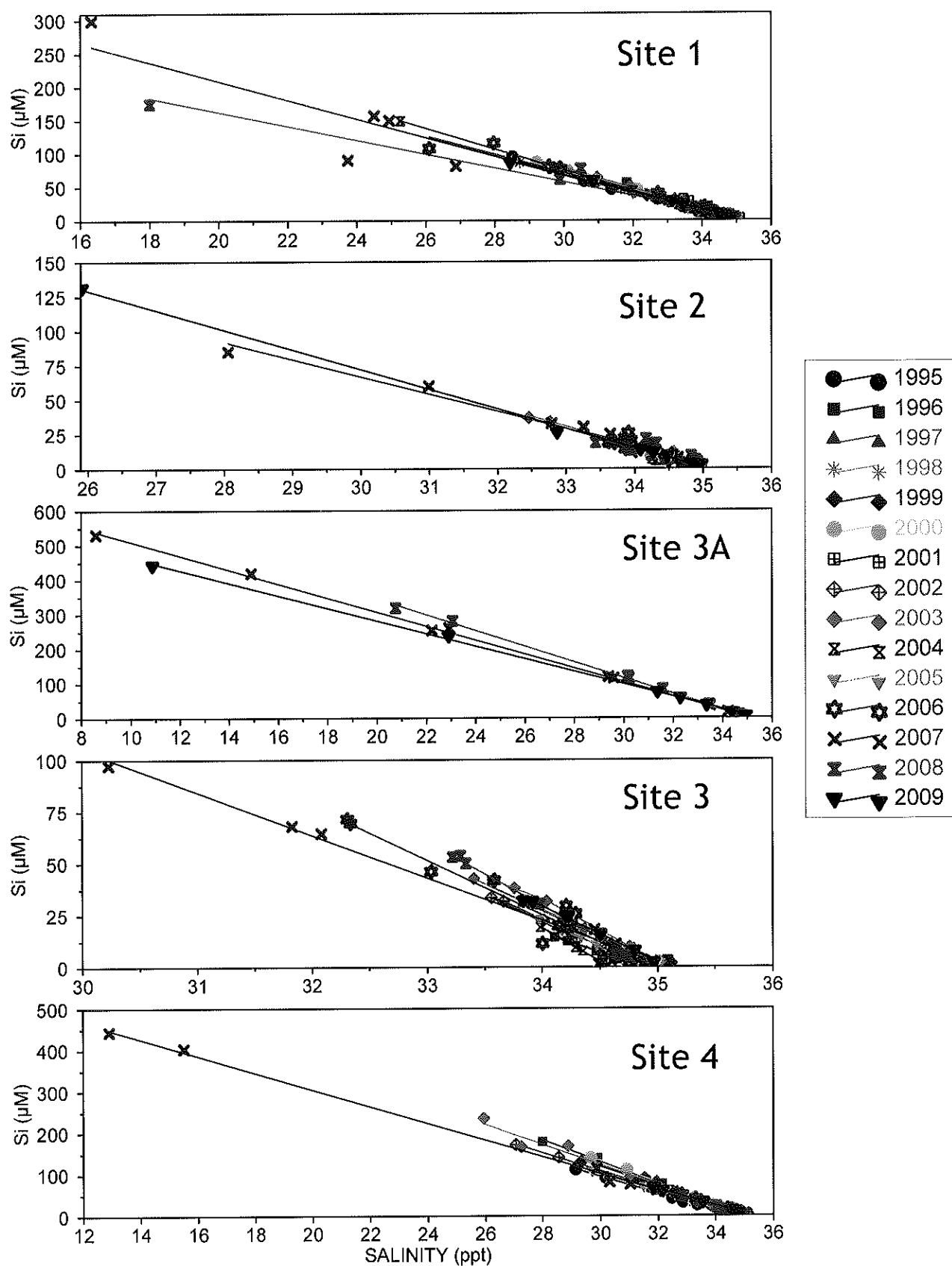


FIGURE 19. Mixing diagram showing yearly concentrations of silicate as functions of salinity from samples collected during annual monitoring surveys at five transect sites offshore of the Makena Resort (Site 3A since 2007). Note axis scale changes between sites. Straight lines are linear regressions through data points for each year. For sampling site locations, see Figure 1.

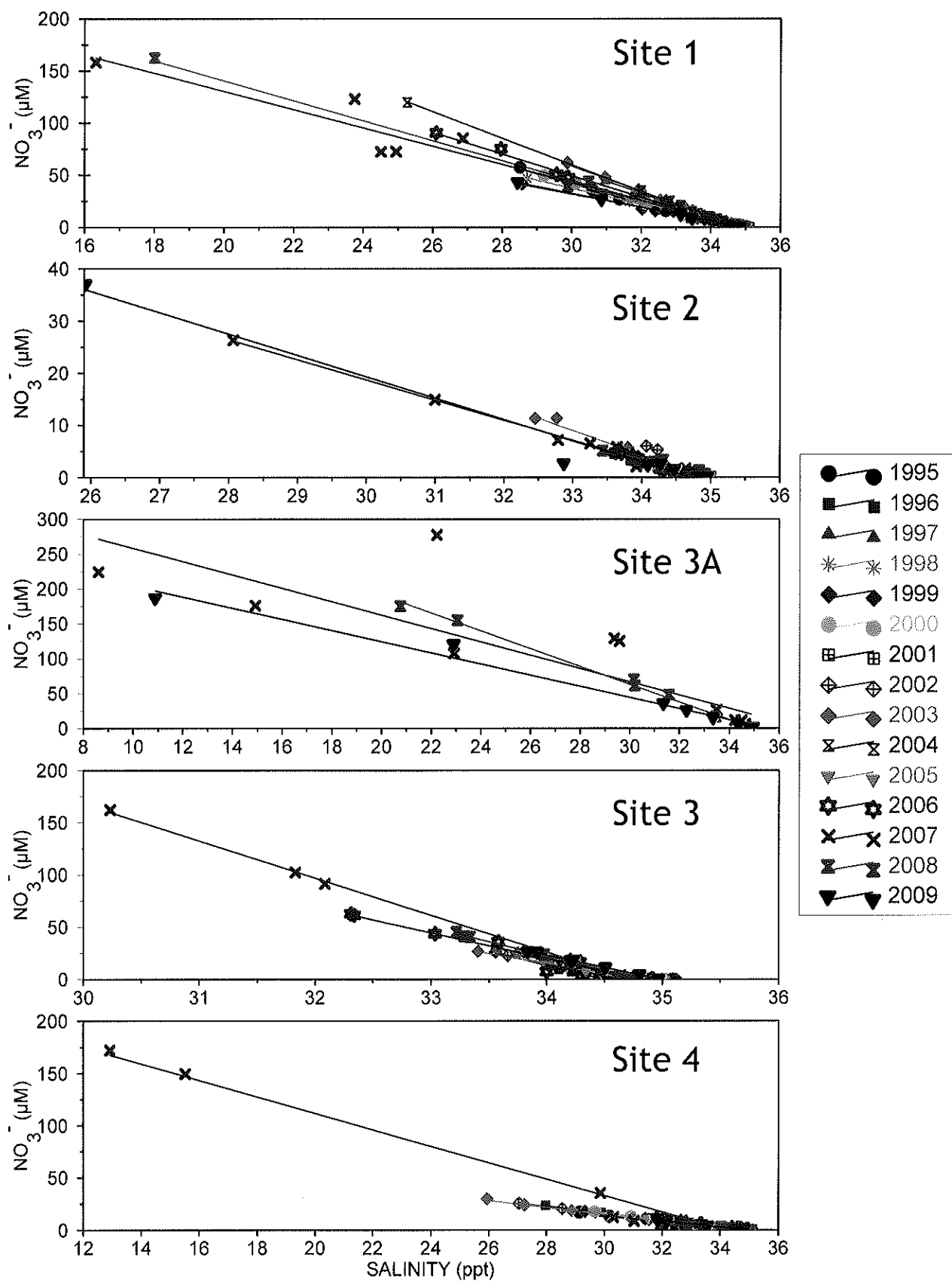


FIGURE 20. Mixing diagram showing yearly concentrations of nitrate as functions of salinity from samples collected during annual monitoring surveys at five transect sites offshore of the Makena Resort (Site 3A since 2007). Note axis scale changes between sites. Straight lines are linear regressions through data points for each year. For sampling site locations, see Figure 1.

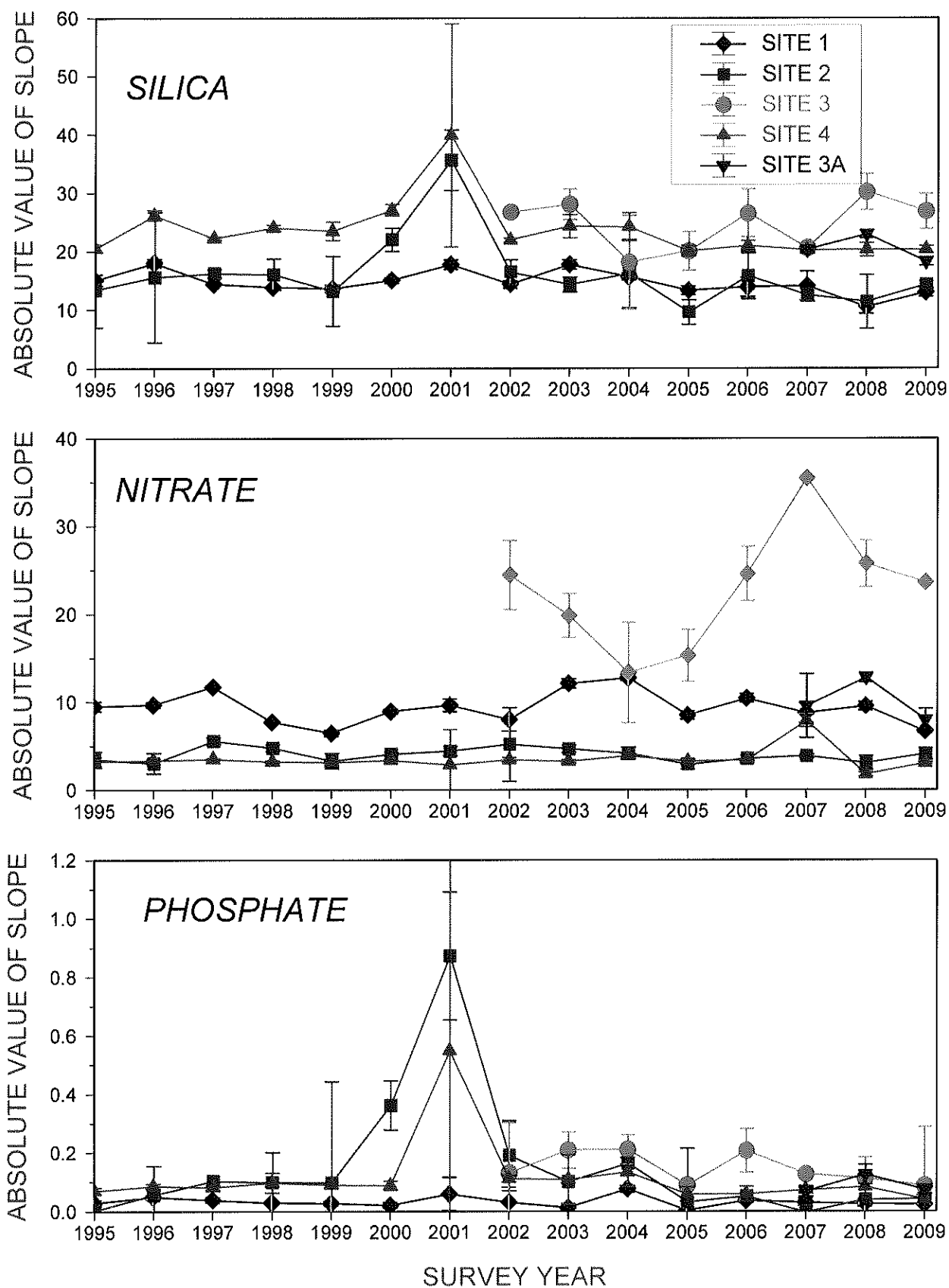


FIGURE 21. Time-course plots of absolute values of slopes of linear regressions of concentrations of silica, nitrate and phosphate as functions of salinity collected annually at each of the transect monitoring stations off the Makena Resort (Site 3A began in June 2007). Error bars are 95% confidence limits (Note error bar for Site 4 Phosphate is off scale). For locations of sampling transect sites, see Figure 1.

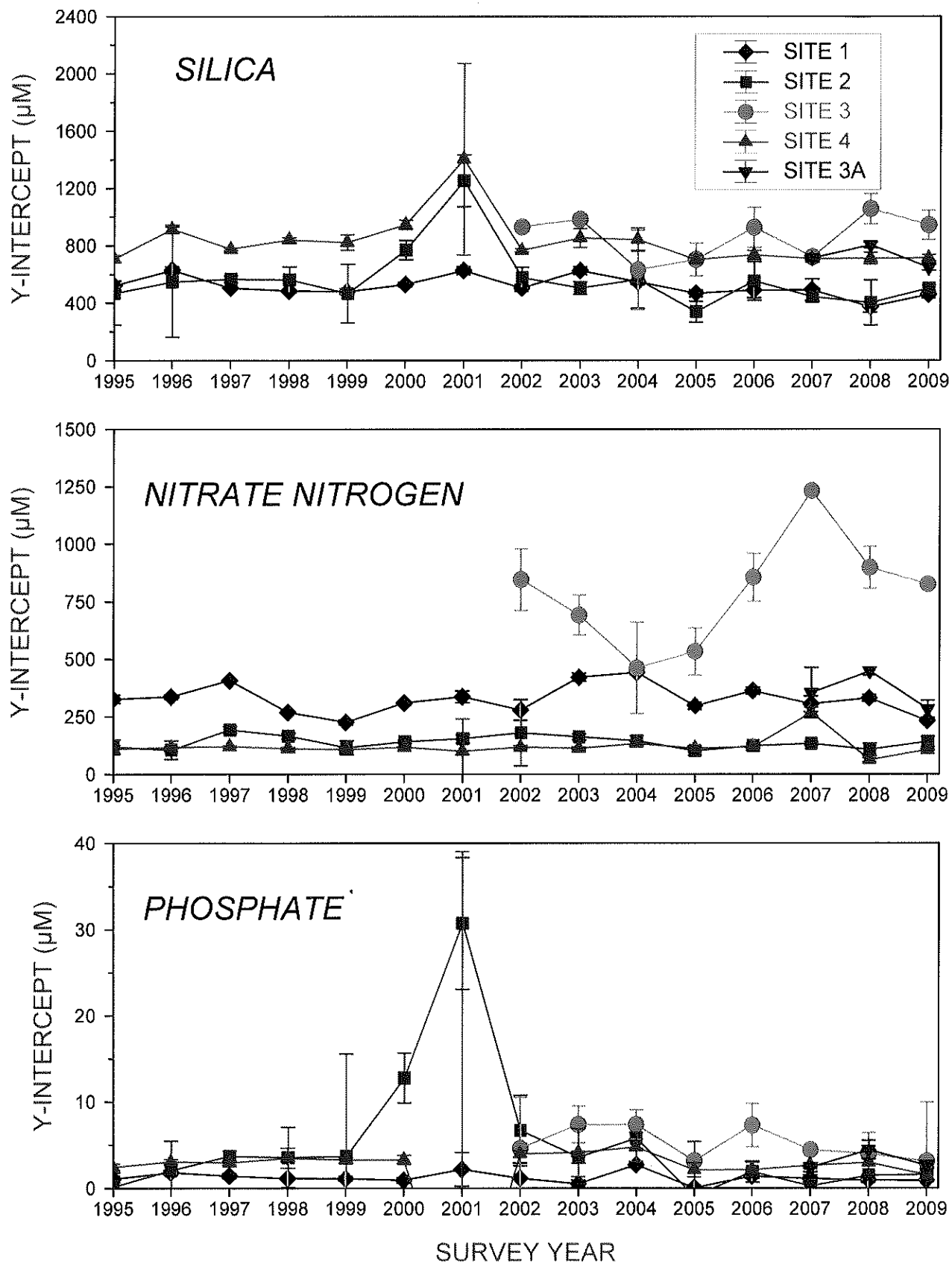


FIGURE 22. Time-course plots of Y-intercepts of linear regressions of concentrations of silica, nitrate and phosphorus as functions of salinity collected annually at each of the transect monitoring stations off the Makena Resort (Site 3A began in June 2007). Error bars are 95% confidence limits. For locations of sampling transect sites, see Figure 1.

MARINE WATER QUALITY MONITORING
MAKENA RESORT, MAKENA, MAUI
WATER CHEMISTRY
REPORT 1-2010

Prepared for

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I. PURPOSE

The Makena Resort fronts approximately 5.4 miles of coastline of southeastern Maui, extending from Papanui Stream (Nahuna Point) on the north and Pu`u Olai (Ahihi Bay) on the south. Within the Resort are two 18-hole golf courses (North and South Courses), as well as a hotel, sewage treatment plant and private residences. No part of the project involves direct alteration of the shoreline or nearshore marine environments.

Evaluations of other golf courses and other forms of resort development located near the ocean in the Hawaiian Islands reveal that there is detectable input to the coastal ocean of materials used for fertilization of turfgrass and landscaping (Dollar and Atkinson 1992). However, few, if any, effects that have been documented have been found to be detrimental to the marine ecosystem. Thus, there is no *a priori* reason to suspect that the construction and responsible operation of the golf courses and other components of the Makena Resort will cause any harmful changes to the marine environment. Nevertheless, in the interest of assuring maintenance of environmental quality, and as a means of ensuring that proper procedures are set forth, a condition of the Land Use Commission District Boundary Amendment for the project was the implementation of an ongoing marine monitoring program off the Makena Resort Development. The primary goals of the program are twofold: 1) to assess the degree that materials used on land to enhance turf growth and landscaping, as well as other nutrient subsidies, leach to groundwater and subsequently reach the ocean, and 2) to determine the fate of these materials within the nearshore zone. In terms of determining fate, the question that is addressed is if the materials that originate from Resort activities disperse with little or no effect, or do they cause changes in water quality sufficient to alter marine biological community structure?

The rationale of the monitoring program is to conduct repetitive evaluations of water chemistry at the same locations at regular time intervals (twice per year). This strategy allows for determination of variations in effects from the Makena Resort in both space (at different locations along the shoreline) and time. These studies also fulfill condition No. 10, Declaration of Conditions pertaining to the Amendment of the District Boundary, as required by the Land Use Commission, dated April 17, 1998. The following report presents the results of the twenty-fourth increment in the monitoring program, and contains data from water chemistry sampling conducted on July 11, 2010.

II. ANALYTICAL METHODS

Three survey sites directly downslope from the Makena Resort have been selected as sampling locations. A fourth site, located offshore of an area with minimal land-based development, particularly golf course operations, was selected as a control. During the June 2007 survey, another sampling location was added near the southern boundary of Maluaka Bay. It is anticipated that this station will remain part of the sampling protocol permanently. Figure 1 is a map showing the shoreline and topographical features of the Makena area, and the location of the North and South Golf Courses. All survey sites are depicted as transects perpendicular to the shoreline extending from the shoreline out to what is considered open coastal ocean (i.e., beyond the effects of activities on land). Survey Site 1 is located near the northern boundary of the project

site off Nahuna Point; Survey Site 2 bisects Makena Bay near Makena Landing. Site 3 bisects the middle of the South course on the north side of Maluaka Point. Site 3A is on the southern corner of Maluaka Bay. Site 4, which is considered the Control site, is located near the northern boundary of the 'Ahihi-Kina'u natural area reserve north of the 1790 lava flow and approximately 1-2 miles south of the existing Makena Golf courses (Figure 1). The control site was located off a shoreline area with minimal land uses (i.e., residences near the shoreline and upslope ranchlands) rather than off the completely uninhabited 1790 lava flow. This location was selected as the most appropriate control site, as it is the farthest location from the Makena Resort with the same geophysical structural of the land area. The completely different geological structure of the lava flow off the natural reserve likely results in very different groundwater dynamics compared to the land area where the Makena Resort is located, hence making the lava flow an unsuitable control site.

In July of 2002, Site 3 was relocated from a location at the southern boundary of the project offshore of Oneloa Beach to the location directly off the Makena Golf Course, as described above. The relocation of Site 3 was deemed necessary as the original location consistently showed virtually no input of groundwater to the ocean. Such lack of groundwater discharge resulted in little potential for evaluating effects from the project. The new location of Site 3 is directly downslope from both the portion of the golf course nearest to the ocean, several newly constructed private residences, and a 3-acre recently restored wetland area. As a result, the new location represents an area that reflects the maximum influence on nearshore water quality from a variety of land uses and natural habitat.

All fieldwork for the present survey was conducted on July 11, 2010. Environmental conditions during sample collection consisted of mild winds (8-10 knots), partly cloudy skies, and very little swell. Virtually no rainfall was measured in the Makena area within the previous month and drought conditions prevailed.

Water samples were collected at stations along transects that extend from the highest wash of waves to between 125-200 meters (m) offshore, depending on the site. Such a sampling scheme is designed to span the greatest range of salinity with respect to freshwater efflux at the shoreline. Sampling was more concentrated in the nearshore zone because this area is most likely to show the effects of land-based activities. With the exception of the two stations closest to the shoreline (0 and 2 m offshore), samples were collected at two depths; a surface sample was collected within approximately 10 centimeters (cm) of the sea surface, and a bottom sample was collected within one m of the sea floor.

Water samples from the shoreline to a distance of 10 m offshore were collected in triple-rinsed 1-liter polyethylene bottles by swimmers working from the shoreline. A digital refractometer was used to pinpoint the location of maximum groundwater flux to the ocean shoreline origin of each transect site. Water samples beyond 10 m from the shoreline were collected from a small boat using a 1.8-liter Niskin-type oceanographic sampling bottle. This bottle was lowered to the desired depth in an open position where spring-loaded endcaps were triggered to close by a messenger released from the surface. Upon recovery, each sample was placed on ice until further processing in Honolulu. Water samples were also collected from six golf course irrigation wells (No's 1, 2, 3, 5, 6, and 10) and one irrigation lake on August 3, 2010.

Water quality parameters evaluated included the 10 specific criteria designated for open coastal waters in Chapter 11-54, Section 06 (Open Coastal waters) of the State of Hawaii Department of Health Water Quality Standards. These criteria include: total nitrogen (TN) which is defined as inorganic nitrogen [nitrate + nitrite nitrogen ($\text{NO}_3^- + \text{NO}_2^-$), ammonium (NH_4^+)], plus total organic nitrogen (TON), total phosphorus (TP) which is defined as inorganic phosphorus (PO_4^{3-}) plus total organic phosphorus, chlorophyll a (Chl a), turbidity, temperature, pH and salinity. In addition, orthophosphate phosphorus (PO_4^{3-}) and silica (Si) were reported because these constituents are sensitive indicators of biological activity and the degree of groundwater mixing, respectively.

Analyses for $\text{NO}_3^- + \text{NO}_2^-$ (hereafter termed NO_3^-), NH_4^+ and PO_4^{3-} , were performed on filtered samples using a Technicon autoanalyzer according to standard methods for seawater analysis (Strickland and Parsons 1968, Grasshoff 1983). TN and TP were analyzed in a similar fashion on unfiltered samples following digestion. Total organic nitrogen (TON) and Total organic phosphorus (TOP) were calculated as the difference between TN and inorganic N, and TP and inorganic P, respectively. Limits of detection for the dissolved nutrients are $0.01 \mu\text{M}$ ($0.14 \mu\text{g/L}$) for NO_3^- and NH_4^+ , $0.01 \mu\text{M}$ ($0.31 \mu\text{g/L}$) for PO_4^{3-} , $0.1 \mu\text{M}$ ($1.4 \mu\text{g/L}$) for TN and $0.1 \mu\text{M}$ ($3.1 \mu\text{g/L}$) for TP.

Chl a was measured by filtering 300 ml of water through glass fiber filters; pigments on filters were extracted in 90% acetone in the dark at -5°C for 12-24 hours, and the fluorescence before and after acidification of the extract was measured with a Turner Designs fluorometer (level of detection $0.01 \mu\text{g/L}$). Salinity was determined using an AGE Model 2100 laboratory salinometer with a precision of 0.003‰.

In situ field measurements included water temperature, pH, dissolved oxygen and salinity which were acquired using an RBR Model XR-420 CTD calibrated to factory specifications. The CTD has a readability of 0.001°C , 0.001 pH units, 0.001% oxygen saturation, and 0.001 parts per thousand (‰) salinity. Shoreline salinity was measured in the field using an Atago PAL-06S digital refractometer.

Nutrient, turbidity, Chl a and salinity analyses were conducted by Marine Analytical Specialists located in Honolulu, Hawaii. This laboratory possesses acceptable ratings from EPA-compliant proficiency and quality control testing.

III. RESULTS and DISCUSSION

A. General Overview

Table 1 shows results of all marine water chemical analyses for samples collected off Makena on July 11, 2010 with nutrient concentrations reported in micromolar units (μM). Table 2 shows similar results with nutrient concentrations presented in units of micrograms per liter ($\mu\text{g/L}$). Tables 3 and 4 show geometric means of ocean samples at Sites 1, 2 and 4 for 24 surveys, 15 surveys at Site 3, and 6 surveys from Site 3-A, with nutrient concentrations shown in μM and $\mu\text{g/L}$.

respectively. Table 5 shows water chemistry measurements (in units of μM and $\mu\text{g/L}$) for samples collected from irrigation wells and one irrigation lake located on the Makena Resort Golf Courses. Concentrations of twelve chemical constituents in surface and deep-water samples from the July 2010 sampling are plotted as functions of distance from the shoreline in Figures 2 and 3. Mean concentrations (\pm standard error) of twelve chemical constituents in surface and deep water samples as functions of distance from the shoreline at Sites 1-4 collected since 1995 and from Site 3A collected since 2007 are plotted in Figures 4-18. In addition, data from the most recent sampling in July 2010 are also plotted on Figures 4-18.

During the July 2010 sampling, nearshore concentrations of dissolved Si, NO_3^- and TN on all five transects were elevated up to four orders of magnitude compared to samples collected at the sampling stations farthest from shore (Figure 2, Tables 1 and 2). The horizontal gradients of nutrients were steepest on transect Sites 1 and 3-A where NO_3^- at the shoreline ($182 \mu\text{M}$ and $186 \mu\text{M}$, respectively) decreased by at least three orders of magnitude between the shoreline and 150 m offshore ($1.91 \mu\text{M}$ and below detection, respectively). At transect Sites 2, 3, and 4, peak values of NO_3^- at the shoreline were between 9 and $31 \mu\text{M}$, with values at the most offshore stations ranging from below the detectable limit to $1.65 \mu\text{M}$. (Figure 2, Table 1). Salinity displayed mirror images of the patterns for nutrients, with lowest salinity at the shoreline of Sites 1 and 3-A (9.2 and 11.8‰, respectively), with rapidly increasing values with increasing distance from shore to near oceanic values (34.7‰) at the ends of the transects (Figure 3, Table 1). Distinct horizontal gradients extended to a distance of 100 - 150 m from the shoreline at all five transect sites (Tables 1 and 2).

Horizontal gradients in the surface concentrations of phosphate phosphorus (PO_4^{3-}) and TP were also evident at Sites 1, 3-A and 3 with the highest values in the samples collected near the shoreline, and progressively lower concentrations with increasing distance from shore. While there were distinct gradients in the concentrations of PO_4^{3-} , the magnitude of the range in values was far less than for Si, NO_3^- and TN (Figure 2, Tables 1 and 2) and the gradient extended out only to a distance of 5 - 10 m from the shoreline. At sites 2 and 4, no horizontal gradients were evident for PO_4^{3-} or TP during the July 2010 survey.

With no streams in the sampling area, nor heavy rainfall and runoff preceding sampling, the pattern of elevated Si, NO_3^- , PO_4^{3-} and TN with corresponding reduced salinity indicates groundwater entering the ocean near the shoreline. Low salinity groundwater, which contains high concentrations of Si, NO_3^- , TN and PO_4^{3-} (see values for well waters in Table 5), percolates to the ocean near the shoreline, resulting in a distinct zone of mixing in the nearshore region. The zone of mixing is discernible by distinct decreasing gradients of nutrients and increasing gradients of salinity with distance from shoreline. During periods of low tide when sea conditions are calm, the zone of mixing between groundwater and ocean water is most pronounced. The July 2010 sampling was conducted at low tide (-0.6 ft) with calm winds, resulting in a marked zone of mixing extending approximately 150 m from shore. Past monitoring surveys at Makena Resort conducted during periods of high tide and strong winds (e.g. December 2005) showed substantially smaller horizontal gradients than the present survey. Comparing the results of surveys conducted during different sea conditions clearly indicates that tidal state, as well as wind and wave energy, greatly effect groundwater mixing in the nearshore zone.

Dissolved nutrient constituents that are not usually associated with groundwater input (NH_4^+ , TON, TOP) showed varying results between transects. While elevated values of these constituents occur in the nearshore samples at Site 1, no distinct horizontal gradients with progressively decreasing values with distance from shore occur throughout the sampling regime (Figure 2). The highest concentrations of NH_4^+ were recorded in the shoreline samples at Site 1 ($2.6 \mu\text{M}$), while concentrations of NH_4^+ at the shoreline origins of the other transect sites fell below $0.32 \mu\text{M}$ (Table 1). Concentrations of TOP were elevated with 5 m of the shoreline at Sites 1, 3-A and 3 with values approximately double that measured at the other transect sites (Tables 1 and 2). A distinctly higher concentration of TON ($23.92 \mu\text{M}$) was measured in the shoreline sample at Site 1, compared to all other measurements where the concentration of TON ranged between 0.55 and $8.1 \mu\text{M}$ (Figure 2, Tables 1 and 2).

Turbidity was highest near the shoreline at all five transect locations, with highest values near the shoreline at Sites 1 and 2 (Table 1, Figure 3). In previous surveys, turbidity has generally been highest on Transect 2 compared to the other sites. Transect 2 bisects Makena Bay, which is semi-enclosed embayment with a silt/sand bottom rather than the predominantly "hard" reef or sand bottoms that occur at the other transect sites. In addition, it has been observed that during flash floods originating in the ranch lands upslope of the Makena Resort, terrigenous sediment may flow to the ocean in Makena Bay. As a result of wave-induced resuspension of the naturally occurring silt/sand substratum, as well as terrigenous runoff which may be partially retained within the embayment, turbidity has often been elevated at Transect 2 relative to the other transect sites. It is important to note that in surveys conducted since July 2002, water clarity in Makena Bay has improved greatly compared to preceding surveys in 2001 which reflected conditions following substantial input of terrigenous materials from a flash-flood that occurred in October 1999. Since that time, a large retention basin has been constructed on the upper slopes of Makena Resort in the watershed that flows into Makena Bay.

Concentrations of Chl *a* were higher near the shoreline compared to offshore values at four of the five sites during the July 2010 survey, with shoreline values lower than offshore values at Site 4 (Figure 3). Site 1 had distinctly higher shoreline values ($1.32 \mu\text{g/L}$) compared to all other sites (Table 1 and Figure 3).

Surface water temperature ranged between 23.7°C and 25.9°C during the July 2010 survey with the lowest measurement near the shoreline and increasing to a distance of 100 m from the shoreline at Sites 1 and 3-A (Figure 3 and Tables 1 and 2). At Sites 2, 3 and 4 temperature remained nearly constant along the entire length of the transect varying by only $0.1 - 0.4^\circ\text{C}$. Temperature near the shoreline was approximately $1 - 1.5^\circ\text{C}$ warmer at Sites 2 and 3 compared to the other three sites during July 2010.

In many areas of the Hawaiian Islands, input of low salinity groundwater to the nearshore ocean creates a distinct buoyant surface lens that can persist for some distance offshore. Buoyant surface layers are generally found in areas where turbulent processes (primarily wave action) are insufficient to completely mix the water column in the nearshore zone. Figures 2 -18 and Tables 1 and 2 show concentrations of water chemistry constituents with respect to vertical stratification. During the July 2010 survey, vertical stratification was evident for Si, NO_3^- , TN and salinity along all transects with the most pronounced gradients.

With respect to the other constituents of water chemistry, variations between surface and deep samples were generally small and showed no apparent trend with distance offshore (Figures 2-18).

B. Temporal Comparison of Monitoring Results

Figures 4-18 show mean concentrations (\pm standard error) of water chemistry constituents from surface and deep samples at Transect Sites 1-4 from monitoring surveys conducted between 1995 and 2010 and from Site 3-A for monitoring surveys conducted since 2007. In addition, the results of the most recent survey in July 2010 are also shown on each plot.

With a few exceptions, surface concentrations of most constituents during the July 2010 survey were within the mean ranges of past surveys (Figures 4-18). Deviations from the means were most notable at Site 1 where the July 2010 data for nearly all constituents were higher or lower than the mean within 5 m of the shoreline (Figures 4-6). Similar deviations were evident at Site 3 (Figures 10-12). Turbidity during the present survey was also higher than mean values at Sites 3 and 3-A. At site 3-A, however, the differences were evident only within 5 m of the shoreline (Figures 12 and 18). Measurements of Chl *a* during July 2010 were distinctly lower than the mean values at four of the five sites (Figures 9, 12, 15 and 18). These variations can be a result of sampling during a period of particularly low mixing of groundwater and ocean water in the nearshore zone, or may reflect an increase in nutrient subsidies to groundwater as a result of activities on land.

C. Conservative Mixing Analysis

A useful treatment of water chemistry data for interpreting the extent of material input from land is application of a hydrographic mixing model. In the simplest form, such a model consists of plotting the concentration of a dissolved chemical species as a function of salinity. Comparison of the curves produced by such plots with conservative mixing lines provides an indication of the origin and fate of the material in question (Officer 1979, Dollar and Atkinson 1992, Smith and Atkinson 1993).

Figure 19 shows plots of concentrations of four chemical constituents (Si , NO_3^- , PO_4^{3-} , and NH_4^+) as functions of salinity for samples collected in July 2010. Figures 20 and 21 show the same type of plot with data pooled by transect site for a composite of all past surveys, as well as for the most recent survey. Each graph also shows a conservative mixing line that was constructed by connecting the end member concentrations of open ocean water with irrigation well No. 6 located off the North Course of the Makena Resort (representative of groundwater upslope of the Makena Resort).

If the parameter in question displays purely conservative behavior (no input or removal from any process other than physical mixing), data points should fall on, or very near, the conservative mixing line. If, however, external material is added to the system through processes such as leaching of fertilizer nutrients to groundwater, data points will fall above the mixing line. If

material is being removed from the system by processes such as uptake by biotic metabolic processes, data points will fall below the mixing line.

Dissolved Si represents a check on the model as this material is present in high concentration in groundwater, but is not a major component of fertilizer. In addition, Si is not utilized rapidly within the nearshore environment by biological processes. It can be seen in Figure 19 that when concentrations of Si are plotted as functions of salinity, most data points fall in a linear array on or near the conservative mixing line created by connecting endpoint concentrations from water collected from the upslope irrigation well and the open ocean. Such good agreement indicates that marine waters at the five transect sites are primarily a mixture of groundwater flowing beneath the project and ocean water. Four points from Site 1 fell below the mixing line and were from shoreline samples with salinities less than 30 ‰. Over the course of monitoring, data points from Site 1 have consistently been below the Si mixing lines (Figure 20). At Site 3-A, the four data points from July 2010 with salinities lower than 30 ‰ fell above the conservative mixing line (Figures 19 and 20). Data plotted over the 6-year course of monitoring at this site, also reveal consistently higher Si measurements at Site 3-A (Figure 20). These results indicate that with the exception of Transects 1 and 3, groundwater endmembers from upslope Well No. 6 provides a valid representation of groundwater that enters the ocean following flow through the Makena development. Over the course of monitoring since 1995, the relationship between salinity and Si has remained nearly constant (Figure 20).

NO_3^- is the form of nitrogen most common in fertilizer mixes that are used for enhancing turf growth. When the concentrations of NO_3^- are plotted as functions of salinity, data from different transect prescribes distinctly different patterns (Figure 19). Data points from Transects 2 (Makena Bay) and 4 (Control transect) lie on the well water and ocean water conservative mixing line. The position of these two data arrays indicates that the source of NO_3^- entering the ocean at these sites contains little or no subsidies from activities on land. Inspection of the long-term mixing data (Figure 20) indicates that with the exception of two data points, all of the values of NO_3^- from Control Site 4 fall on, or very near, the conservative mixing line. Such a result validates that Site 4 is indeed a good water quality "control" area.

Conversely, data points from the nearshore samples at Transects 1, 3, and 3-A all fall well above the conservative mixing line, indicating various subsidies of NO_3^- to the ocean from sources on land. Data points for Sites 1 and 3-A are similar in slope, and are substantially less steep than data points from Site 3 (Figure 19). Such relationships indicate subsidies of NO_3^- at Transect sites 1, 3 and 3-A are likely a result of leaching of golf course fertilizers to the groundwater lens. In addition to the golf courses, however, residences near the shoreline at Site 1 include landscaping and lawns, while residences and a wetland lie directly inshore from Site 3. Site 3-A lies directly offshore of a residential community clubhouse that is currently under construction.

Transect Site 1 has also been used as a monitoring station for a similar evaluation of the effects of the Wailea Golf Courses on water chemistry that commenced in 1989. The lowest concentrations of NO_3^- relative to salinity at Transect site 1 occurred during the initial two years of study, with subsequent higher concentrations since 1992. Hence, there appears to have been an increase of NO_3^- in nearshore waters since 1992 that was not occurring in 1989-1991. Completion of the Wailea Gold Course occurred in December 1993, while completion of the Makena North Course

occurred in November 1993. As the southern region of the Wailea Course and the northern part of the Makena Course abut each other in the makai-mauka direction landward of ocean Transect 1, the increased concentrations of NO_3^- evident in Figure 19 may be a result of leaching of fertilizer materials from the combined golf courses to groundwater that enters the ocean in the sampling area.

Mixing analyses also indicate an ongoing input of NO_3^- at the shoreline of Stations 3 and 3A located off the existing Makena Golf Course and several new residences that have been constructed adjacent to the Golf Course (Figures 19 and 20). Such subsidies have been noted in past surveys, as can be seen in Figure 20. When data points for the July 2010 survey are compared to the combined set of data points from past surveys shown as black and green symbols in Figure 20, it is evident that subsidies of NO_3^- have not increased during the most recent survey. Future monitoring will clarify if the trend of NO_3^- input to the ocean is indeed decreasing.

While the data reveal a long-term subsidy to the concentration of NO_3^- in groundwater and the nearshore zone at several of the sampling sites, the concentrations of NO_3^- fall in clearly linear relationship as functions of salinity. The linearity of the data array indicates that there is no detectable uptake of this material by the marine environment. Such lack of uptake indicates that the nutrients are not being removed from the water column by metabolic reactions that could change the composition of the marine environment. Rather, the nutrient subsidies are diluted to background oceanic levels by physical processes of wind and wave mixing. As a result, the increased nutrients do not appear to have the potential to cause alteration in biological community composition or function.

Similar situations have also been observed in other locales in the Hawaiian islands where nutrient subsidies from golf course leaching result in excess NO_3^- in the nearshore zone. At Keauhou Bay on the Big Island, it was shown that owing to the distinct vertical stratification in the nearshore zone, the excess nutrients never come into contact with benthic communities, thereby limiting the potential for increased uptake by benthic algae. In addition, the residence time of the high nutrient water was short enough within the embayment to preclude phytoplankton blooms. As a result, while NO_3^- concentrations doubled as a result of golf course leaching for a period of at least several years, there was no detectable negative effect to the marine environment (Dollar and Atkinson 1992). Owing to the unrestricted nature of circulation and mixing off the Makena project (no confined embayments) it is reasonable to assume that the excess NO_3^- subsidies that are apparent in the present study will not result in alteration to biological communities.

Indeed, surveys of the nearshore marine habitats off of Makena reveal a generally healthy coral reef that does not appear to exhibit any negative effects from nutrient loading, particularly in the form of abundant algal biomass (Marine Research Consultants 2006). In addition to the lack of negative impacts to offshore coral communities, inspection of the entire shoreline fronting the Makena Resort revealed that there are no areas where excessive algal growth is presently occurring.

The other form of dissolved inorganic nitrogen, NH_4^+ , does not show a linear pattern of distribution with respect to salinity for either the July 2010 survey (Figure 19) or the entire monitoring program (Figure 21). Some samples with near oceanic salinity also displayed the

highest concentrations of NH_4^+ . The lack of a correlation between salinity and concentration of NH_4^+ suggests that this form of nitrogen is not present in the marine environment as a result of mixing from groundwater sources. Rather, NH_4^+ is generated by natural biotic activity in the ocean waters off Makena. However, during the July 2010 survey, the highest measurements for NH_4^+ occurred in low salinity nearshore water from Site 1.

PO_4^{3-} is also a major component of fertilizer, but is usually not found to leach to groundwater to the extent of NO_3^- , owing to a high absorptive affinity of phosphorus in soils. During July 2010, data points with salinities less than 32.5‰ fall below the mixing line at Site 1 and above the mixing line at Site 3. Data points for Site 3-A lie both above and below the mixing line. The lack of consistent linearity with respect to the conservative mixing line for samples collected near the shoreline suggest that there is not a consistent source of PO_4^{3-} from activities on land to the ocean. Thus, the elevated NO_3^- , which is likely a result of golf course and residential landscaping, is not reflected in similar subsidies of PO_4^{3-} .

D. Time Course Mixing Analyses

While it is possible to evaluate temporal changes from repetitive surveys conducted over time in terms of concentrations of water chemistry constituents (See Section C), a more informative and accurate method of evaluating changes over time is to utilize the results of scaling nutrient concentrations to salinity. As discussed above, the simple hydrographic mixing model consisting of plotting concentrations of nutrient constituents versus salinity eliminates the ambiguity associated with comparing only the concentrations of samples collected during multiple samplings at different stages of tide and weather conditions. Figures 22 and 23 show plots of Si and NO_3^- , respectively, as functions of salinity collected during each year of sampling (1995-2010). Also shown in Figures 22 and 23 are straight lines that represent the least squares linear regression fitted through concentrations of Si and NO_3^- as functions of salinity at each monitoring site for each year. Tables 6-8 show the numerical values of the Y-intercepts, slopes, and respective upper and lower 95% confidence limits of linear regressions fitted through the data points for Si, NO_3^- , and PO_4^{3-} as functions of salinity for each year of monitoring.

The magnitude of the contribution of nutrients originating from land based activities to groundwater will be reflected in both the steepness of the slope and the magnitude of the Y-intercept of the regression line fitted through the concentrations scaled to salinity (the Y-intercept can be interpreted as the concentration that would occur at a salinity of zero if the distribution of data points is linear). This relationship is valid because with increasing contributions from land, nutrient concentrations in any given parcel of water will increase with no corresponding change in salinity. Hence, if the contribution from land to groundwater nutrient composition is increasing over time, there would be progressive increases in the absolute value of the slopes, as well as the Y-intercepts of the regression lines fitted through each set of annual nutrient concentrations when plotted as functions of salinity. Conversely, if the contributions to groundwater from land are decreasing, there will be decreases in the absolute values of the slopes and Y-intercepts.

Plots of the values of the slopes (Figure 24) and Y-intercepts (Figure 25) of regression lines fitted through concentrations of Si, NO_3^- and PO_4^{3-} scaled to salinity during each survey year provide an

indication of the changes that have been occurring over time in the nearshore ocean off the Makena Resort. As stated above, Si provides the best case for evaluating the effectiveness of the method, as Si is present in high concentration in groundwater but is not a component of fertilizers. NO_3^- and PO_4^{3-} are the forms of nitrogen and phosphorus that are found in high concentrations in groundwater relative to ocean water, and are the major nutrient constituents found in fertilizers.

Examination of Figures 24 and 25, as well as Tables 6-8 reveal that none of the slopes or Y-intercepts of Si, NO_3^- and PO_4^{3-} from 1995 to 2010 at any of the transect sites exhibit any indication of progressively increasing or decreasing values over the course of monitoring. The term "REGSLOPE" in Tables 6-8 denotes the values of the slopes and 95% confidence limits of linear regressions of the values of the yearly slopes and Y-intercepts as a function of time. For all sites, the span of the upper and lower 95% confidence limits of the REGSLOPE coefficients are not significantly different than zero, indicating that there is no statistically significant increase or decrease in the salinity-scaled concentrations of Si, NO_3^- and PO_4^{3-} over the course of the monitoring program (Tables 6-8).

For all three nutrients, there is little variation in either slopes or Y-intercepts during any single year at Site 1, located off the "5 Graves" area downslope from the juncture of the Wailea and Makena Resorts (Figures 24 and 25). Such lack of variation indicates relatively consistent concentrations of Si, NO_3^- and PO_4^{3-} in groundwater entering the ocean over the fifteen years of monitoring. Sites 2 (Makena Landing) and 4 ('Ahihi-Kina'u) also show relatively constant trends with time with the exception of 2001 which is marked by large spikes in Si and PO_4^{3-} . Such a fluctuation is not present for NO_3^- in 2001. Sampling in 2001 was conducted during a period of rough winter sea conditions marked by vigorous mixing of the water column. As a result, there was very weak linear relationship between nutrient concentrations and salinity.

At Site 3, located directly downslope for the point of the Makena Golf Course closest to the ocean, there is a trend of decreasing NO_3^- between 2002 and 2004, an increasing trend from 2004 to 2007, followed by another downturn in 2008 – 2009 (Figures 24 and 25). As a result of these reversing trends, there is no significant change over the seven-year period of monitoring. The multiple reversing trends may reflect changes in land use, such as variation in fertilizer application or construction-related activities in 2002-2004 versus 2004-2007. In June of 2008, the golf course fronting the ocean in this area was shut down for re-alignment and re-planting. Underground retention/filtration systems were also constructed to mitigate adverse affects of stormwater runoff. At the time of this survey, new turf grass had been applied but the course remained closed and the filtration systems were not yet operational.

F. Compliance with DOH Standards

Tables 1 and 2 also show samples that exceed DOH water quality standards for open coastal waters under "wet" and "dry" conditions. These criteria are applied depending upon whether the area is likely to receive less than (dry) or greater than (wet) 3 million gallons of groundwater and/or surface water input per mile per day. As it is not possible to accurately estimate groundwater and surface water discharge, both wet and dry standards are considered. DOH standards include specific criteria for three situations; criteria that are not to be exceeded during

either 10% or 2% of the time, and criteria that are not to be exceeded by the geometric mean of samples. With only one or two samplings collected per year over more than 15 years, comparison of the 10% or 2% of the time criteria for any sample is not statistically meaningful. However, comparing sample concentrations to these criteria provide an indication of whether water quality is near the stated specific criteria.

Boxed values in Tables 1 and 2 show instances where measurements exceed the DOH standards under dry conditions, while boxed and shaded values show instances where measurements exceed DOH standards under wet conditions.

Results from the July 2010 survey indicated several measurements of NO_3^- , NH_4^+ and TN along all five transect sites exceeded the 10% DOH criteria under wet or dry conditions (Tables 1 and 2). Most of the instances where the DOH criteria for NO_3^- and TN were exceeded were from samples collected within 50 m of the shoreline. Seven measurements of TP, eight of turbidity and two measurements of Chl *a* exceeded the 10% DOH criteria under dry conditions. Under "wet" criteria, six measurements of TP and one measurement of Chl *a* exceeded the DOH criteria while no measurements of turbidity exceeded the standard. It is of interest to note that at Transect Site 4, which is considered the control station beyond the influence of the Makena Resort, exceedance of DOH criteria occurred for NO_3^- and TN. At Site 4, an unusual exceedance of NH_4^+ occurred in the deep water 150 m offshore (Tables 1 and 2).

Tables 3 and 4 show geometric means of samples collected at the same locations during the twenty-four increments of the monitoring program at Sites 1, 2 and 4. Geometric means of samples collected over fifteen increments of sampling at Site 3 and six increments of sampling at Site 3-A are also shown. These tables also specify the samples that exceed the DOH geometric mean limits for open coastal waters under "dry" (boxed) and "wet" (boxed and shaded) conditions. For NO_3^- , NH_4^+ , and TN numerous dry and wet standards were exceeded on all transects. Six samples of TP and eighteen samples of turbidity exceeded standards. All but three samples exceed the geometric mean standards for Chl *a*.

Site 4 is considered a control transect, in that it is not located offshore of a resort, golf course or dense residential development. It can be seen in Tables 3 and 4, however, that the number of samples that exceed geometric mean criteria at Site 4 are comparable to the other four sites, all of which are located downslope from the Makena Resort. Hence, Resort activities, including golf courses cannot be attributed as the sole (or even major) factor causing water quality to exceed geometric mean standards.

Several comments can be made regarding the present DOH water quality standards and how they apply to the monitoring program at the Makena Resort. As noted above, the category of water quality standards that are applicable for the Makena Monitoring program are "Open Coastal Waters." As the name implies, these standards apply to "open" waters that can be reasonably defined as "waters beyond the direct influence of land." In order to evaluate the effects of land uses on the nearshore ocean off Makena, the selected sampling regime collects water within a zone that extends from the shoreline to the open coastal ocean. As a result, sampling takes place within the region of ocean that is directly influenced by land. If the monitoring protocol were changed to include only those sampling locations beyond 50-100 m from shore (i.e., open coastal waters), which is completely valid with respect to meeting DOH regulatory compliance,

virtually none of the factors discussed above relating to the effects of activities on land to the nearshore ocean would not be observed.

Initial steps have been taken by DOH to rectify this situation. During revision of the Department of Health water quality standards in 2004, a unique set of monitoring criteria was added for the West Coast of the Island of Hawaii (i.e., "Kona standards"). The rationale for these unique standards was the recognition that existing numerical "standards" represent offshore coastal waters that are beyond the natural confluence of land and the nearshore ocean. As a result, the West Hawaii standards recognize that groundwater entering the ocean at the shoreline contains substantially elevated nutrients relative to open coastal waters. As a result, the Kona criteria provide the potential to meet water quality standards with elevated nutrient concentrations resulting from natural sources of groundwater input. As the same processes of groundwater discharge to the coastal ocean have been documented in Maui, it is hopeful that similar new provisions of the water quality standards will soon be applicable to the South Maui area.

III. SUMMARY

- The twenty-fourth phase of water chemistry monitoring of the nearshore ocean off the Makena Resort was carried out on July 11, 2010. Sixty-two ocean water samples were collected on four transects spaced along the project ocean frontage and on one control transect. Site 1 was located at the northern boundary of the project, Site 2 was located near the central part of the Makena North Golf Course in the center of Makena Bay, Site 3-A (initiated during the June 2007 survey) was located near the southern boundary of Maluaka Bay, Site 3 was downslope from the part of Makena South Golf Course that comes closest to the shoreline, and Control Site 4 was located to the south of Makena Resort near the northern boundary of the 'Ahihi-Kina'u Natural Area Reserve. Sampling transects extended from the shoreline out to the open coastal ocean. Water samples were analyzed for chemical criteria specified by DOH water quality standards, as well as several additional criteria. In addition, water samples were collected from six irrigation wells and an irrigation lake located on the golf courses.
- Water chemistry constituents that occur in high concentration in groundwater (Si, NO_3^- and TN) displayed distinct horizontal gradients with high concentrations nearest to shore and decreasing concentrations moving seaward. Groundwater input (based on salinity) was greatest at Sites 1 and 3-A, but was also evident at the other three sites (2, 3, and 4). As Site 4 served as a control, and was not located in the vicinity of the Makena Resort, it is apparent that groundwater input is not solely a function of Resort land usage.
- Vertical stratification of the water column was also evident on all transects during July 2010, with many surface samples displaying higher nutrient and lower salinities than the corresponding bottom samples. The strong vertical and horizontal patterns of distribution indicate that physical mixing processes generated by tide, wind, waves and currents were insufficient to completely mix the water column throughout the sampling area during the time of the monitoring survey.

- Chl *a* was elevated near the shoreline compared to offshore samples with Site 2 having distinctly higher values. Turbidity was elevated in the shoreline samples at all five sites and was higher in magnitude at Sites 1 and 4 compared to the other sites. Site 2, located at the point where sediment-laden storm water runoff entered the ocean following a flash flood in October 1999 did not display elevated turbidity during the present survey.
- Other organic water chemistry constituents that do not occur in high concentrations in groundwater (NH_4^+ , TON, TOP) did not show any distinctive patterns with respect to horizontal gradients. Concentrations of NH_4^+ , however, were elevated in the shoreline samples at four of the five sites.
- Scaling nutrient concentrations to salinity indicates that there were measurable subsidies of NO_3^- to groundwater that enters the nearshore ocean at three Transect sites. Results of the July 2010 monitoring indicated that these subsidies were greatest in magnitude at Site 3, followed by Sites 1 and 3A. No subsidies of NO_3^- were apparent at Site 2 (Makena Landing) or Site 4 ('Ahihi-Kina'u). These subsidies, which are likely a result of land uses involving fertilizers, substantially increase the concentration of NO_3^- with respect to salinity in groundwater flowing to the ocean compared to natural groundwater. The area shoreward of Site 1 includes the juncture of the southern part of the Wailea Gold Course and the northern part of the Makena North Course, as well as residential development. Sites 3 and 3A are directly downslope from the Makena South Course in an area where the golf course extends to the shoreline. In addition, private residences are near completion upslope of Transect 3, and it is possible that a cesspool remains from a house that was recently torn down. Hence, the subsidies of NO_3^- noted at these sites may result from a combination of sources.
- Linear regression statistics of nutrient concentration plotted as functions of salinity are useful for evaluating changes to water quality over time. When the regression values of nutrient concentrations versus salinity are plotted as a function of time, there are no statistically significant increases or decreases over the fourteen years of monitoring at any of the survey sites. The lack of increase in these slopes and intercepts indicate that there has been no consistent change in nutrient input from land to groundwater that enters the ocean from 1995 to 2009 (2002 to 2009 at Site 2). At Site 3 off the Makena Resort South Golf Course, there was a progressive decrease in NO_3^- input between 2002 and 2004, followed by an increase between 2004 and 2007, and another decrease in 2008-2009. Further monitoring at this site will be of interest to note the future direction of the oscillating trends noted in the last seven years.
- Comparing water chemistry parameters to DOH standards revealed that several measurements of NO_3^- , NH_4^+ and TN, and a few of TP, turbidity and Chl *a* exceeded the DOH "not to exceed more than 10% of the time" criteria for dry and wet conditions of open coastal waters. It is apparent that the concentrations of NO_3^- in nearshore marine waters that contains a mixture of seawater and natural groundwater may exceed DOH criteria with no subsidies from human activities on land. Numerous values of NO_3^- , NH_4^+ , TN, turbidity and Chl *a* exceeded specified limits for geometric means. Such exceedances occurred at all survey sites, including the control site that was far from any golf course influence. The consistent exceedance of water quality standards is in large part a consequence of the standards not

accounting for the natural effects of groundwater discharge to the nearshore ocean and resultant zones of mixing.

- As in past surveys, there is a subsidy of dissolved inorganic nutrients (e.g., NO_3^- and sometimes to a lesser extent PO_4^{3-}) to groundwater that enters the nearshore ocean at sampling sites downslope from parts of the Makena Resort. Without question, such input is a consequence of various land use activities. However, none of these inputs have increased significantly over time, and there is an indication of the beginning of a declining trend in the most recent data. Monitoring of coral reef community structure that is part of the ongoing monitoring, as well as the noted lack of any nuisance algal aggregations in the nearshore area indicate that the nutrient subsidies are not detrimental to marine community structure.
- The next phase of the Makena Resort monitoring program is scheduled for the December of 2010.

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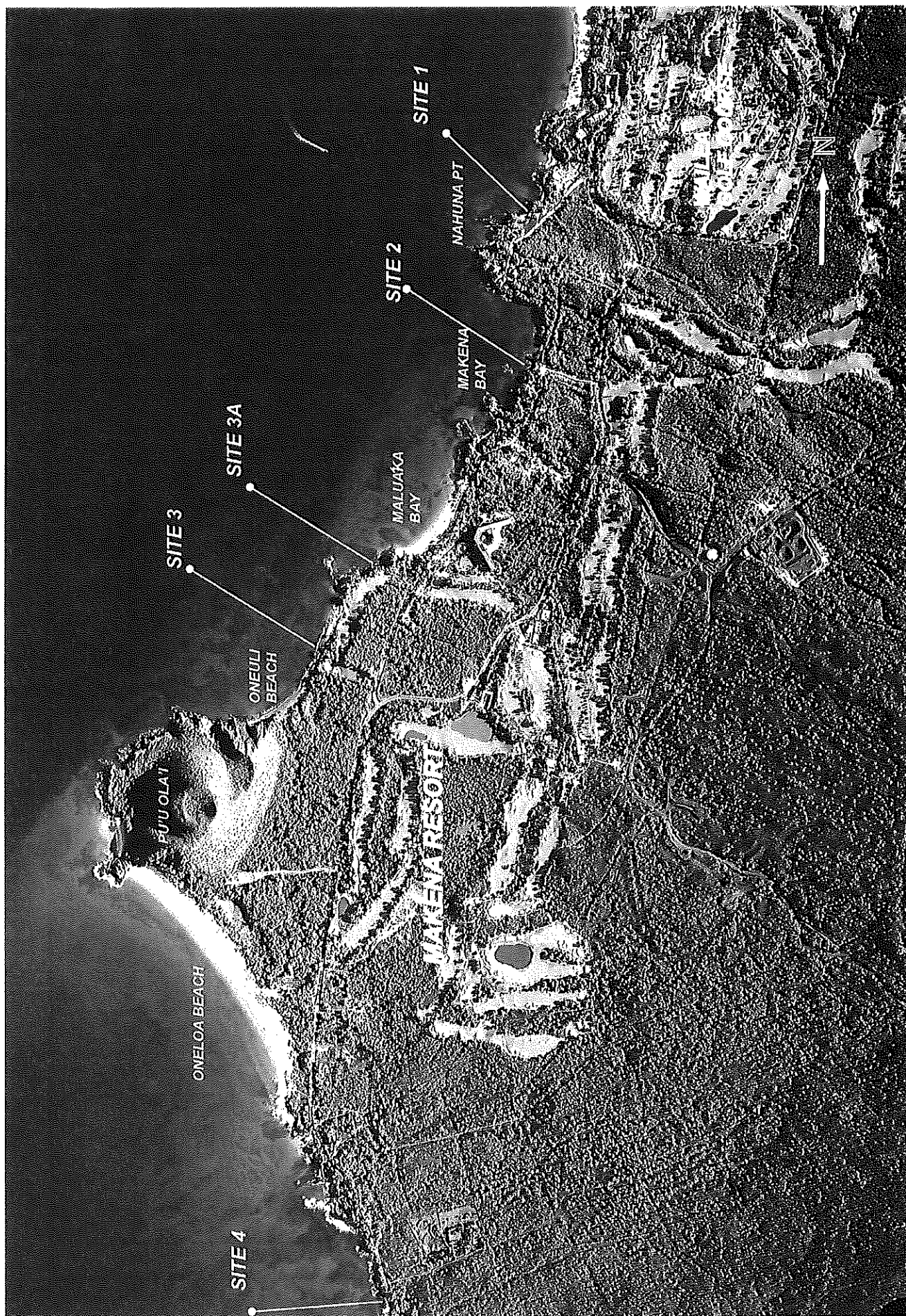


FIGURE 1. Aerial photograph of Makena Resort on southwest coastline of Maui. Also shown are locations of five water sampling transects that extend from the shoreline to 150-200 m from shore. The southern end of the Wailea golf course is visible at right.

TABLE 1. Water chemistry measurements from ocean water samples collected in the vicinity of the Makena Resort on July 11, 2010. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit. Also shown are the State of Hawaii, Department of Health (DOH) "not to exceed more than 10% of the time" and "not to exceed more than 2% of the time" water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH 10% "dry" standards; boxed and shaded values exceed DOH 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	DEPTH (m)	PO ₄ ³⁻ (μM)	NO ₃ ⁻ (μM)	NH ₄ ⁺ (μM)	Si (μM)	TOP (μM)	TON (μM)	TP (μM)	TN (μM)	TURB (NTU)	SALINITY (ppt)	CHL a (μg/L)	TEMP (deg.C)	pH (std.units)	O2 % Sat
MAKENA 1	0 S	0.1	1.56	182.72	0.88	389.4	0.48	23.92	2.04	207.52	0.28	9.171	0.53	25.0	7.97	108.4
	2 S	0.1	0.92	146.84	2.68	275.6	0.84	20.92	1.76	170.44	0.36	15.610	1.32	24.8	7.99	103.6
	5 S	0.1	0.39	68.57	0.11	141.3	0.26	7.66	0.65	76.34	0.32	24.768	0.41	23.7	8.05	105.0
	5 D	1.0	0.29	33.63	0.16	75.25	0.28	8.25	0.57	42.04	0.34	29.872	0.27	25.2	8.03	108.6
	10 S	0.1	0.22	11.10	0.11	26.55	0.30	8.81	0.52	20.02	0.99	33.247	0.17	25.3	8.00	105.8
	10 D	1.7	0.09	4.85	0.41	14.01	0.30	6.65	0.39	11.91	0.23	34.064	0.21	25.5	8.05	105.2
	50 S	0.1	0.05	2.37	0.17	9.12	0.31	7.11	0.36	9.65	0.47	34.327	0.20	25.8	8.12	98.3
	50 D	4.4	0.11	0.16	0.04	1.57	0.33	7.15	0.44	7.35	0.20	34.834	0.27	25.6	8.09	100.0
	100 S	0.1	0.27	2.12	0.57	8.31	0.23	6.75	0.50	9.44	0.15	34.400	0.13	25.9	8.10	98.5
	100 D	6.2	0.08	0.06	0.10	1.23	0.31	7.16	0.39	7.32	0.12	34.861	0.08	25.5	8.08	97.2
	150 S	0.1	0.05	1.91	0.42	7.11	0.37	7.22	0.42	9.55	0.23	34.550	0.12	25.8	8.06	96.0
	150 D	11.7	0.07	0.05	0.28	1.42	0.32	6.00	0.39	6.33	0.11	34.862	0.08	25.4	8.09	95.9
MAKENA 2	0 S	0.1	0.11	5.53	0.14	24.05	0.31	5.98	0.42	11.65	0.99	33.363	0.34	25.6	8.07	94.4
	2 S	0.1	0.21	6.04	0.05	24.07	0.31	6.99	0.52	13.08	0.67	33.346	0.18	25.5	8.08	94.4
	5 S	0.1	0.13	4.14	0.08	16.88	0.34	6.86	0.47	11.08	1.13	33.866	0.20	25.6	8.04	94.3
	5 D	1.2	0.12	4.50	0.05	20.07	0.35	6.43	0.47	10.98	0.72	33.861	0.35	25.6	8.03	94.6
	10 S	0.1	0.03	3.00	0.27	13.48	0.32	6.32	0.35	9.59	0.49	34.227	0.21	25.6	8.04	94.5
	10 D	1.5	0.06	2.78	0.55	12.41	0.31	6.03	0.37	9.36	0.77	34.105	0.20	25.6	8.02	94.4
	50 S	0.1	0.07	3.17	0.51	15.52	0.33	6.15	0.40	9.83	0.38	33.913	0.09	25.9	8.07	96.2
	50 D	2.8	0.22	0.12	1.33	2.57	0.17	5.79	0.39	7.24	0.26	34.825	0.10	25.6	8.07	96.2
	100 S	0.1	0.16	2.19	0.06	14.16	0.25	6.39	0.41	8.64	0.31	34.119	0.26	25.9	8.08	97.0
	100 D	4.7	0.07	0.04	BDL	2.38	0.28	6.08	0.35	6.12	0.18	34.834	0.06	25.5	8.08	95.9
	150 S	0.1	0.13	0.58	0.07	5.90	0.28	6.41	0.41	7.06	0.15	34.705	0.05	25.7	8.07	94.6
	150 D	11.4	0.11	BDL	0.10	2.15	0.28	5.64	0.39	5.74	0.09	34.983	0.03	25.4	8.09	95.1
	200 S	0.1	0.07	BDL	0.07	2.47	0.31	6.37	0.38	6.44	0.13	34.814	0.04	25.5	8.09	95.1
	200 D	16.0	0.09	0.04	0.14	2.04	0.28	7.69	0.37	7.87	0.10	34.934	0.07	25.3	8.09	96.1
MAKENA 3-A	0 S	0.1	1.96	185.92	0.32	495.8	0.52	6.60	2.48	192.84	0.66	11.814	0.19	24.3	7.85	96.4
	2 S	0.1	1.20	139.04	0.04	368.1	0.76	2.04	1.96	141.12	0.35	17.876	0.15	24.4	7.84	97.3
	5 S	0.1	0.88	40.16	0.88	119.7	0.60	7.60	1.48	48.64	0.18	29.858	0.13	24.9	7.98	100.9
	5 D	1.0	1.04	48.16	0.32	143.4	0.28	4.92	1.32	53.40	0.21	28.591	0.14	25.1	7.98	104.2
	10 S	0.1	0.07	14.28	0.11	46.60	0.27	6.56	0.34	20.95	0.20	32.697	0.09	25.3	8.00	105.9
	10 D	1.8	0.04	2.28	0.29	10.93	0.29	6.88	0.33	9.45	0.25	34.475	0.19	25.4	8.03	105.9
	50 S	0.1	0.12	3.01	0.05	13.48	0.29	6.80	0.41	9.86	0.16	34.350	0.10	25.8	8.06	98.8
	50 D	4.3	0.13	0.09	0.09	2.89	0.32	7.38	0.45	7.56	0.20	34.820	0.07	25.6	8.07	97.3
	100 S	0.0	0.13	0.72	0.06	5.33	0.29	6.58	0.42	7.36	0.17	34.725	0.09	25.7	8.06	95.0
	100 D	5.0	0.06	0.01	0.08	2.20	0.28	5.83	0.34	5.92	0.27	34.841	0.04	25.4	8.08	96.4
	150 S	0.1	0.19	BDL	0.05	2.14	0.31	7.90	0.50	7.95	0.16	34.856	0.05	24.9	8.08	94.9
	150 D	11.5	0.10	0.01	0.05	2.04	0.31	6.48	0.41	6.54	0.21	34.862	0.07	25.3	8.09	96.4
	150 D	11.5	0.10	0.01	0.05	2.04	0.31	6.48	0.41	6.54	0.21	34.862	0.07	25.3	8.09	96.4
MAKENA 3	0 S	0.1	0.13	31.93	0.07	34.65	0.32	5.73	0.45	37.73	0.42	33.533	0.10	25.8	8.14	96.2
	2 S	0.1	0.36	52.37	0.10	52.46	0.26	0.55	0.62	53.02	0.46	32.858	0.19	25.8	8.04	95.8
	5 S	0.1	0.60	47.40	0.40	59.32	0.68	4.80	1.28	52.60	0.31	33.060	0.27	25.8	7.99	96.2
	5 D	1.0	0.13	19.36	0.04	25.00	0.31	5.85	0.44	25.25	0.34	34.029	0.28	25.8	8.02	96.6
	10 S	0.1	0.12	10.61	0.12	15.85	0.29	6.01	0.41	16.74	0.34	34.358	0.21	25.8	8.02	96.8
	10 D	1.9	0.18	8.33	0.05	13.88	0.30	5.90	0.48	14.28	0.22	34.421	0.27	25.8	8.00	96.7
	50 S	0.1	0.16	9.84	0.25	17.46	0.28	5.10	0.44	15.19	0.26	34.318	0.14	25.8	8.04	99.4
	50 D	2.3	0.14	0.13	0.09	2.00	0.30	6.24	0.44	6.46	0.14	34.848	0.07	25.5	8.06	94.2
	100 S	0.1	0.18	0.20	0.09	3.19	0.31	7.75	0.49	8.04	0.14	34.797	0.12	25.6	8.06	93.7
	100 D	6.3	0.12	BDL	0.12	1.58	0.34	6.16	0.46	6.28	0.10	34.890	0.09	25.3	8.08	96.1
	150 S	0.1	0.04	BDL	0.06	1.20	0.29	7.82	0.33	7.88	0.10	34.902	0.06	25.5	8.15	94.5
	150 D	9.2	0.06	0.01	0.03	1.24	0.32	8.52	0.38	8.56	0.12	34.939	0.18	25.4	8.16	96.4
	150 D	9.2	0.06	0.01	0.03	1.24	0.32	8.52	0.38	8.56	0.12	34.939	0.18	25.4	8.16	96.4
MAKENA 4	0 S	0.1	0.13	9.26	0.12	57.16	0.33	8.00	0.46	17.38	0.30	32.149	0.10	25.0	8.16	95.2
	2 S	0.1	0.12	12.12	0.13	54.91	0.31	3.10	0.43	15.35	0.66	32.329	0.06	25.0	8.14	95.3
	5 S	0.1	0.16	5.00	0.25	35.49	0.30	7.22	0.46	12.47	0.15	33.324	0.20	25.0	8.14	95.2
	5 D	1.0	0.16	5.26	0.11	37.73	0.31	7.52	0.47	12.89	0.16	33.231	0.21	25.0	8.14	96.4
	10 S	0.1	0.08	1.11	0.13	13.23	0.33	8.07	0.41	9.31	0.16	34.493	0.09	25.0	8.12	96.7
	10 D	2.0	0.12	0.89	0.14	12.55	0.36	8.60	0.48	9.63	0.13	34.511	0.16	25.0	8.12	94.9
	50 S	0.1	0.10	1.72	0.15	17.60	0.32	6.55	0.42	8.42	0.12	34.228	0.07	25.1	8.14	95.0
	50 D	4.4	0.08	BDL	0.17	4.19	0.32	7.08	0.40	7.25	0.12	34.854	0.12	25.1	8.13	93.9
	100 S	0.1	0.05	1.62	0.05	17.53	0.33	7.39	0.38	9.06	0.16	34.248	0.09	25.2	8.14	95.4
	100 D	6.4	0.04	0.02	0.11	2.39	0.32	8.10	0.36	8.23	0.13	34.910	0.08	25.2	8.15	96.6
	150 S	0.1	0.13	1.65	0.13	16.43	0.32	6.26	0.45	8.04	0.12	34.302	0.07	25.2	8.14	96.0
	150 D	7.7	0.08	0.15	0.75	4.61	0.32	5.95	0.40	6.85	0.17	34.788	0.12	25.3	8.16	95.2
	150 D	7.7	0.08	0.15	0.75	4.61	0.32	5.95	0.40	6.85	0.17	34.788	0.12	25.3	8.16	95.2
DOH WQS	DRY	10% 2%	0.71 1.43	0.36 0.64					0.96 1.45	12.86 17.86	0.50 1.00	*	0.50 1.00	**	***	****
	WET	10% 2%	1.00 1.78	0.61 1.07					1.29 1.93	17.85 25.00	1.25 2.00	*	0.90 1.75	**	***	****

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

****Dissolved Oxygen not to be below 75% saturation.

TABLE 2. Water chemistry measurements from ocean water samples (in $\mu\text{g/L}$) collected in the vicinity of the Makena Resort on July 11, 2010. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit. Also shown are the State of Hawaii, Department of Health (DOH) "not to exceed more than 10% of the time" and "not to exceed more than 2% of the time" water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH 10% "dry" standards; boxed and shaded values exceed DOH 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	DEPTH (m)	PO ₄ ³⁻ ($\mu\text{g/L}$)	NO ₃ ⁻ ($\mu\text{g/L}$)	NH ₄ ⁺ ($\mu\text{g/L}$)	Si ($\mu\text{g/L}$)	TOP ($\mu\text{g/L}$)	TON ($\mu\text{g/L}$)	TP ($\mu\text{g/L}$)	TN ($\mu\text{g/L}$)	TURB (NTU)	SALINITY (ppt)	CHL <i>a</i> ($\mu\text{g/L}$)	TEMP (deg.C)	pH (std. units)	O2 (% Sat)
MAKENA 1	0 S	0.1	48.36	2558	12.33	10942	14.88	334.88	63.24	2905	0.28	9.171	0.53	25.0	7.97	108.4
	2 S	0.1	28.52	2056	37.54	7744	26.04	292.88	54.56	2386	0.36	15.610	1.32	24.8	7.99	103.6
	5 S	0.1	12.09	960.0	1.54	3972	8.06	107.24	20.15	1069	0.32	24.768	0.41	23.7	8.05	105.0
	5 D	1.0	8.99	470.8	2.24	2115	8.68	115.50	17.67	588.6	0.34	29.872	0.27	25.2	8.03	108.6
	10 S	0.1	6.82	155.4	1.54	746.1	9.30	123.34	16.12	280.3	0.99	33.247	0.17	25.3	8.00	105.8
	10 D	1.7	2.79	67.90	5.74	393.7	9.30	93.10	12.09	166.7	0.23	34.064	0.21	25.5	8.05	105.2
	50 S	0.1	1.55	33.18	2.38	256.3	9.61	99.54	11.16	135.1	0.47	34.327	0.20	25.8	8.12	98.3
	50 D	4.4	3.41	2.24	0.56	44.1	10.23	100.10	13.64	102.9	0.20	34.834	0.27	25.6	8.09	100.0
	100 S	0.1	8.37	29.68	7.98	233.5	7.13	94.50	15.50	132.2	0.15	34.400	0.13	25.9	8.10	98.5
	100 D	6.2	2.48	0.84	1.40	34.6	9.61	100.24	12.09	102.5	0.12	34.861	0.08	25.5	8.08	97.2
	150 S	0.1	1.55	26.74	5.88	199.8	11.47	101.08	13.02	133.7	0.23	34.550	0.12	25.8	8.06	96.0
	150 D	11.7	2.17	0.70	3.92	39.9	9.92	84.00	12.09	88.62	0.11	34.862	0.08	25.4	8.09	95.9
MAKENA 2	0 S	0.1	3.41	77.42	1.96	675.8	9.61	83.72	13.02	163.1	0.99	33.363	0.34	25.6	8.07	94.4
	2 S	0.1	6.51	84.56	0.70	676.4	9.61	97.86	16.12	183.1	0.67	33.346	0.18	25.5	8.08	94.4
	5 S	0.1	4.03	57.96	1.12	474.3	10.54	96.04	14.57	155.1	1.13	33.866	0.20	25.6	8.04	94.3
	5 D	1.2	3.72	63.00	0.70	564.0	10.85	90.02	14.57	153.7	0.72	33.861	0.35	25.6	8.03	94.6
	10 S	0.1	0.93	42.00	3.78	378.8	9.92	88.48	10.85	134.3	0.49	34.227	0.21	25.6	8.04	94.5
	10 D	1.5	1.86	38.92	7.70	348.7	9.61	84.42	11.47	131.0	0.77	34.105	0.20	25.6	8.02	94.4
	50 S	0.1	2.17	44.38	7.14	436.1	10.23	86.10	12.40	137.6	0.38	33.913	0.09	25.9	8.07	96.2
	50 D	2.8	6.82	1.68	18.63	72.2	5.27	81.06	12.09	101.4	0.26	34.825	0.10	25.6	8.07	96.2
	100 S	0.1	4.96	30.66	0.84	397.9	7.75	89.46	12.71	121.0	0.31	34.119	0.26	25.9	8.08	97.0
	100 D	4.7	2.17	0.56	BDL	66.9	8.68	85.12	10.85	85.68	0.18	34.834	0.06	25.5	8.08	95.9
	150 S	0.1	4.03	8.12	0.98	165.8	8.68	89.74	12.71	98.84	0.15	34.705	0.05	25.7	8.07	94.6
	150 D	11.4	3.41	BDL	1.40	60.4	8.68	78.96	12.09	80.36	0.09	34.983	0.03	25.4	8.09	95.1
	200 S	0.1	2.17	BDL	0.98	69.4	9.61	89.18	11.78	90.16	0.13	34.814	0.04	25.5	8.09	95.1
	200 D	16.0	2.79	0.56	1.96	57.3	8.68	107.66	11.47	110.18	0.10	34.934	0.07	25.3	8.09	96.1
MAKENA 3-A	0 S	0.1	60.76	2603	4.48	13933	16.12	92.40	76.88	2700	0.66	11.814	0.19	24.3	7.85	96.4
	2 S	0.1	37.20	1947	0.56	10343	23.56	28.56	60.76	1976	0.35	17.876	0.15	24.4	7.84	97.3
	5 S	0.1	27.28	562.2	12.33	3364	18.60	106.4	45.88	681.0	0.18	29.858	0.13	24.9	7.98	100.9
	5 D	1.0	32.24	674.2	4.48	4030	8.68	68.88	40.92	747.6	0.21	28.591	0.14	25.1	7.98	104.2
	10 S	0.1	2.17	199.9	1.54	1309	8.37	91.84	10.54	293.3	0.20	32.697	0.09	25.3	8.00	105.9
	10 D	1.8	1.24	31.92	4.06	307.1	8.99	96.32	10.23	132.3	0.25	34.475	0.19	25.4	8.03	105.9
	50 S	0.1	3.72	42.14	0.70	378.8	8.99	95.20	12.71	138.0	0.16	34.350	0.10	25.8	8.06	98.8
	50 D	4.3	4.03	1.26	1.26	81.2	9.92	103.3	13.95	105.8	0.20	34.820	0.07	25.6	8.07	97.3
	100 S	0.0	4.03	10.08	0.84	149.8	8.99	92.12	13.02	103.0	0.17	34.725	0.09	25.7	8.06	95.0
	100 D	5.0	1.86	0.14	1.12	61.8	8.68	81.62	10.54	82.88	0.27	34.841	0.04	25.4	8.08	96.4
	150 S	0.1	5.89	BDL	0.70	60.1	9.61	110.6	15.50	111.3	0.16	34.856	0.05	24.9	8.08	94.9
	150 D	11.5	3.10	0.14	0.70	57.3	9.61	90.72	12.71	91.56	0.21	34.862	0.07	25.3	8.09	96.4
MAKENA 3	0 S	0.1	4.03	447.0	0.98	973.7	9.92	80.22	13.95	528.2	0.42	33.533	0.10	25.8	8.14	96.2
	2 S	0.1	11.16	733.2	1.40	1474	8.06	7.70	19.22	742.3	0.46	32.858	0.19	25.8	8.04	95.8
	5 S	0.1	18.60	663.6	5.60	1667	21.08	67.20	39.68	736.4	0.31	33.060	0.27	25.8	7.99	96.2
	5 D	1.0	4.03	271.0	0.56	702.5	9.61	81.90	13.64	353.5	0.34	34.029	0.28	25.8	8.02	96.6
	10 S	0.1	3.72	148.5	1.68	445.4	8.99	84.14	12.71	234.4	0.34	34.358	0.21	25.8	8.02	96.8
	10 D	1.9	5.58	116.6	0.70	390.0	9.30	82.60	14.88	199.9	0.22	34.421	0.27	25.8	8.00	96.7
	50 S	0.1	4.96	137.8	3.50	490.6	8.68	71.40	13.64	212.7	0.26	34.318	0.14	25.8	8.04	99.4
	50 D	2.3	4.34	1.82	1.26	56.2	9.30	87.36	13.64	90.44	0.14	34.848	0.07	25.5	8.06	94.2
	100 S	0.1	5.58	2.80	1.26	89.6	9.61	108.5	15.19	112.6	0.14	34.797	0.12	25.6	8.06	93.7
	100 D	6.3	3.72	BDL	1.68	44.4	10.54	86.24	14.26	87.92	0.10	34.890	0.09	25.3	8.08	96.1
	150 S	0.1	1.24	BDL	0.84	33.7	8.99	109.5	10.23	110.3	0.10	34.902	0.06	25.5	8.15	94.5
	150 D	9.2	1.86	0.14	0.42	34.8	9.92	119.3	11.78	119.8	0.12	34.939	0.18	25.4	8.16	96.4
MAKENA 4	0 S	0.1	4.03	129.6	1.68	1606	10.23	112.0	14.26	243.3	0.30	32.149	0.10	25.0	8.16	95.2
	2 S	0.1	3.72	169.7	1.82	1543	9.61	43.40	13.33	214.9	0.66	32.329	0.06	25.0	8.14	95.3
	5 S	0.1	4.96	70.00	3.50	997.3	9.30	101.1	14.26	174.6	0.15	33.324	0.20	25.0	8.14	95.2
	5 D	1.0	4.96	73.64	1.54	1060	9.61	105.3	14.57	180.5	0.16	33.231	0.21	25.0	8.14	96.4
	10 S	0.1	2.48	15.54	1.82	371.8	10.23	113.0	12.71	130.3	0.16	34.493	0.09	25.0	8.12	96.7
	10 D	2.0	3.72	12.46	1.96	352.7	11.16	120.4	14.88	134.8	0.13	34.511	0.16	25.0	8.12	94.9
	50 S	0.1	3.10	24.08	2.10	494.6	9.92	91.70	13.02	117.9	0.12	34.228	0.07	25.1	8.14	95.0
	50 D	4.4	2.48	BDL	2.38	117.7	9.92	99.12	12.40	101.5	0.12	34.854	0.12	25.1	8.13	93.9
	100 S	0.1	1.55	22.68	0.70	492.6	10.23	103.5	11.78	126.8	0.16	34.248	0.09	25.2	8.14	95.4
	100 D	6.4	1.24	0.28	1.54	67.2	9.92	113.4	11.16	115.2	0.13	34.910	0.08	25.2	8.15	96.6
	150 S	0.1	4.03	23.10	1.82	461.7	9.92	87.64	13.95	112.6	0.12	34.302	0.07	25.2	8.14	96.0
	150 D	7.7	2.48	2.10	10.50	129.5	9.92	83.30	12.40	95.90	0.17	34.788	0.12	25.3	8.16	95.2
DOH WQS	DRY	10%	10.00	5.00					30.00	180.00	0.50	.	0.50	..	...	....
		2%	20.00	9.00					45.00	250.00	1.00	.	1.00	..	...	....
	WET	10%	14.00	8.50					40.00	250.00	1.25	.	0.90	..	...	....
		2%	25.00	15.00					60.00	350.00	2.00	.	1.75	..	...	....

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

*** pH shall not deviate more than 0.5 units from a value of 8.1.

**** Dissolved Oxygen not to be below 75% saturation.

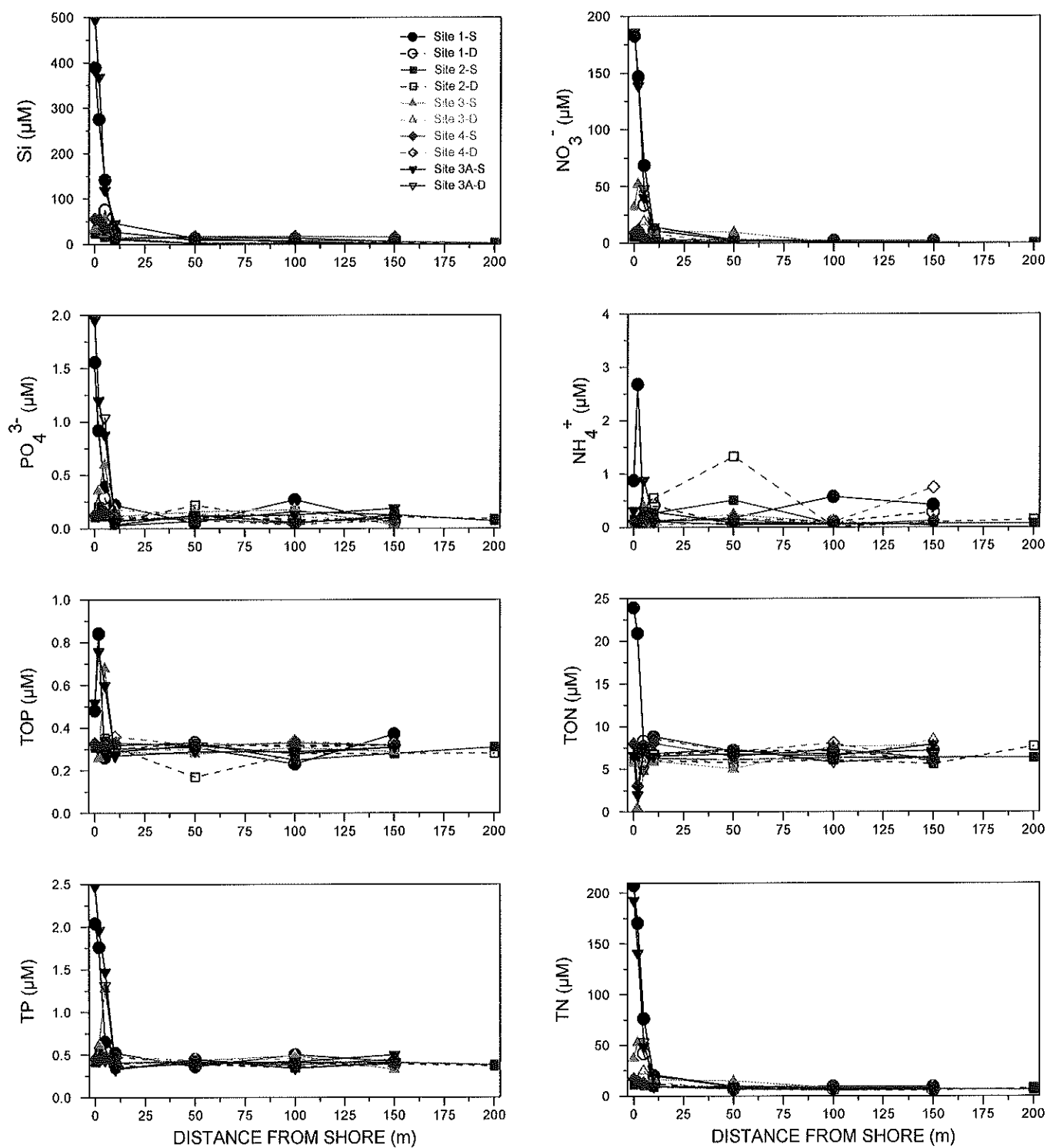
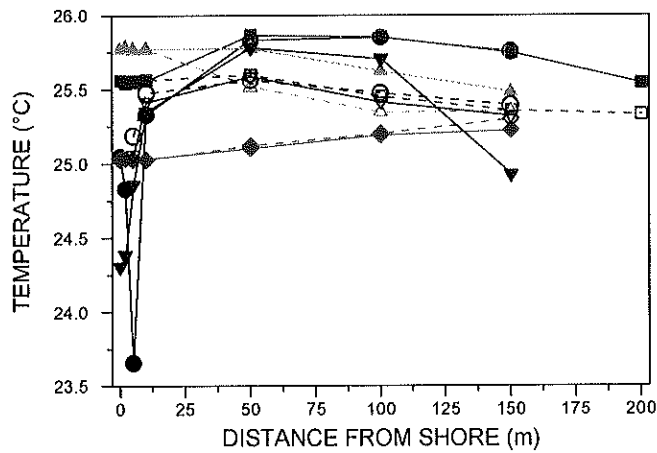
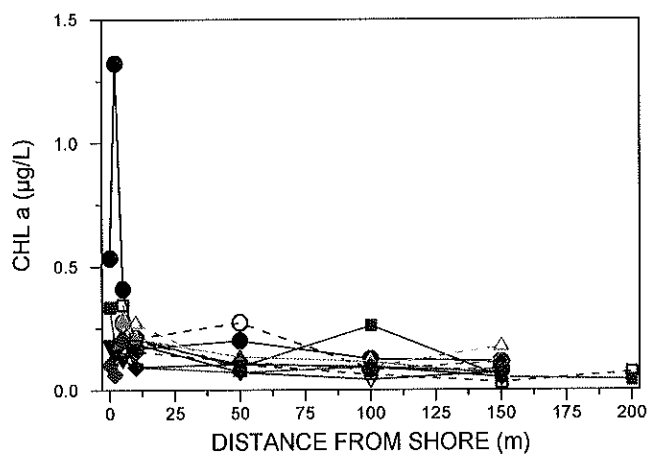
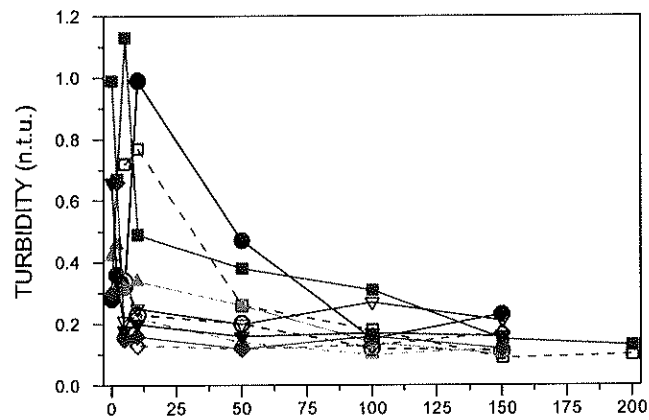
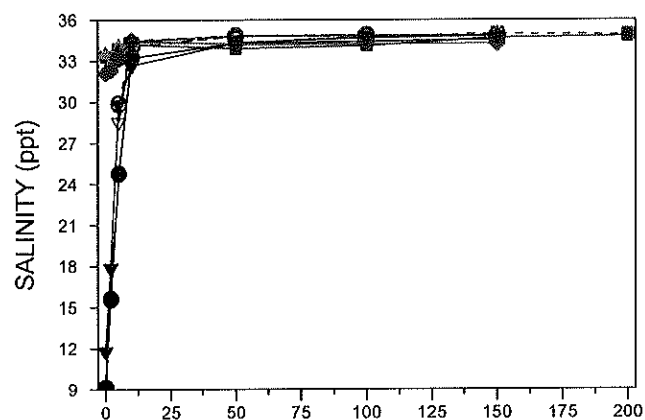


FIGURE 2. Plots of dissolved nutrients in surface (S) and deep (D) samples collected on July 11, 2010 as a function of distance from the shoreline in the vicinity of Makena Resort. For site locations, see Figure 1.



● Site 1-S ○ Site 1-D ■ Site 2-S □ Site 2-D ▲ Site 3-S △ Site 3-D ◆ Site 4-S ◇ Site 4-D ▼ Site 3A-S ▽ Site 3A-D

FIGURE 3. Plots of water chemistry constituents in surface (S) and deep (D) samples collected on July 11, 2010 as a function of distance from the shoreline in the vicinity of Makena Resort. For site locations, see Figure 1.

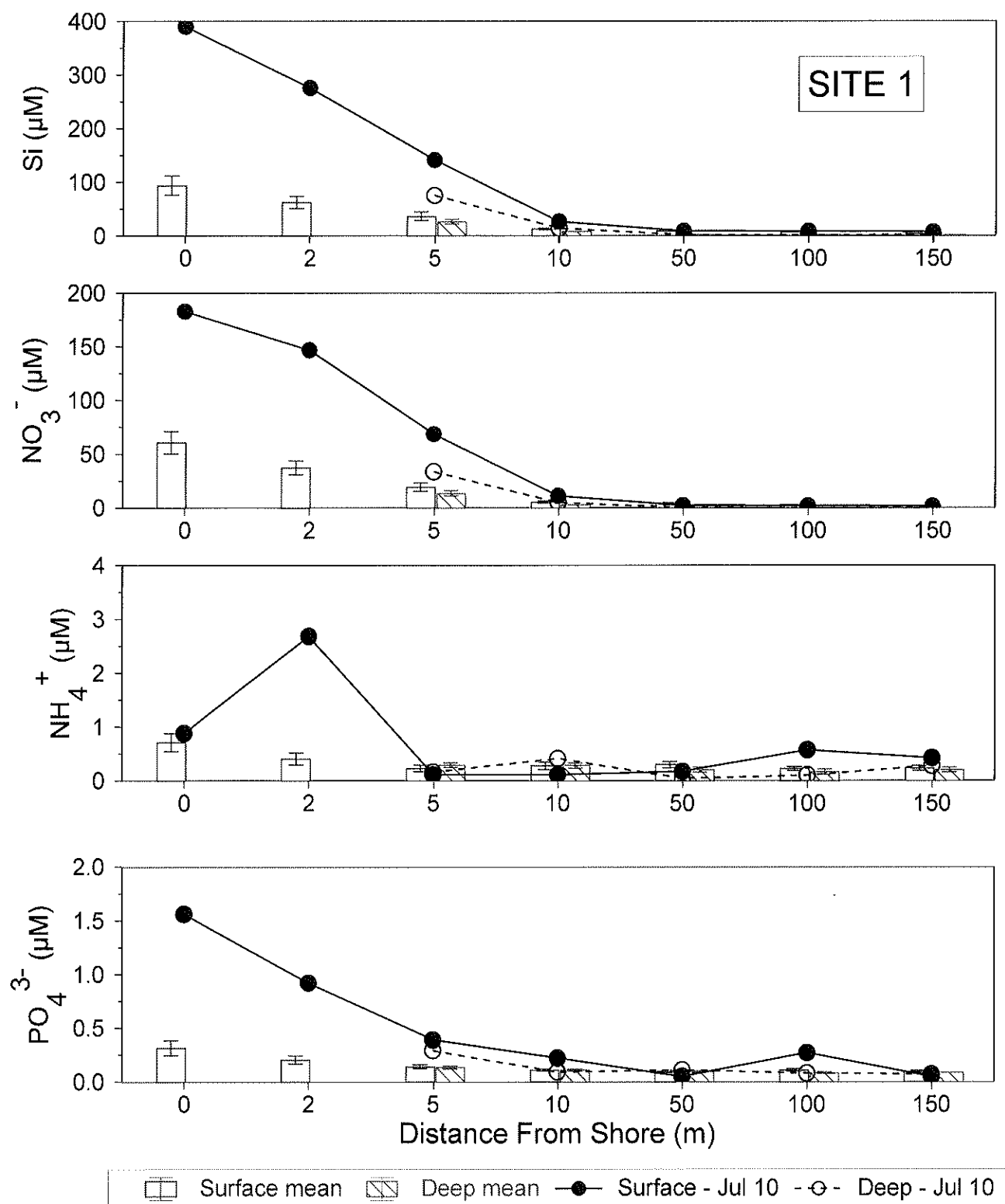


FIGURE 4. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 1, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

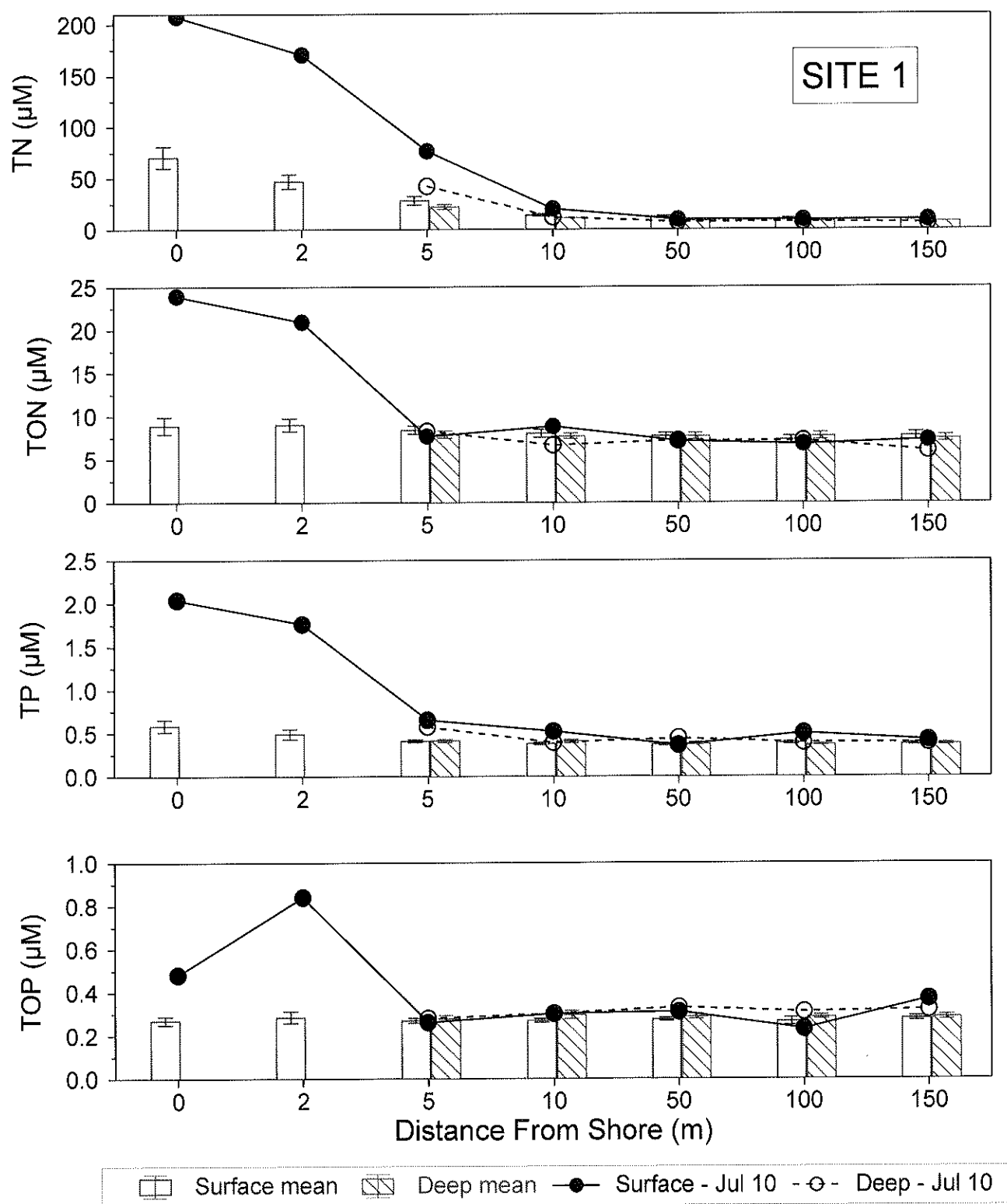


FIGURE 5. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 1, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

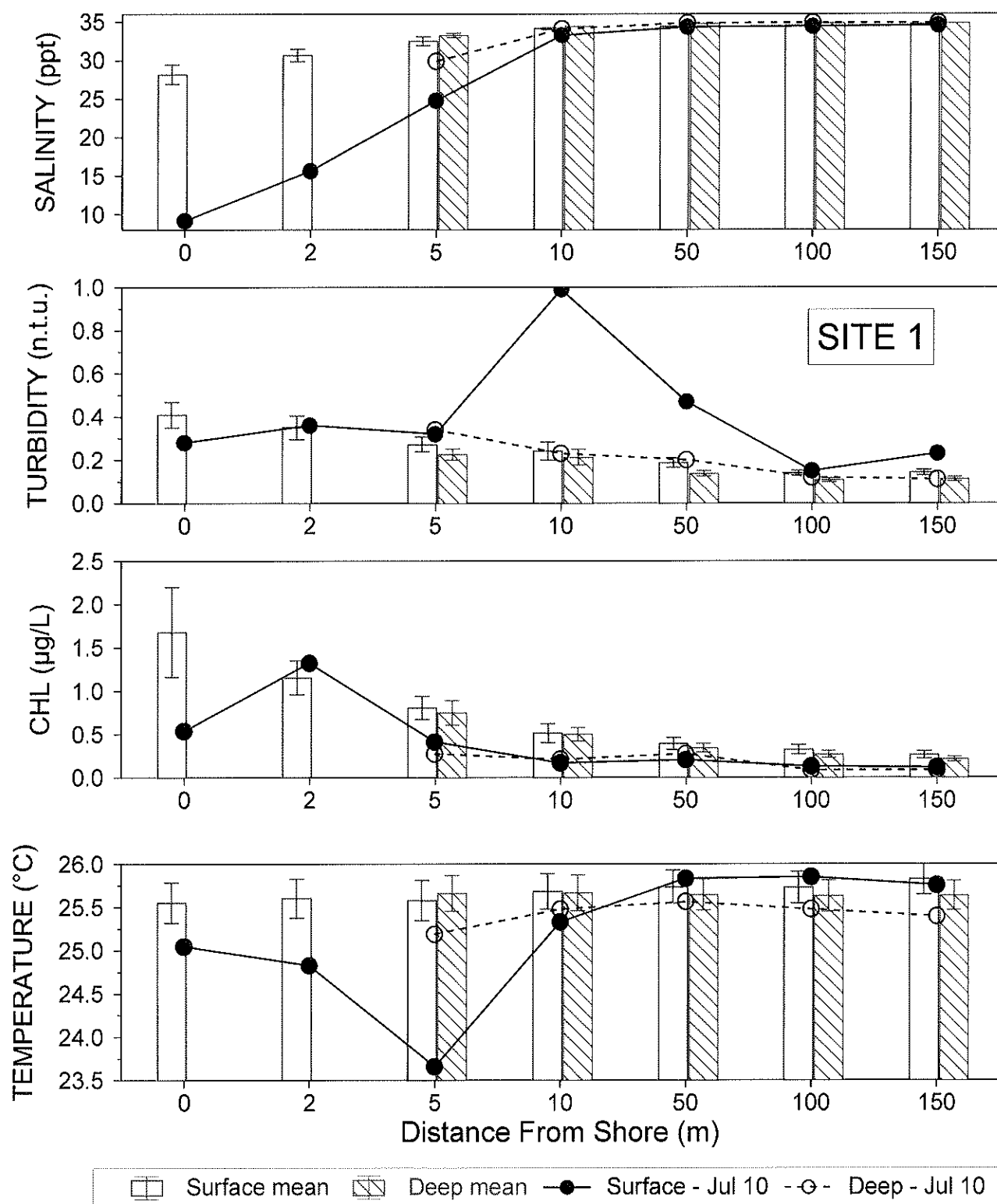


FIGURE 6. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 1, offshore of the Makena Resort. Data points and connected lines from samples collected during the most survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

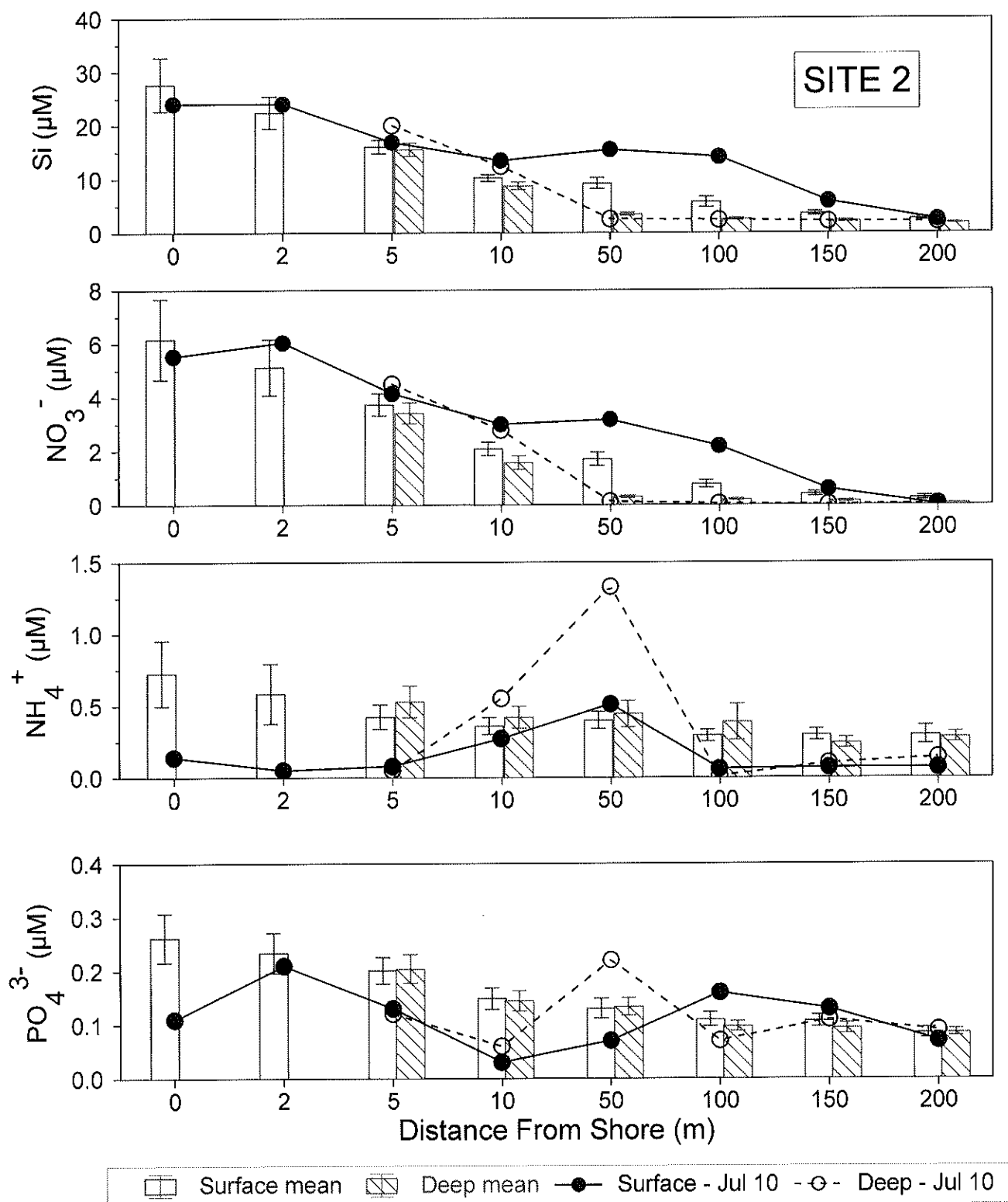


FIGURE 7. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 2, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

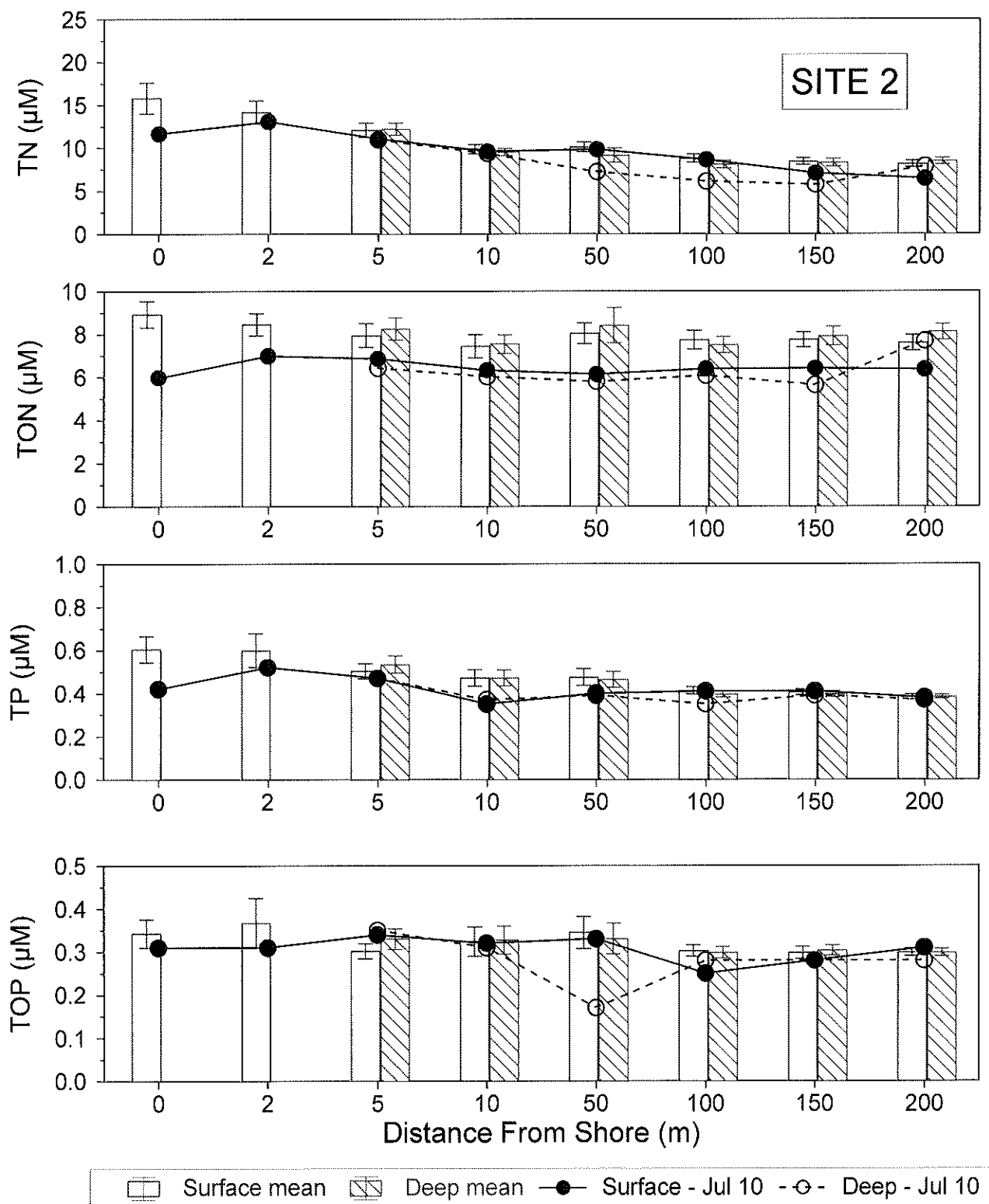


FIGURE 8. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 2, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

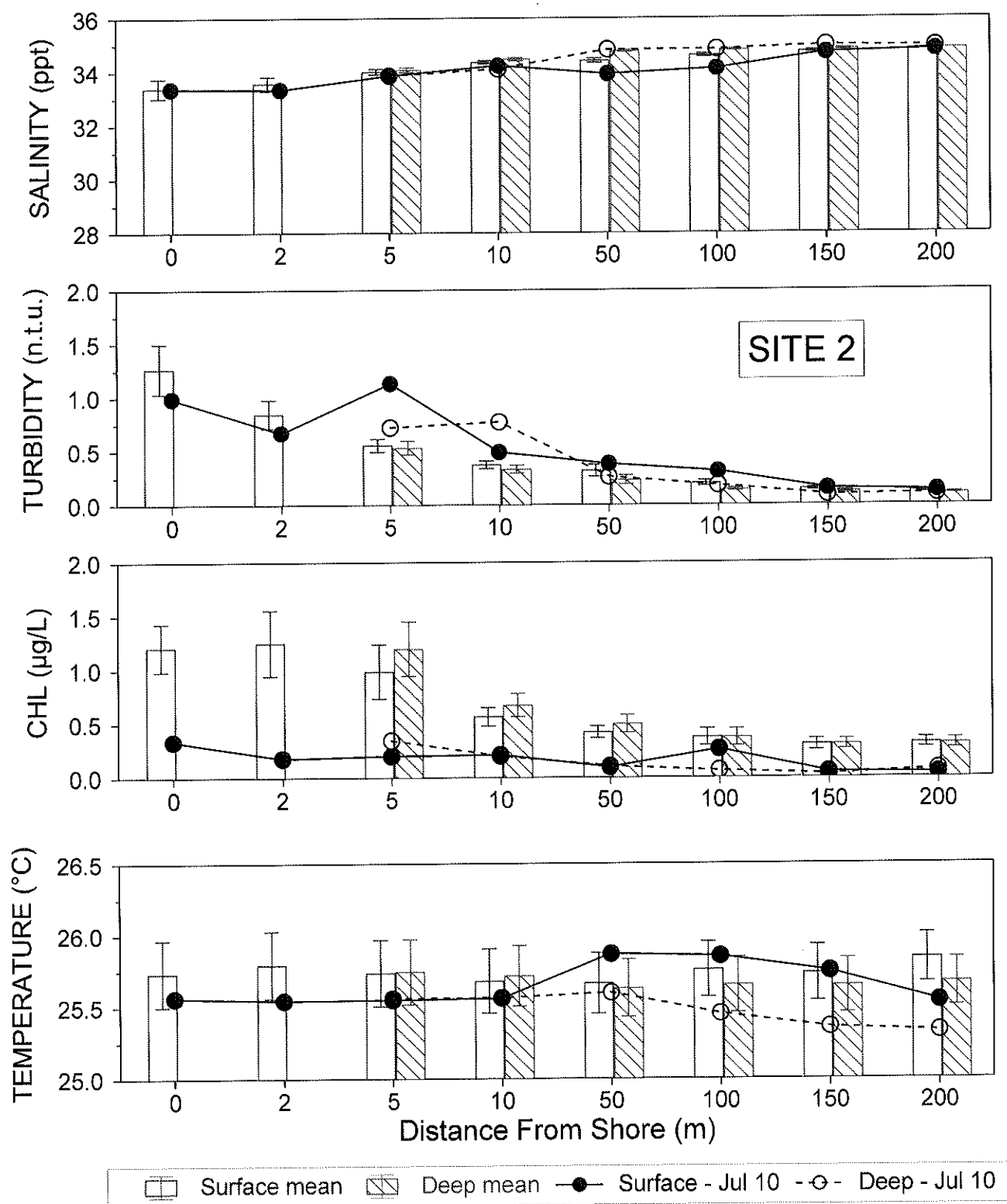


FIGURE 9. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 2, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

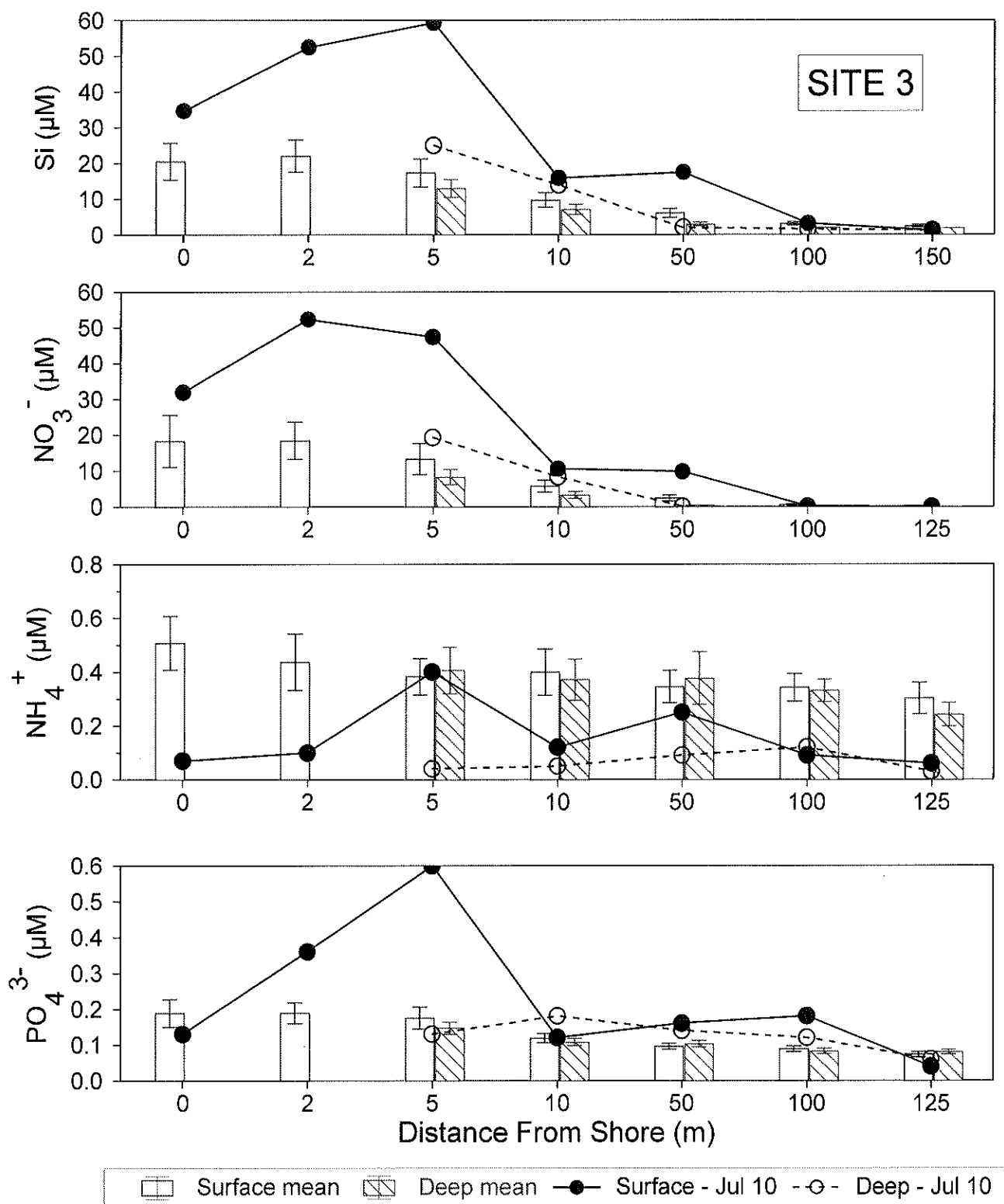


FIGURE 10. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

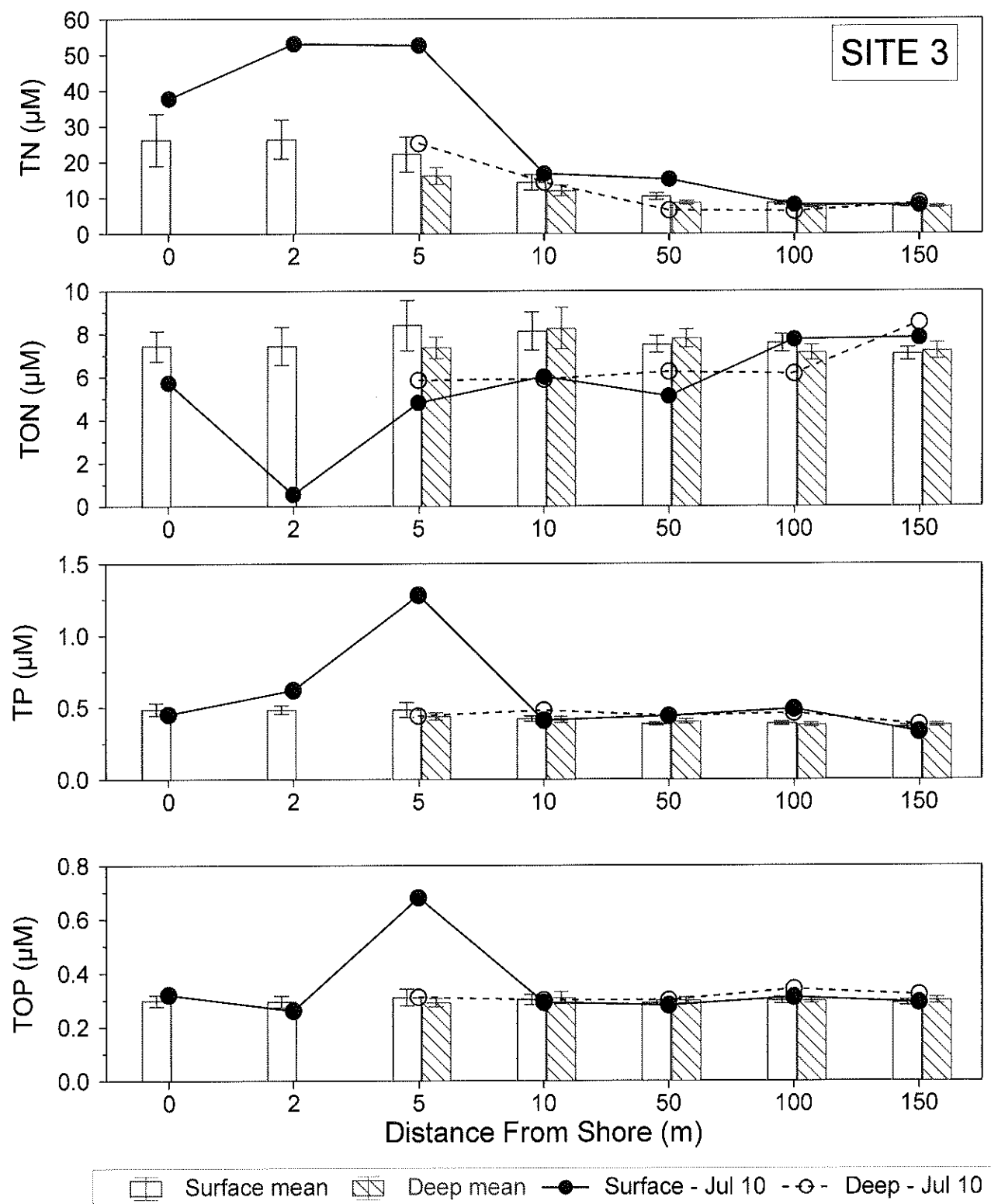


FIGURE 11. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

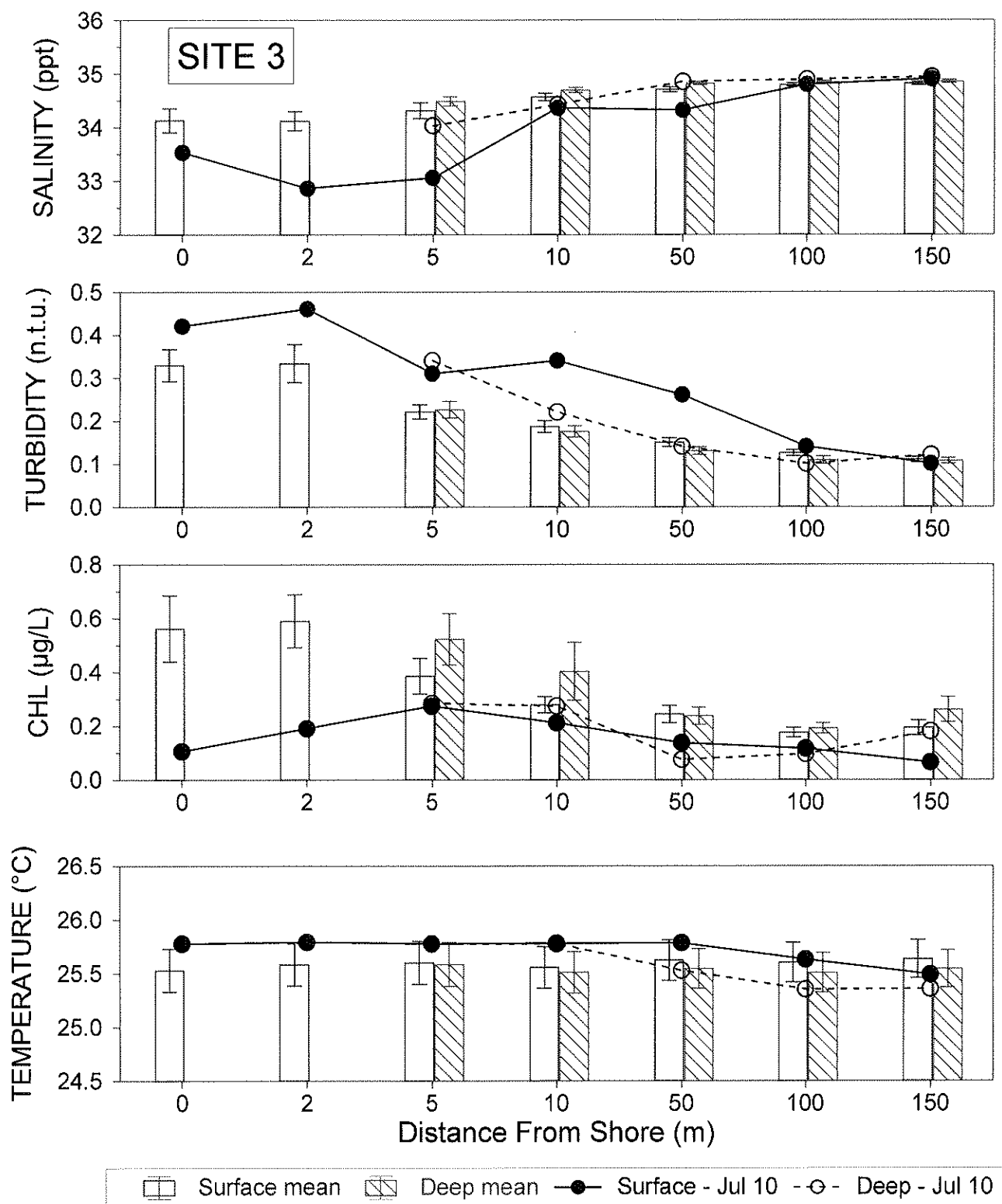


FIGURE 12. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

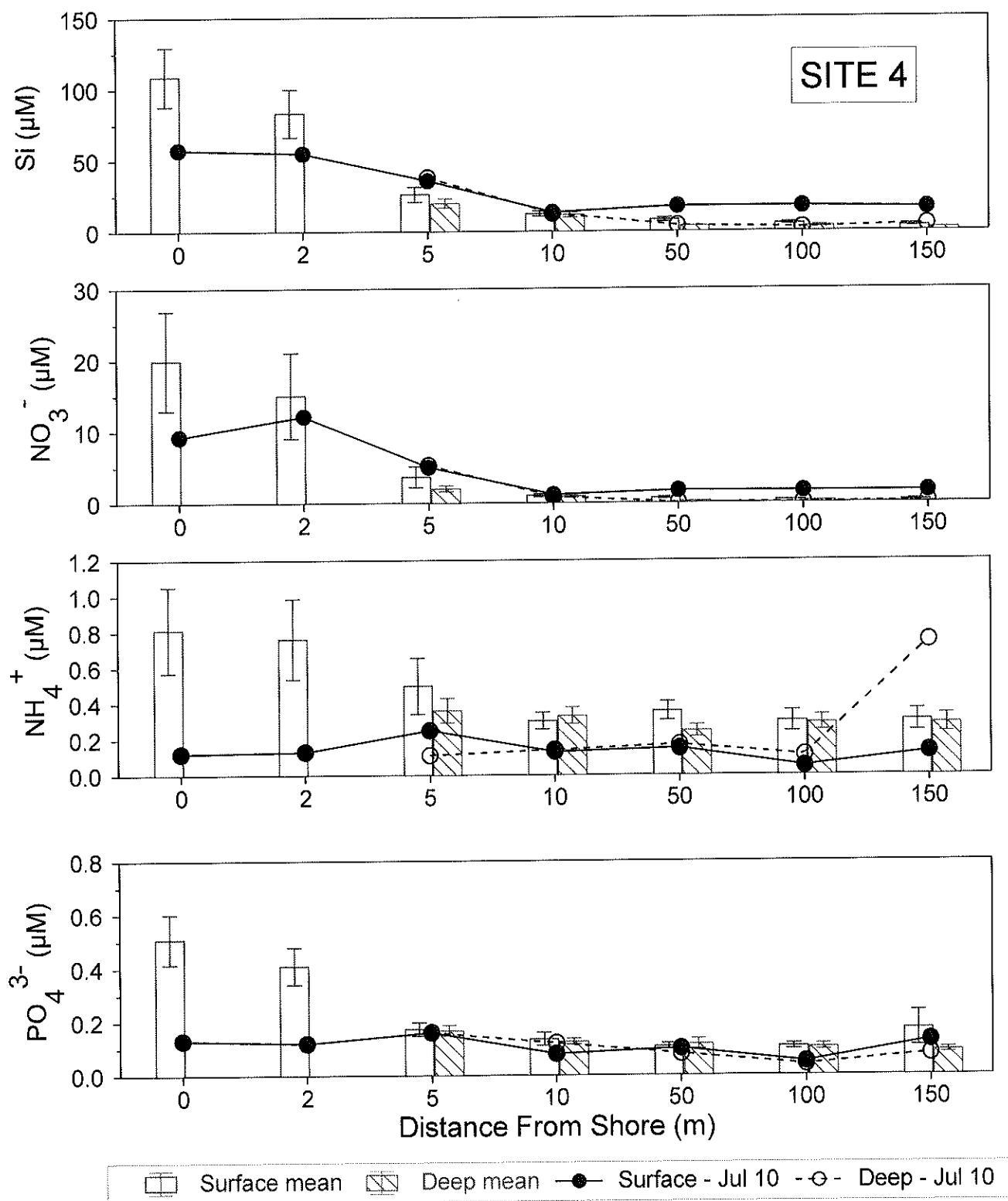


FIGURE 13. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 4, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

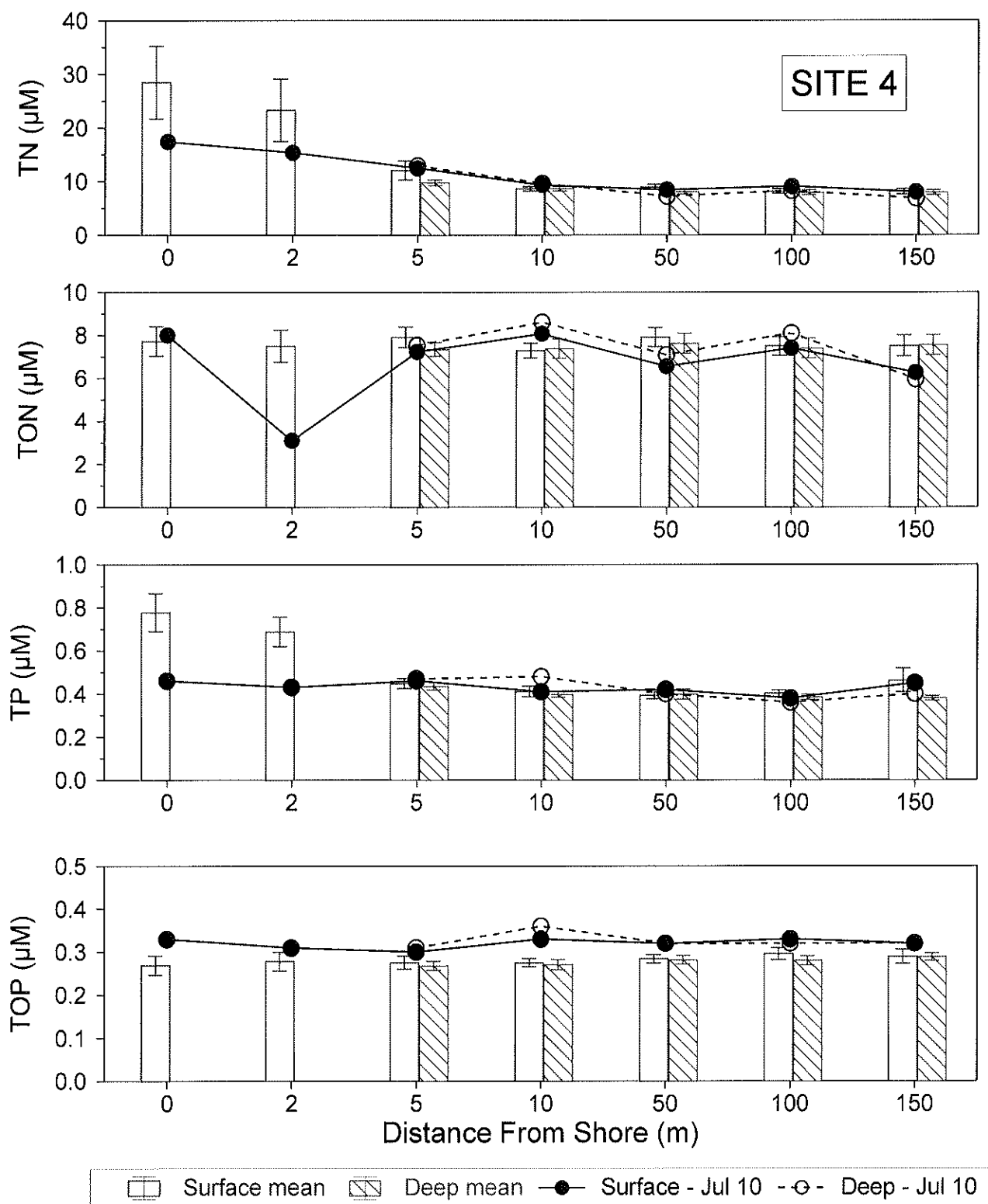


FIGURE 14. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 4, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

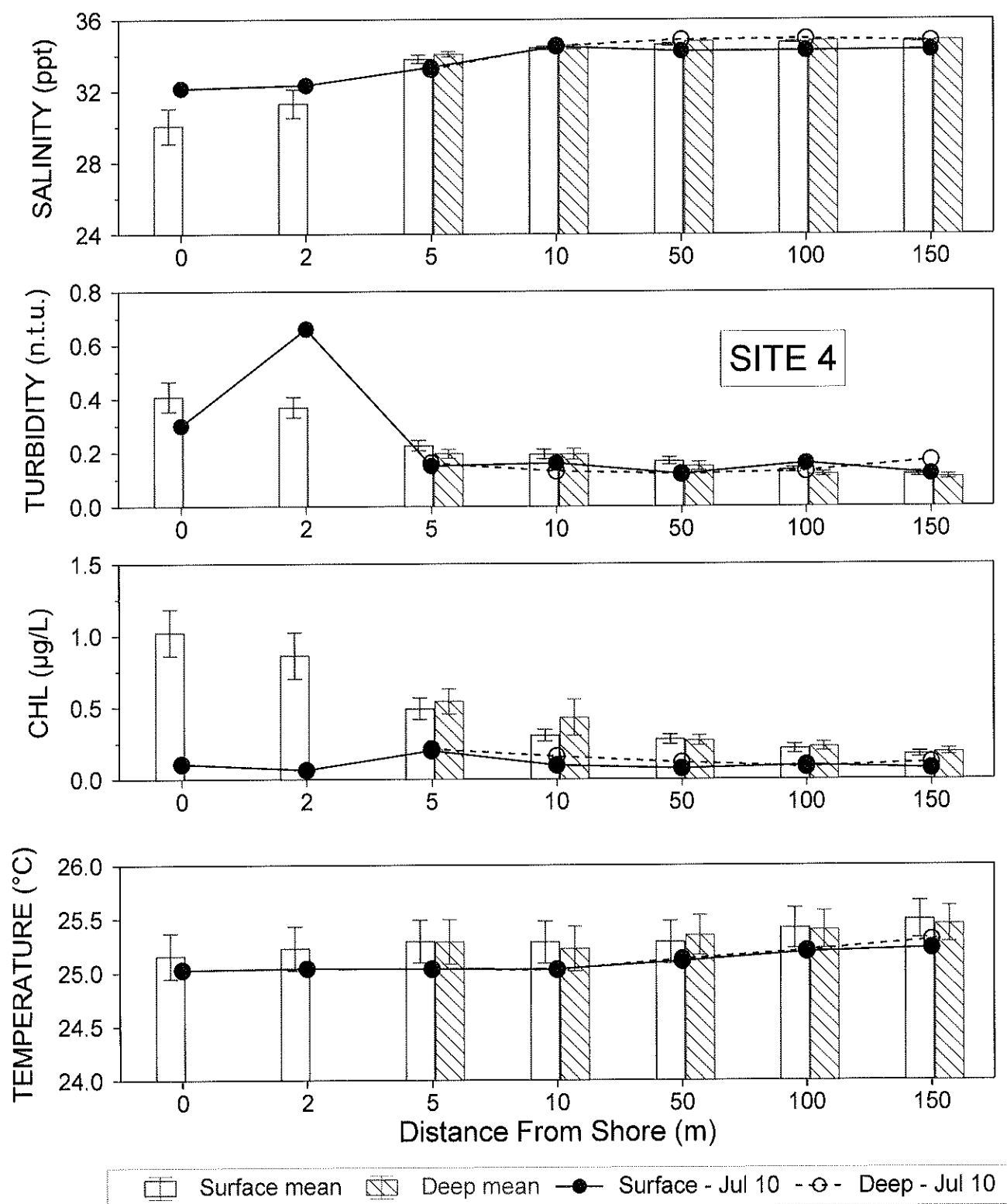


FIGURE 15. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 4, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since August 1995 (N=24). Error bars represent standard error of the mean. For site location, see Figure 1.

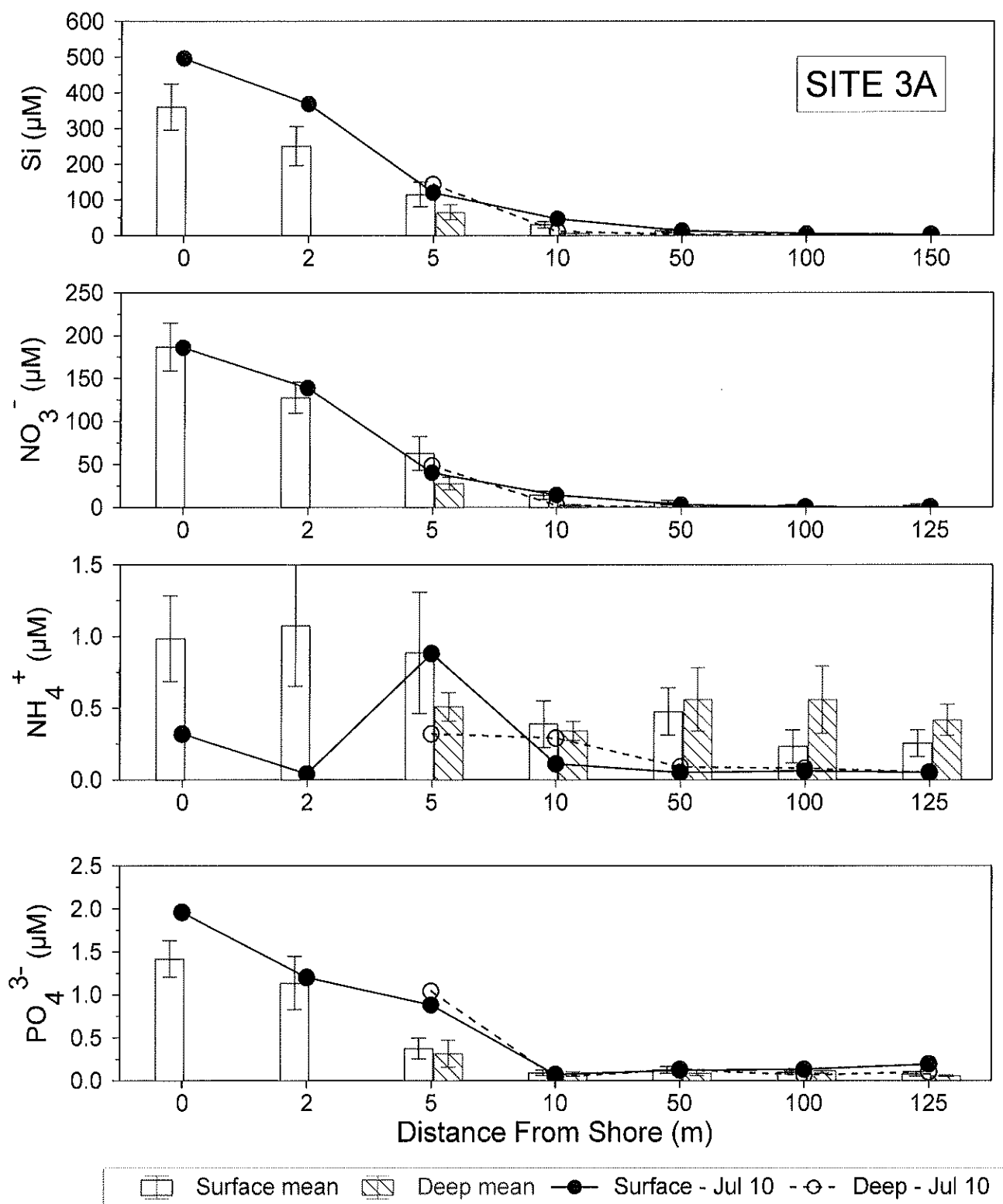


FIGURE 16. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3A, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since June 2007 (N=6). Error bars represent standard error of the mean. For site location, see Figure 1.

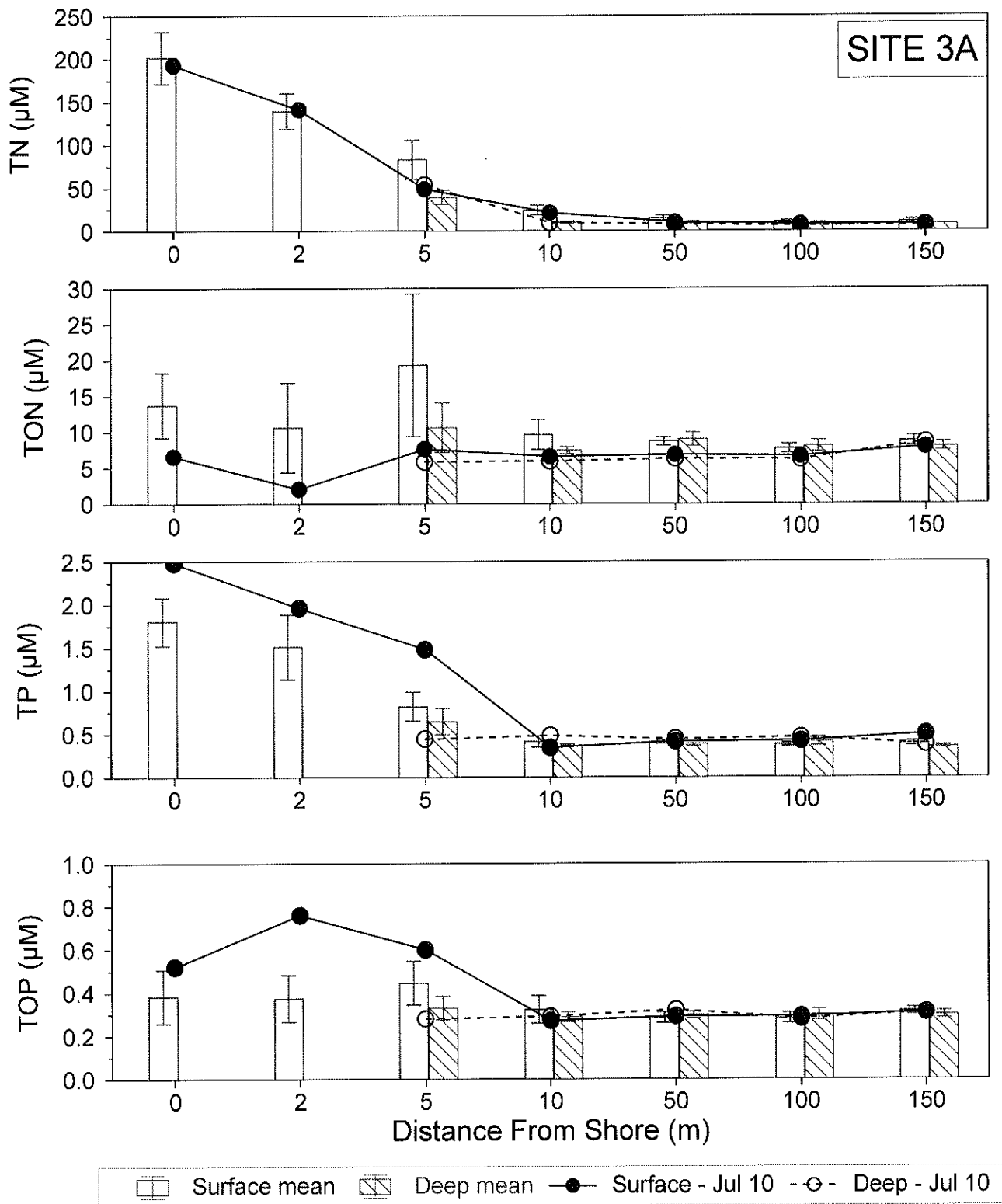


FIGURE 17. Plots of dissolved nutrient constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3A, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since June 2007 (N=6). Error bars represent standard error of the mean. For site location, see Figure 1.

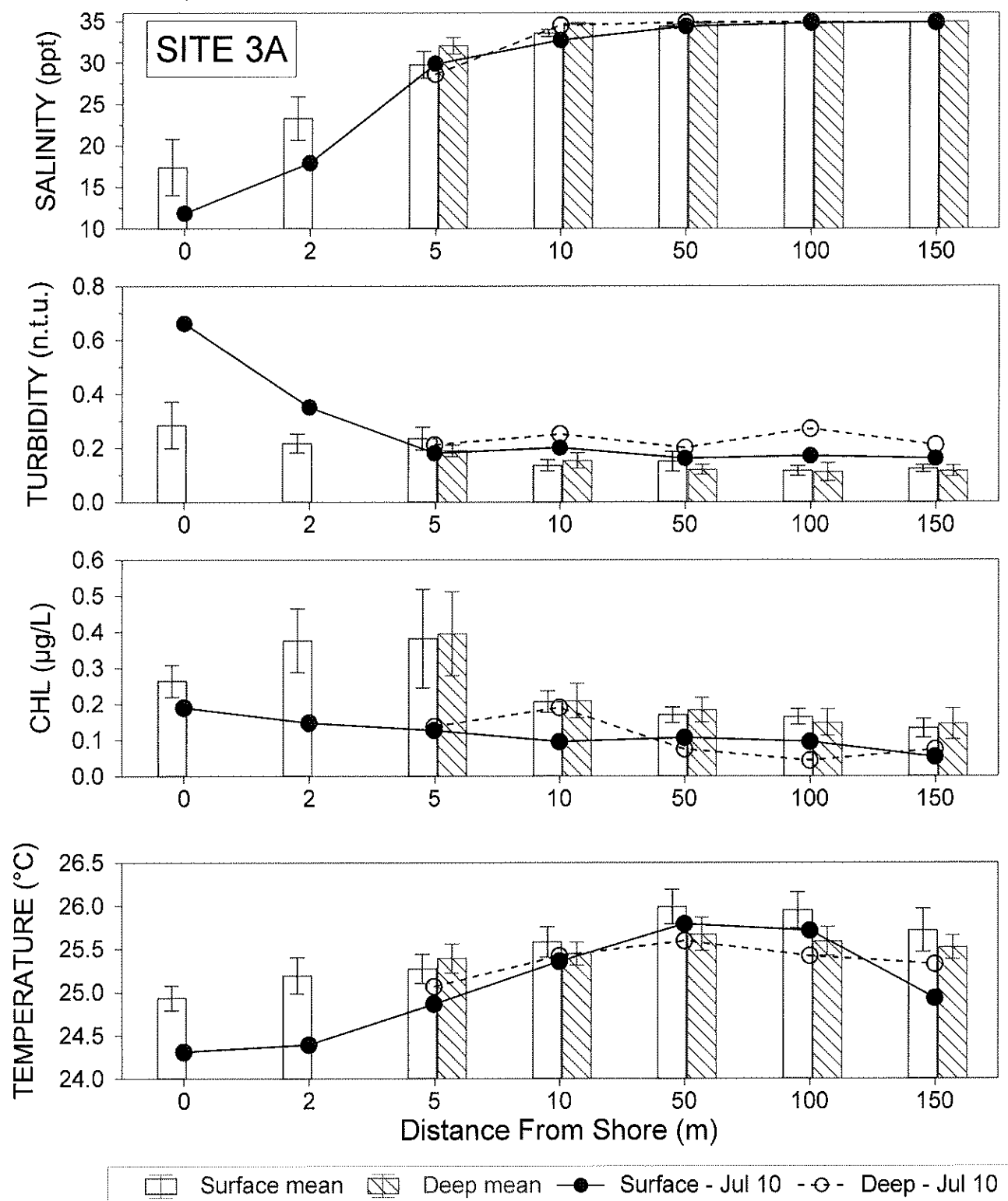


FIGURE 18. Plots of water chemistry constituents measured in surface and deep water samples as a function of distance from the shoreline at Site 3A, offshore of the Makena Resort. Data points and connected lines from samples collected during the most recent survey, bar graphs represent mean values at each sampling station for surveys conducted since June 2007 (N=6). Error bars represent standard error of the mean. For site location, see Figure 1.

TABLE 3. Geometric mean data from water chemistry measurements (in μM) off the Makena Resort collected since August 1995 from Sites 1, 2, and 4 (N=24); since June 2002 from Site 3 (N=15) and since June 2007 from Site 3-A (N=6). For geometric mean calculations, detection limits were used in cases where sample was below detection limit. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep. Also shown are State of Hawaii, Department of Health (DOH) geometric mean water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH GM 10% "dry" standards; boxed and shaded values exceed DOH GM 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	PO ₄ ³⁻ (μM)	NO ₃ ⁻ (μM)	NH ₄ ⁺ (μM)	Si (μM)	TOP (μM)	TON (μM)	TP (μM)	TN (μM)	TURB (NTU)	SALINITY (ppt)	CHL <i>a</i> ($\mu\text{g/L}$)	TEMP (deg.C)	pH	O ₂
MAKENA 1	0 S	0.21	39.39	0.37	65.51	0.24	7.63	0.52	54.47	0.34	27.263	0.89	25.5	8.12	103.1
	2 S	0.15	26.56	0.20	47.17	0.26	8.34	0.45	38.67	0.29	30.353	0.88	25.6	8.15	103.4
	5 S	0.11	10.46	0.13	22.82	0.26	8.10	0.40	22.77	0.23	32.393	0.60	25.6	8.16	104.4
	5 D	0.11	8.25	0.21	18.99	0.27	7.63	0.40	19.22	0.19	33.211	0.51	25.6	8.16	105.3
	10 S	0.10	3.86	0.16	10.39	0.26	7.66	0.37	13.03	0.19	34.139	0.38	25.7	8.15	105.4
	10 D	0.10	2.33	0.21	7.01	0.28	7.56	0.40	10.98	0.17	34.399	0.40	25.7	8.15	104.3
	50 S	0.08	2.52	0.21	7.19	0.27	7.44	0.36	11.29	0.16	34.402	0.30	25.7	8.14	100.1
	50 D	0.08	0.29	0.13	2.49	0.28	7.45	0.37	8.12	0.12	34.787	0.28	25.6	8.14	98.7
	100 S	0.09	1.11	0.17	4.95	0.27	6.86	0.38	9.79	0.13	34.524	0.25	25.7	8.13	97.7
	100 D	0.07	0.10	0.09	2.03	0.28	7.44	0.36	7.79	0.10	34.834	0.22	25.6	8.15	97.0
	150 S	0.08	0.33	0.17	3.11	0.27	7.40	0.37	8.73	0.13	34.714	0.20	25.8	8.14	96.7
	150 D	0.08	0.07	0.13	1.80	0.28	7.17	0.37	7.50	0.10	34.838	0.17	25.6	8.15	97.2
MAKENA 2	0 S	0.19	4.22	0.39	22.79	0.32	8.46	0.55	14.35	0.89	33.340	0.87	25.7	8.13	97.0
	2 S	0.18	3.73	0.27	19.66	0.32	8.12	0.53	13.16	0.64	33.549	0.82	25.8	8.13	98.2
	5 S	0.17	3.07	0.29	14.95	0.29	7.37	0.48	11.52	0.48	34.014	0.65	25.7	8.13	97.9
	5 D	0.17	2.82	0.35	14.32	0.31	7.59	0.51	11.78	0.45	34.077	0.83	25.7	8.13	97.3
	10 S	0.12	1.71	0.24	9.75	0.30	5.72	0.44	9.55	0.33	34.362	0.45	25.7	8.14	97.8
	10 D	0.12	1.11	0.28	8.09	0.30	7.28	0.44	9.35	0.28	34.471	0.52	25.7	8.14	96.9
	50 S	0.10	1.22	0.30	7.72	0.32	7.74	0.45	9.82	0.24	34.421	0.35	25.6	8.13	96.6
	50 D	0.11	0.23	0.26	3.23	0.30	7.72	0.44	8.48	0.19	34.778	0.39	25.6	8.14	96.2
	100 S	0.09	0.50	0.21	4.35	0.29	7.45	0.40	8.52	0.17	34.612	0.29	25.7	8.12	96.9
	100 D	0.08	0.14	0.21	2.36	0.29	7.30	0.39	7.88	0.13	34.810	0.27	25.6	8.14	95.9
	150 S	0.09	0.24	0.24	3.16	0.29	7.56	0.39	8.24	0.13	34.756	0.23	25.7	8.14	95.9
	150 D	0.08	0.09	0.16	2.03	0.29	7.65	0.39	8.05	0.10	34.834	0.23	25.6	8.15	96.4
	200 S	0.07	0.11	0.17	2.31	0.29	7.42	0.38	7.98	0.11	34.828	0.25	25.8	8.15	97.2
	200 D	0.07	0.05	0.20	1.72	0.29	7.94	0.38	8.29	0.09	34.862	0.25	25.7	8.16	96.4
MAKENA 3-A	0 S	1.32	173.28	0.72	323.13	0.29	10.25	1.67	186.60	0.23	15.761	0.29	24.9	7.82	94.4
	2 S	0.72	118.98	0.55	215.39	0.29	5.84	1.21	129.40	0.20	22.539	0.41	25.2	7.85	95.4
	5 S	0.27	32.42	0.45	68.00	0.37	11.27	0.73	59.51	0.21	29.543	0.37	25.3	7.95	96.3
	5 D	0.17	17.75	0.46	41.29	0.31	8.81	0.57	33.14	0.18	31.964	0.39	25.4	8.01	96.9
	10 S	0.07	6.79	0.27	19.25	0.29	8.77	0.39	19.80	0.12	33.556	0.22	25.6	8.04	97.4
	10 D	0.05	1.22	0.28	5.15	0.28	7.36	0.36	9.64	0.13	34.713	0.27	25.4	8.07	99.6
	50 S	0.08	2.03	0.33	8.77	0.27	8.56	0.40	13.48	0.13	34.376	0.16	26.0	8.08	98.1
	50 D	0.06	0.09	0.40	2.97	0.29	8.73	0.38	9.36	0.11	34.789	0.16	25.7	8.10	99.6
	100 S	0.07	1.03	0.10	5.82	0.27	7.58	0.37	9.82	0.10	34.670	0.16	25.9	8.08	96.4
	100 D	0.09	0.02	0.37	2.12	0.29	7.85	0.40	8.36	0.09	34.904	0.13	25.6	8.11	99.0
	150 S	0.06	0.12	0.15	3.30	0.31	8.62	0.38	10.12	0.11	34.781	0.13	25.7	8.10	97.0
	150 D	0.04	0.01	0.31	1.54	0.29	7.90	0.35	8.33	0.10	34.922	0.17	25.5	8.11	100.0
MAKENA 3	0 S	0.12	8.16	0.37	18.33	0.28	6.24	0.47	23.48	0.28	33.728	0.53	25.7	8.13	100.6
	2 S	0.15	13.91	0.29	24.90	0.27	5.73	0.48	28.58	0.29	33.699	0.58	25.8	8.11	100.7
	5 S	0.12	8.93	0.22	16.80	0.29	7.94	0.47	22.42	0.21	34.029	0.35	25.8	8.10	100.7
	5 D	0.13	5.68	0.22	12.46	0.28	7.05	0.44	17.40	0.20	34.314	0.43	25.7	8.11	99.9
	10 S	0.09	4.31	0.25	9.59	0.29	7.54	0.41	15.34	0.17	34.413	0.27	25.7	8.11	99.2
	10 D	0.08	2.36	0.20	6.84	0.30	7.73	0.40	12.71	0.15	34.615	0.29	25.6	8.11	99.1
	50 S	0.08	1.73	0.21	5.78	0.28	7.55	0.38	11.22	0.14	34.628	0.22	25.7	8.10	95.1
	50 D	0.09	0.35	0.18	2.76	0.29	7.84	0.39	8.77	0.10	34.811	0.21	25.6	8.12	93.1
	100 S	0.08	0.47	0.25	3.14	0.29	7.54	0.38	8.74	0.11	34.778	0.17	25.7	8.12	95.3
	100 D	0.06	0.09	0.25	1.87	0.29	7.04	0.37	7.61	0.09	34.835	0.17	25.6	8.13	95.1
	150 S	0.05	0.14	0.15	2.15	0.29	7.06	0.36	7.75	0.10	34.802	0.15	25.7	8.15	95.6
	150 D	0.06	0.07	0.11	1.74	0.29	7.08	0.36	7.43	0.10	34.862	0.17	25.6	8.16	96.7
MAKENA 4	0 S	0.21	39.39	0.37	65.51	0.24	7.63	0.52	54.47	0.34	27.263	0.89	25.5	8.12	99.0
	2 S	0.15	26.56	0.20	47.17	0.26	8.34	0.45	38.67	0.29	30.353	0.88	25.6	8.15	100.6
	5 S	0.11	10.46	0.13	22.82	0.26	8.10	0.40	22.77	0.23	32.393	0.60	25.6	8.16	102.0
	5 D	0.11	8.25	0.21	18.99	0.27	7.63	0.40	19.22	0.19	33.211	0.51	25.6	8.16	102.2
	10 S	0.10	3.86	0.16	10.39	0.26	7.66	0.37	13.03	0.19	34.139	0.38	25.7	8.15	100.2
	10 D	0.10	2.33	0.21	7.01	0.28	7.56	0.40	10.98	0.17	34.399	0.40	25.7	8.15	100.1
	50 S	0.08	2.52	0.21	7.19	0.27	7.44	0.36	11.29	0.16	34.402	0.30	25.7	8.14	94.2
	50 D	0.08	0.29	0.13	2.49	0.28	7.45	0.37	8.12	0.12	34.787	0.28	25.6	8.14	93.7
	100 S	0.09	1.11	0.17	4.95	0.27	6.86	0.38	9.79	0.13	34.524	0.25	25.7	8.13	94.1
	100 D	0.07	0.10	0.09	2.03	0.28	7.44	0.36	7.79	0.10	34.834	0.22	25.6	8.15	92.8
	150 S	0.08	0.33	0.17	3.11	0.27	7.40	0.37	8.73	0.13	34.714	0.20	25.8	8.14	95.7
	150 D	0.08	0.07	0.13	1.80	0.28	7.17	0.37	7.50	0.10	34.838	0.17	25.6	8.15	94.3
DOH WQS		DRY	0.25	0.14				0.52	7.86	0.20		0.15	**	***	
GEOMETRIC MEAN		WET	0.36	0.25				0.64	10.71	0.50		0.30			

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

TABLE 4. Geometric mean data (in $\mu\text{g/L}$) from water chemistry measurements (in μM) off the Makena Resort collected since August 1995 for Sites 1, 2, and 4 (N=24); since June 2002 from Site 3 (N=15) and since June 2007 from Site 3-A (N=6). For geometric mean calculations, detection limits were used in cases where sample was below detection limit. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep. Also shown are State of Hawaii, Department of Health (DOH) geometric mean water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH GM 10% "dry" standards; boxed and shaded values exceed DOH GM 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	PO ₄ ³⁻ ($\mu\text{g/L}$)	NO ₃ ⁻ ($\mu\text{g/L}$)	NH ₄ ⁺ ($\mu\text{g/L}$)	Si ($\mu\text{g/L}$)	TOP ($\mu\text{g/L}$)	TON ($\mu\text{g/L}$)	TP ($\mu\text{g/L}$)	TN ($\mu\text{g/L}$)	TURB (NTU)	SALINITY (ppt)	CHL <i>a</i> ($\mu\text{g/L}$)	TEMP (deg.C)	pH	O2
MAKENA 1	0 S	6.50	551.6	5.10	1840	7.40	106.8	16.10	762.9	0.34	27.263	0.89	25.5	8.12	103.1
	2 S	4.60	371.9	2.80	1325	8.00	116.8	13.90	541.6	0.29	30.353	0.88	25.6	8.15	103.4
	5 S	3.40	146.5	1.80	641.0	8.00	113.4	12.30	318.9	0.23	32.393	0.60	25.6	8.16	104.4
	5 D	3.40	115.5	2.90	533.4	8.30	106.8	12.30	269.1	0.19	33.211	0.51	25.6	8.16	105.3
	10 S	3.00	54.00	2.20	291.9	8.00	107.2	11.40	182.4	0.19	34.139	0.38	25.7	8.15	105.4
	10 D	3.00	32.60	2.90	196.9	8.60	105.8	12.30	153.7	0.17	34.399	0.40	25.7	8.15	104.3
	50 S	2.40	35.20	2.90	202.0	8.30	104.2	11.10	158.1	0.16	34.402	0.30	25.7	8.14	100.1
	50 D	2.40	4.00	1.80	69.94	8.60	104.3	11.40	113.7	0.12	34.787	0.28	25.6	8.14	98.7
	100 S	2.70	15.50	2.30	139.0	8.30	96.00	11.70	137.1	0.13	34.524	0.25	25.7	8.13	97.7
	100 D	2.10	1.40	1.20	57.02	8.60	104.2	11.10	109.1	0.10	34.834	0.22	25.6	8.15	97.0
	150 S	2.40	4.60	2.30	87.36	8.30	103.6	11.40	122.2	0.13	34.714	0.20	25.8	8.14	96.7
	150 D	2.40	0.90	1.80	50.56	8.60	100.4	11.40	105.0	0.10	34.838	0.17	25.6	8.15	97.2
MAKENA 2	0 S	5.80	59.10	5.40	640.2	9.90	118.4	17.00	200.9	0.89	33.340	0.87	25.7	8.13	97.0
	2 S	5.50	52.20	3.70	552.2	9.90	113.7	16.40	184.3	0.64	33.549	0.82	25.8	8.13	98.2
	5 S	5.20	42.90	4.00	419.9	8.90	103.2	14.80	161.3	0.48	34.014	0.65	25.7	8.13	97.9
	5 D	5.20	39.40	4.90	402.2	9.60	106.3	15.70	164.9	0.45	34.077	0.83	25.7	8.13	97.3
	10 S	3.70	23.90	3.30	273.9	9.20	80.10	13.60	133.7	0.33	34.362	0.45	25.7	8.14	97.8
	10 D	3.70	15.50	3.90	227.2	9.20	101.9	13.60	130.9	0.28	34.471	0.52	25.7	8.14	96.9
	50 S	3.00	17.00	4.20	216.9	9.90	108.4	13.90	137.5	0.24	34.421	0.35	25.6	8.13	96.6
	50 D	3.40	3.20	3.60	90.73	9.20	108.1	13.60	118.7	0.19	34.778	0.39	25.6	8.14	96.2
	100 S	2.70	7.00	2.90	122.2	8.90	104.3	12.30	119.3	0.17	34.612	0.29	25.7	8.12	96.9
	100 D	2.40	1.90	2.90	66.29	8.90	102.2	12.00	110.3	0.13	34.810	0.27	25.6	8.14	95.9
	150 S	2.70	3.30	3.30	88.76	8.90	105.8	12.00	115.4	0.13	34.756	0.23	25.7	8.14	95.9
	150 D	2.40	1.20	2.20	57.02	8.90	107.1	12.00	112.7	0.10	34.834	0.23	25.6	8.15	96.4
MAKENA 3-A	0 S	40.80	2427	10.00	9077	8.90	143.5	51.70	2613.5	0.23	15.761	0.29	24.9	7.82	94.4
	2 S	22.30	1666	7.70	6050	8.90	81.70	37.40	1812.3	0.20	22.539	0.41	25.2	7.85	95.4
	5 S	8.30	454.0	6.30	1910	11.40	157.8	22.60	833.4	0.21	29.543	0.37	25.3	7.95	96.3
	5 D	5.20	248.6	6.40	1160	9.60	123.3	17.60	464.1	0.18	31.964	0.39	25.4	8.01	96.9
	10 S	2.10	95.10	3.70	540.7	8.90	122.8	12.00	277.3	0.12	33.556	0.22	25.6	8.04	97.4
	10 D	1.50	17.00	3.90	144.7	8.60	103.0	11.10	135.0	0.13	34.713	0.27	25.4	8.07	99.6
	50 S	2.40	28.40	4.60	246.3	8.30	119.8	12.30	188.8	0.13	34.376	0.16	26.0	8.08	98.1
	50 D	1.80	1.20	5.60	83.43	8.90	122.2	11.70	131.0	0.11	34.789	0.16	25.7	8.1	99.6
	100 S	2.10	14.40	1.40	163.5	8.30	106.1	11.40	137.5	0.10	34.670	0.16	25.9	8.08	96.4
	100 D	2.70	0.20	5.10	59.55	8.90	109.9	12.30	117.0	0.09	34.904	0.13	25.6	8.11	99.0
	150 S	1.80	1.60	2.10	92.7	9.60	120.7	11.70	141.7	0.11	34.781	0.13	25.7	8.1	97.0
	150 D	1.20	0.10	4.30	43.26	8.90	110.6	10.80	116.6	0.10	34.922	0.17	25.5	8.11	100.0
MAKENA 3	0 S	3.70	114.2	5.10	514.9	8.60	87.30	14.50	328.8	0.28	33.728	0.53	25.7	8.13	100.6
	2 S	4.60	194.8	4.00	699.4	8.30	80.20	14.80	400.2	0.29	33.699	0.58	25.8	8.11	100.7
	5 S	3.70	125.0	3.00	471.9	8.90	111.2	14.50	314.0	0.21	34.029	0.35	25.8	8.1	100.7
	5 D	4.00	79.50	3.00	350.0	8.60	98.70	13.60	243.7	0.20	34.314	0.43	25.7	8.11	99.9
	10 S	2.70	60.30	3.50	269.4	8.90	105.6	12.60	214.8	0.17	34.413	0.27	25.7	8.11	99.2
	10 D	2.40	33.00	2.80	192.1	9.20	108.2	12.30	178.0	0.15	34.615	0.29	25.6	8.11	99.1
	50 S	2.40	24.20	2.90	162.4	8.60	105.7	11.70	157.1	0.14	34.628	0.22	25.7	8.1	95.1
	50 D	2.70	4.90	2.50	77.53	8.90	109.8	12.00	122.8	0.10	34.811	0.21	25.6	8.12	93.1
	100 S	2.40	6.50	3.50	88.20	8.90	105.6	11.70	122.4	0.11	34.778	0.17	25.7	8.12	95.3
	100 D	1.80	1.20	3.50	52.53	8.90	98.60	11.40	106.5	0.09	34.835	0.17	25.6	8.13	95.1
	150 S	1.50	1.90	2.10	60.39	8.90	98.80	11.10	108.5	0.10	34.802	0.15	25.7	8.15	95.6
	150 D	1.80	0.90	1.50	48.88	8.90	99.10	11.10	104.0	0.10	34.862	0.17	25.6	8.16	96.7
MAKENA 4	0 S	6.50	551.6	5.10	1840	7.40	106.8	16.10	762.9	0.34	27.263	0.89	25.5	8.12	99.0
	2 S	4.60	371.9	2.80	1325	8.00	116.8	13.90	541.6	0.29	30.353	0.88	25.6	8.15	100.6
	5 S	3.40	146.5	1.80	641.0	8.00	113.4	12.30	318.9	0.23	32.393	0.60	25.6	8.16	102.0
	5 D	3.40	115.5	2.90	533.4	8.30	106.8	12.30	269.1	0.19	33.211	0.51	25.6	8.16	102.2
	10 S	3.00	54.00	2.20	291.9	8.00	107.2	11.40	182.4	0.19	34.139	0.38	25.7	8.15	100.2
	10 D	3.00	32.60	2.90	196.9	8.60	105.8	12.30	153.7	0.17	34.399	0.40	25.7	8.15	100.1
	50 S	2.40	35.20	2.90	202.0	8.30	104.2	11.10	158.1	0.16	34.402	0.30	25.7	8.14	94.2
	50 D	2.40	4.00	1.80	69.94	8.60	104.3	11.40	113.7	0.12	34.787	0.28	25.6	8.14	93.7
	100 S	2.70	15.50	2.30	139.0	8.30	96.00	11.70	137.1	0.13	34.524	0.25	25.7	8.13	94.1
	100 D	2.10	1.40	1.20	57.02	8.60	104.2	11.10	109.1	0.10	34.834	0.22	25.6	8.15	92.8
	150 S	2.40	4.60	2.30	87.36	8.30	103.6	11.40	122.2	0.13	34.714	0.20	25.8	8.14	95.7
	150 D	2.40	0.90	1.80	50.56	8.60	100.4	11.40	105.0	0.10	34.838	0.17	25.6	8.15	94.3
DOH WQS		DRY	3.50	2.00				16.00	110.00	0.20	*	0.15	**	***	
GEOMETRIC MEAN		WET	5.00	3.50				20.00	150.00	0.50		0.30			

* Salinity shall not vary more than ten percent from natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

TABLE 5. Water chemistry measurements in μM and $\mu\text{g/L}$ (shaded) from irrigation wells and an irrigation lake collected in the vicinity of the Makena Resort on August 3, 2010. For sampling site locations, see Figure 1.

WELL	PO_4^{3-} (μM)	PO_4^{3-} ($\mu\text{g/L}$)	NO_3^- (μM)	NO_3^- ($\mu\text{g/L}$)	NH_4^+ (μM)	NH_4^+ ($\mu\text{g/L}$)	Si (μM)	Si ($\mu\text{g/L}$)	TOP (μM)	TOP ($\mu\text{g/L}$)	TON (μM)	TON ($\mu\text{g/L}$)	TP (μM)	TP ($\mu\text{g/L}$)	TN (μM)	TN ($\mu\text{g/L}$)	SALINITY (ppt)
1	2.32	71.92	133.0	1862.6	4.00	56.00	517.2	14533.3	1.44	44.64	6.72	94.08	3.76	116.56	143.8	2012.6	1.371
2	4.48	138.88	148.5	2078.7	18.88	264.32	726.1	20402.8	0.88	27.28	1.60	22.40	5.36	166.16	169.0	2365.4	1.926
3	5.44	168.64	144.4	2021.6	12.32	172.48	737.0	20708.6	0.16	4.96	7.76	108.64	5.60	173.60	164.5	2302.7	2.061
5	3.44	106.64	171.6	2402.4	9.20	128.80	593.1	16666.7	1.04	32.24	7.36	103.04	4.48	138.88	188.2	2634.2	1.543
6	3.20	99.20	182.0	2548.0	3.68	51.52	580.2	16302.5	1.20	37.20	10.72	150.08	4.40	136.40	196.4	2749.6	1.592
10	4.08	126.48	154.2	2159.4	6.96	97.44	657.6	18478.6	0.72	22.32	5.52	77.28	4.80	148.80	166.7	2334.1	1.993
IL10	2.08	64.48	61.0	854.6	14.16	198.24	553.8	15560.7	2.56	79.36	57.36	803.04	4.64	143.84	132.6	1855.8	2.086

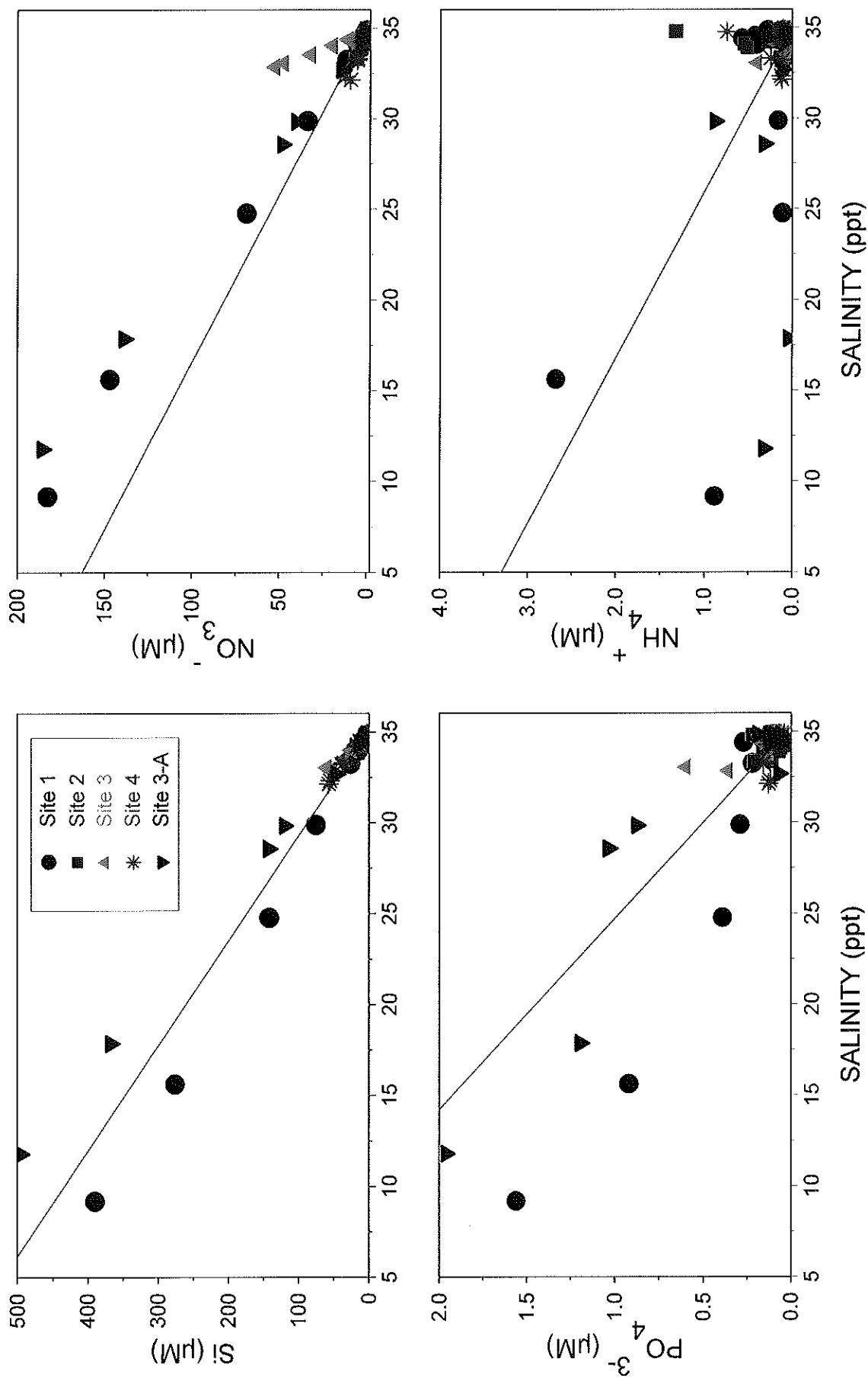


FIGURE 19. Mixing diagram showing concentration of dissolved nutrients from samples collected offshore of the Makena Resort on July 11, 2010 as functions of salinity. Solid red line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from an irrigation well upslope of the Makena Golf Courses. For sampling site locations, see Figure 1.

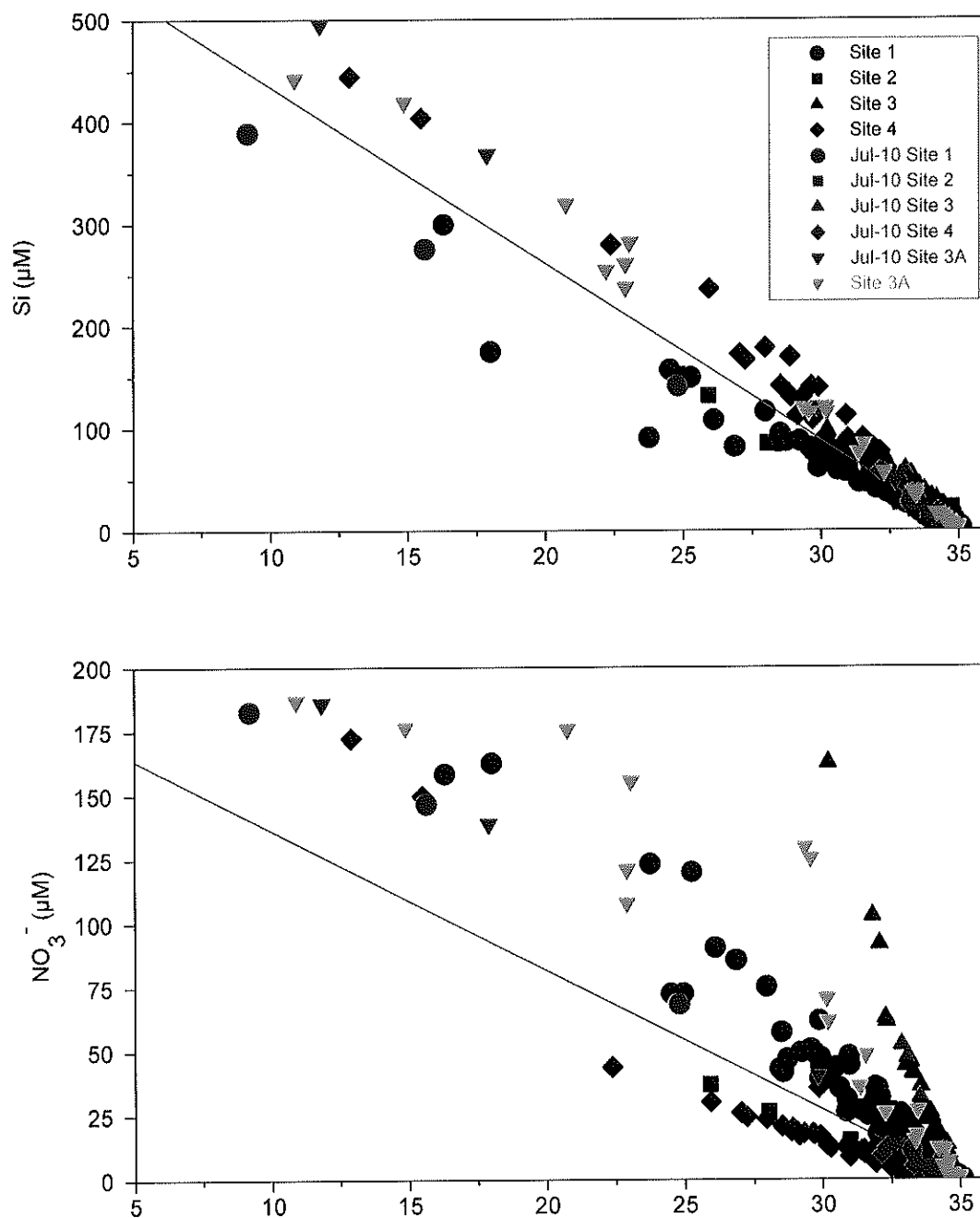


FIGURE 20. Silicate and nitrate, plotted as a function of salinity for surface samples collected since August 1995 at four sites offshore of the Makena Golf Course. Black symbols represent combined data from surveys conducted between August 1995 and June 2009. Green symbols represent data from surveys at Site 3A commencing in June 2007. Red symbols are data from most recent survey. Solid red line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from golf course irrigation well #6. For sampling site locations, see Figure 1.

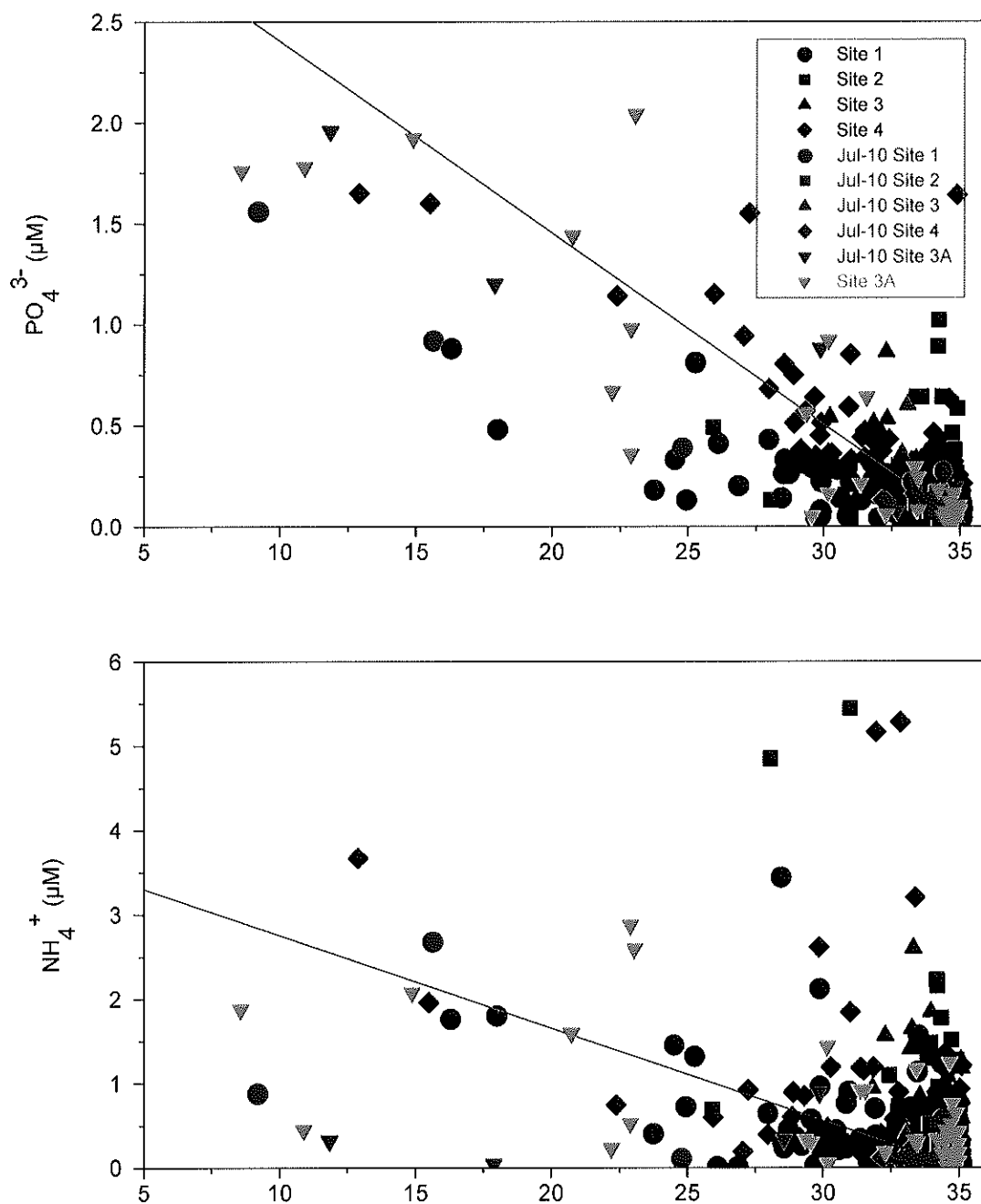


FIGURE 21. Phosphate and ammonium, plotted as a function of salinity for surface samples collected since August 1995 at four sites offshore of the Makena Golf Course. Black symbols represent combined data from surveys conducted between August 1995 and June 2009. Green symbols represent data from surveys at Site 3A commencing in June 2007. Red symbols are data from the most recent survey. Solid red line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from golf course irrigation well #6. For sampling site locations, see Figure 1.

TABLE 6. Linear regression statistics (y-intercept and slope) of concentrations of silica as functions of salinity from four ocean transect sites off of the Makana Resort collected during monitoring surveys from 1995 to July 2010 (Transect Site 3 has been monitored since 2002; Transect Site 3A since 2007). Also shown are standard errors and upper and lower 95% confidence limits around the y-intercepts and slopes. "REGSLOPE" indicates regression statistics for slope of yearly coefficients as a function of time. For location of transect sites, see Figure 1.

SILICA - Y-INTERCEPT

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	522.34	12.18	491.03	553.66
1996	629.56	11.05	605.49	653.64
1997	504.17	2.83	496.89	511.46
1998	484.14	2.44	477.86	490.41
1999	479.11	9.89	457.55	500.66
2000	528.68	5.87	513.58	543.77
2001	625.85	10.91	597.82	653.88
2002	502.98	8.68	480.66	525.30
2003	625.85	10.91	597.82	653.88
2004	546.00	8.33	527.84	564.16
2005	466.59	11.09	442.42	490.75
2006	487.68	24.60	434.08	541.28
2007	491.19	34.99	414.95	567.42
2008	371.80	16.96	334.85	408.75
2009	457.28	10.01	431.54	483.02
2010	515.27	7.85	495.09	535.45
REGSLOPE	-6.04	3.45	-13.43	1.35

SITE 2				
1995	468.41	85.54	248.51	688.30
1996	549.09	177.83	164.91	933.28
1997	567.57	9.71	543.80	591.33
1998	563.20	37.23	472.10	654.30
1999	466.74	95.75	261.37	672.11
2000	770.15	27.32	703.31	837.00
2001	1254.31	74.17	1072.82	1435.81
2002	577.53	29.40	505.60	649.46
2003	505.05	20.10	461.94	548.15
2004	565.31	93.71	364.33	766.29
2005	339.08	33.78	266.64	411.52
2006	553.48	62.93	418.51	688.45
2007	443.05	17.15	406.27	479.84
2008	402.41	73.66	244.42	560.41
2009	501.76	9.02	479.69	523.82
2010	490.17	22.77	434.46	545.87
REGSLOPE	-10.11	11.30	-34.34	14.12

SITE 3A				
2007	714.10	5.58	701.94	726.27
2008	805.12	9.00	785.52	824.73
2009	646.37	7.80	626.32	666.43
2010	750.91	5.70	736.26	765.56
REGSLOPE	-4.83	36.34	-161.20	151.53

SITE 3				
2002	931.92	27.54	861.13	1002.71
2003	984.76	41.58	894.16	1075.35
2004	632.75	127.62	354.68	910.82
2005	704.38	52.31	590.40	818.35
2006	928.22	64.18	788.40	1068.05
2007	722.80	15.07	689.97	755.63
2008	1058.06	48.59	952.18	1163.94
2009	943.91	40.06	840.94	1046.89
2010	962.57	74.39	771.34	1153.79
REGSLOPE	14.48	19.66	-32.02	60.98

SITE 4				
1995	710.45	8.83	687.74	733.15
1996	917.33	13.38	888.18	946.47
1997	776.74	3.53	767.66	785.82
1998	841.35	6.75	824.00	858.70
1999	823.63	24.78	769.63	877.62
2000	946.97	12.51	914.80	979.14
2001	1403.91	260.13	735.22	2072.61
2002	767.85	4.37	756.63	779.08
2003	854.37	29.88	789.26	919.48
2004	843.49	37.55	761.67	925.31
2005	703.97	14.00	673.47	734.46
2006	735.05	14.01	704.53	765.57
2007	710.11	7.14	694.56	725.66
2008	712.32	18.22	672.63	752.01
2009	715.30	7.99	694.75	735.84
2010	673.09	6.27	656.98	689.21
REGSLOPE	-12.51	9.27	-32.39	7.37

SILICA - SLOPE

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	-15.08	0.38	-16.05	-14.12
1996	-18.05	0.32	-18.75	-17.34
1997	-14.43	0.08	-14.65	-14.21
1998	-13.83	0.07	-14.02	-13.64
1999	-13.63	0.29	-14.27	-12.99
2000	-15.08	0.18	-15.54	-14.62
2001	-17.76	0.32	-18.57	-16.94
2002	-14.38	0.26	-15.05	-13.72
2003	-17.76	0.32	-18.57	-16.94
2004	-15.68	0.25	-16.23	-15.14
2005	-13.31	0.33	-14.02	-12.61
2006	-13.88	0.76	-15.53	-12.23
2007	-14.11	1.14	-16.59	-11.62
2008	-10.46	0.52	-11.59	-9.33
2009	-12.98	0.30	-13.76	-12.20
2010	-14.78	0.28	-15.49	-14.06
REGSLOPE	0.18	0.10	-0.03	0.39

SITE 2				
1995	-13.47	2.51	-19.93	-7.00
1996	-15.62	5.15	-26.75	-4.49
1997	-16.26	0.29	-16.96	-15.56
1998	-16.11	1.08	-18.76	-13.45
1999	-13.21	2.78	-19.18	-7.23
2000	-22.06	0.80	-24.02	-20.11
2001	-35.68	2.12	-40.87	-30.49
2002	-16.54	0.86	-18.64	-14.44
2003	-14.37	0.59	-15.63	-13.11
2004	-16.23	2.73	-22.09	-10.38
2005	-9.61	0.98	-11.70	-7.52
2006	-15.82	1.83	-19.75	-11.89
2007	-12.54	0.51	-13.64	-11.45
2008	-11.41	2.14	-15.99	-6.83
2009	-14.32	0.27	-14.98	-13.66
2010	-13.97	0.67	-15.61	-12.33
REGSLOPE	0.29	0.32	-0.40	0.98

SITE 3A				
2007	-20.35	0.19	-20.75	-19.94
2008	-22.96	0.28	-23.57	-22.36
2009	-18.28	0.26	-18.96	-17.61
2009	-21.44	0.19	-21.94	-20.94
REGSLOPE	0.14	1.07	-4.48	4.76

SITE 3				
2002	-26.75	0.81	-28.83	-24.68
2003	-28.10	1.21	-30.73	-25.47
2004	-18.19	3.69	-26.24	-10.14
2005	-20.11	1.51	-23.40	-16.83
2006	-26.56	1.89	-30.67	-22.46
2007	-20.60	0.44	-21.56	-19.63
2008	-30.22	1.41	-33.29	-27.14
2009	-26.90	1.17	-29.90	-23.91
2010	-27.56	2.19	-33.18	-21.93
REGSLOPE	-0.40	0.56	-1.73	0.93

SITE 4				
1995	-20.55	0.27	-21.25	-19.85
1996	-26.23	0.40	-27.10	-25.37
1997	-22.27	0.11	-22.55	-21.99
1998	-24.07	0.20	-24.58	-23.56
1999	-23.50	0.73	-25.10	-21.90
2000	-27.12	0.37	-28.08	-26.16
2001	-39.92	7.42	-58.99	-20.86
2002	-21.99	0.13	-22.34	-21.65
2003	-24.36	0.91	-26.34	-22.39
2004	-24.27	1.10	-26.66	-21.88
2005	-20.11	0.41	-21.00	-19.22
2006	-20.96	0.41	-21.86	-20.06
2007	-20.27	0.23	-20.77	-19.78
2008	-20.33	0.53	-21.49	-19.17
2009	-20.34	0.24	-20.95	-19.73
2010	-19.14	0.19	-19.62	-18.66
REGSLOPE	0.37	0.26	-0.19	0.93

TABLE 7. Linear regression statistics (y-intercept and slope) of concentrations of nitrate as functions of salinity from four ocean transect sites off of the Makena Resort collected during monitoring surveys from 1995 to July 2010 (Transect Site 3 has been monitored since 2002; Transect Site 3A since 2007). Also shown are standard errors and upper and lower 95% confidence limits around the y-intercepts and slopes. "REGSLOPE" indicates regression statistics for slope of yearly coefficients as a function of time. For location of transect sites, see Figure 1.

NITRATE -Y-INTERCEPT

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	326.50	7.10	308.25	344.75
1996	336.49	4.62	326.41	346.56
1997	406.96	1.93	402.00	411.93
1998	268.90	1.55	264.91	272.89
1999	225.24	5.32	213.66	236.83
2000	309.77	3.36	301.14	318.41
2001	336.53	9.69	311.61	361.44
2002	278.21	17.43	233.40	323.03
2003	421.29	7.81	404.28	438.30
2004	442.33	4.89	431.68	452.99
2005	296.36	7.44	280.16	312.56
2006	361.76	7.20	346.08	377.45
2007	305.06	15.88	270.45	339.67
2008	330.95	7.18	315.29	346.60
2009	231.91	3.07	224.01	239.81
2010	253.63	4.57	241.88	265.38
REGSLOPE	-2.37	3.54	-9.97	5.22

SITE 2				
1995	119.87	12.03	88.95	150.79
1996	106.36	18.44	66.53	146.19
1997	193.75	5.64	179.95	207.55
1998	166.93	5.33	153.89	179.97
1999	116.21	14.04	86.10	146.32
2000	142.07	2.83	135.13	149.01
2001	154.93	7.65	136.21	173.64
2002	180.82	58.78	36.98	324.66
2003	163.36	6.31	149.82	176.91
2004	145.36	10.55	122.74	167.99
2005	102.66	9.11	83.13	122.19
2006	124.74	4.89	114.26	135.22
2007	134.27	3.25	127.30	141.24
2008	108.01	12.87	80.41	135.61
2009	142.21	9.04	120.08	164.34
2010	135.27	10.49	109.60	160.94
REGSLOPE	-1.06	1.49	-4.25	2.12

SITE 3A				
2007	354.33	49.92	245.56	463.11
2008	448.07	7.75	431.19	464.95
2009	283.99	14.63	246.38	321.60
2010	283.25	1.86	278.48	288.02
REGSLOPE	-37.73	33.32	-181.08	105.62

SITE 3				
2002	847.45	52.35	712.88	982.01
2003	693.24	39.54	607.10	779.38
2004	463.72	90.73	266.04	661.40
2005	535.53	47.19	432.72	638.34
2006	856.96	48.22	751.91	962.02
2007	1233.34	18.23	1193.63	1273.06
2008	899.91	41.92	808.57	991.25
2009	827.18	19.10	778.08	876.29
2010	924.44	35.54	833.09	1015.80
REGSLOPE	38.00	27.88	-27.93	103.93

SITE 4				
1995	111.38	6.47	94.74	128.02
1996	118.34	1.63	114.79	121.89
1997	122.56	1.29	119.25	125.88
1998	112.77	1.87	107.97	117.57
1999	109.13	3.30	101.94	116.33
2000	118.51	0.75	116.58	120.43
2001	100.93	54.85	-40.08	241.94
2002	118.91	3.25	110.56	127.25
2003	113.78	2.76	107.77	119.79
2004	134.97	4.64	124.86	145.07
2005	114.59	4.47	104.85	124.33
2006	119.85	1.76	116.03	123.68
2007	269.24	10.13	247.16	291.32
2008	62.93	4.05	54.11	71.74
2009	107.17	1.51	103.30	111.04
2010	148.96	16.96	105.35	192.57
REGSLOPE	1.95	2.33	-3.06	6.95

NITRATE - SLOPE

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	-9.49	0.22	-10.05	-8.92
1996	-9.67	0.14	-9.97	-9.38
1997	-11.70	0.06	-11.85	-11.55
1998	-7.72	0.05	-7.84	-7.60
1999	-6.44	0.16	-6.79	-6.10
2000	-8.91	0.10	-9.17	-8.65
2001	-9.60	0.28	-10.32	-8.88
2002	-7.99	0.52	-9.31	-6.66
2003	-12.09	0.23	-12.60	-11.58
2004	-12.74	0.15	-13.06	-12.42
2005	-8.48	0.22	-8.96	-8.01
2006	-10.40	0.22	-10.89	-9.92
2007	-8.73	0.52	-9.86	-7.60
2008	-9.52	0.22	-10.00	-9.05
2009	-6.65	0.09	-6.89	-6.41
2010	-7.31	0.16	-7.72	-6.89
REGSLOPE	0.07	0.10	-0.15	0.29

SITE 2				
1995	-3.47	0.35	-4.38	-2.56
1996	-3.05	0.53	-4.20	-1.89
1997	-5.57	0.17	-5.97	-5.16
1998	-4.79	0.16	-5.17	-4.41
1999	-3.31	0.41	-4.19	-2.43
2000	-4.08	0.08	-4.29	-3.88
2001	-4.41	0.22	-4.95	-3.88
2002	-5.19	1.72	-9.40	-0.99
2003	-4.68	0.18	-5.07	-4.28
2004	-4.19	0.31	-4.84	-3.53
2005	-2.94	0.26	-3.50	-2.37
2006	-3.57	0.14	-3.88	-3.27
2007	-3.85	0.10	-4.06	-3.64
2008	-3.09	0.37	-3.89	-2.29
2009	-4.10	0.27	-4.76	-3.43
2010	-3.88	0.31	-4.64	-3.13
REGSLOPE	0.03	0.04	-0.06	0.12

SITE 3A				
2007	-9.57	1.67	-13.20	-5.93
2008	-12.81	0.24	-13.33	-12.29
2009	-7.98	0.49	-9.25	-6.72
2010	-8.15	0.06	-8.32	-7.99
REGSLOPE	0.91	1.04	-3.58	5.40

SITE 3				
2002	-24.49	1.53	-28.43	-20.56
2003	-19.86	1.15	-22.36	-17.35
2004	-13.37	2.63	-19.09	-7.64
2005	-15.33	1.36	-18.29	-12.37
2006	-24.61	1.42	-27.70	-21.52
2007	-35.51	0.54	-36.68	-34.34
2008	-25.78	1.22	-28.43	-23.12
2009	-23.65	0.56	-25.08	-22.22
2010	-26.57	1.05	-29.26	-23.88
REGSLOPE	-1.08	0.81	-2.99	0.83

SITE 4				
1995	-3.26	0.20	-3.77	-2.75
1996	-3.40	0.05	-3.50	-3.29
1997	-3.53	0.04	-3.63	-3.43
1998	-3.24	0.05	-3.38	-3.10
1999	-3.13	0.10	-3.34	-2.92
2000	-3.40	0.02	-3.46	-3.34
2001	-2.87	1.56	-6.89	1.15
2002	-3.44	0.10	-3.70	-3.19
2003	-3.28	0.08	-3.46	-3.09
2004	-3.89	0.14	-4.18	-3.59
2005	-3.29	0.13	-3.57	-3.00
2006	-3.43	0.05	-3.54	-3.31
2007	-7.87	0.32	-8.58	-7.17
2008	-1.79	0.12	-2.05	-1.54
2009	-3.07	0.04	-3.18	-2.95
2010	-4.30	0.50	-5.60	-3.00
REGSLOPE	-0.06	0.07	-0.20	0.09

TABLE 8. Linear regression statistics (y-intercept and slope) of concentrations of orthophosphate phosphorus as functions of salinity from four ocean transect sites off of the Makena Resort collected during monitoring surveys from 1995 to July 2010 (Transect site 3 has been monitored since 2002; Transect Site 3A since 2007). Also shown are standard errors and upper and lower 95% confidence limits around the y-intercepts and slopes. For location of transect sites, see Figure 1.

PHOSPHATE -Y-INTERCEPT

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	1.04	0.14	0.68	1.39
1996	1.78	0.12	1.52	2.03
1997	1.40	0.12	1.10	1.69
1998	1.10	0.06	0.95	1.25
1999	1.07	0.12	0.80	1.34
2000	0.89	0.12	0.59	1.19
2001	2.16	0.76	0.22	4.11
2002	1.12	0.68	-0.64	2.88
2003	0.48	0.19	0.06	0.90
2004	2.71	0.17	2.33	3.08
2005	-0.02	0.14	-0.34	0.29
2006	1.36	0.13	1.08	1.65
2007	1.07	0.20	0.64	1.50
2008	0.89	0.13	0.61	1.16
2009	0.87	0.38	-0.12	1.85
2010	1.86	0.18	1.40	2.31
REGSLOPE	-0.01	0.04	-0.09	0.07

SITE 2				
1995	0.15	0.63	-1.46	1.76
1996	2.03	1.59	-1.41	5.48
1997	3.70	0.25	3.10	4.31
1998	3.55	1.44	0.03	7.07
1999	3.68	5.55	-8.22	15.58
2000	12.78	1.18	9.89	15.66
2001	30.73	3.12	23.09	38.37
2002	6.67	1.68	2.57	10.77
2003	3.57	0.31	2.90	4.24
2004	5.76	0.53	4.62	6.91
2005	-0.95	2.96	-7.31	5.40
2006	1.88	0.57	0.67	3.10
2007	0.22	0.26	-0.34	0.78
2008	1.50	1.14	-0.95	3.95
2009	1.54	0.34	0.71	2.38
2010	1.70	1.31	-1.49	4.90
REGSLOPE	-0.29	0.42	-1.19	0.61

SITE 3A				
2007	2.39	0.24	1.86	2.93
2008	4.43	0.49	3.36	5.50
2009	2.60	0.15	2.21	2.99
2010	2.75	0.29	2.01	3.48
REGSLOPE	-0.08	0.51	-2.27	2.12

SITE 3				
2002	4.62	2.31	-1.31	10.55
2003	7.38	0.99	5.24	9.53
2004	7.40	0.78	5.70	9.10
2005	3.17	0.53	2.03	4.32
2006	7.32	1.16	4.80	9.84
2007	4.46	0.46	3.47	5.45
2008	4.01	1.13	1.56	6.47
2009	3.12	2.67	-3.74	9.99
2010	6.25	2.27	0.41	12.09
REGSLOPE	-0.20	0.24	-0.76	0.36

SITE 4				
1995	2.44	0.15	2.04	2.84
1996	3.08	0.13	2.79	3.37
1997	2.95	0.09	2.71	3.19
1998	3.50	0.46	2.32	4.67
1999	3.26	0.14	2.96	3.55
2000	3.29	0.20	2.77	3.82
2001	-19.16	22.66	-77.41	39.09
2002	3.98	0.15	3.60	4.35
2003	4.13	1.29	1.33	6.93
2004	4.75	0.79	3.04	6.47
2005	2.12	0.38	1.28	2.95
2006	2.15	0.40	1.28	3.02
2007	2.65	0.09	2.46	2.83
2008	2.98	0.67	1.52	4.44
2009	1.51	0.65	-0.16	3.19
2010	0.76	0.47	-0.46	1.97
REGSLOPE	0.01	0.31	-0.67	0.68

PHOSPHATE - SLOPE

YEAR	Coefficients	Std Err	Lower 95%	Upper 95%
SITE 1				
1995	-0.03	0.00	-0.04	-0.02
1996	-0.05	0.00	-0.06	-0.04
1997	-0.04	0.00	-0.05	-0.03
1998	-0.03	0.00	-0.03	-0.02
1999	-0.03	0.00	-0.03	-0.02
2000	-0.02	0.00	-0.03	-0.01
2001	-0.06	0.02	-0.12	0.00
2002	-0.03	0.02	-0.08	0.02
2003	-0.01	0.01	-0.02	0.00
2004	-0.08	0.01	-0.09	-0.06
2005	0.00	0.00	-0.01	0.01
2006	-0.04	0.00	-0.04	-0.03
2007	-0.03	0.01	-0.04	-0.02
2008	-0.02	0.00	-0.03	-0.02
2009	-0.02	0.01	-0.05	0.01
2010	-0.05	0.01	-0.07	-0.04
REGSLOPE	0.00	0.00	0.00	0.00

SITE 2				
1995	0.00	0.02	-0.05	0.04
1996	-0.06	0.05	-0.16	0.04
1997	-0.10	0.01	-0.12	-0.09
1998	-0.10	0.04	-0.20	0.00
1999	-0.10	0.16	-0.44	0.25
2000	-0.36	0.03	-0.45	-0.28
2001	-0.87	0.09	-1.09	-0.65
2002	-0.19	0.05	-0.31	-0.07
2003	-0.10	0.01	-0.12	-0.08
2004	-0.16	0.02	-0.20	-0.13
2005	0.03	0.09	-0.15	0.21
2006	-0.05	0.02	-0.09	-0.02
2007	0.00	0.01	-0.02	0.01
2008	-0.04	0.03	-0.11	0.03
2009	-0.04	0.01	-0.07	-0.02
2010	-0.05	0.04	-0.14	0.05
REGSLOPE	0.01	0.01	-0.02	0.03

SITE 3A				
2007	-0.07	0.01	-0.09	-0.05
2008	-0.13	0.02	-0.16	-0.09
2009	-0.07	0.01	-0.09	-0.06
2010	-0.07	0.01	-0.10	-0.05
REGSLOPE	0.00	0.01	-0.06	0.07

SITE 3				
2002	-0.13	0.07	-0.30	0.04
2003	-0.21	0.03	-0.27	-0.15
2004	-0.21	0.02	-0.26	-0.16
2005	-0.09	0.02	-0.12	-0.06
2006	-0.21	0.03	-0.28	-0.13
2007	-0.13	0.01	-0.16	-0.10
2008	-0.11	0.03	-0.18	-0.04
2009	-0.09	0.08	-0.29	0.11
2010	-0.18	0.07	-0.35	-0.01
REGSLOPE	0.01	0.01	-0.01	0.02

SITE 4				
1995	-0.07	0.00	-0.08	-0.06
1996	-0.09	0.00	-0.09	-0.08
1997	-0.08	0.00	-0.09	-0.07
1998	-0.10	0.01	-0.13	-0.06
1999	-0.09	0.00	-0.10	-0.08
2000	-0.09	0.01	-0.10	-0.07
2001	0.55	0.65	-1.11	2.21
2002	-0.11	0.00	-0.12	-0.10
2003	-0.11	0.04	-0.19	-0.02
2004	-0.13	0.02	-0.18	-0.08
2005	-0.06	0.01	-0.08	-0.03
2006	-0.06	0.01	-0.08	-0.03
2007	-0.07	0.00	-0.08	-0.07
2008	-0.08	0.02	-0.13	-0.04
2009	-0.04	0.02	-0.09	0.01
2010	-0.02	0.01	-0.06	0.02
REGSLOPE	0.00	0.01	-0.02	0.02

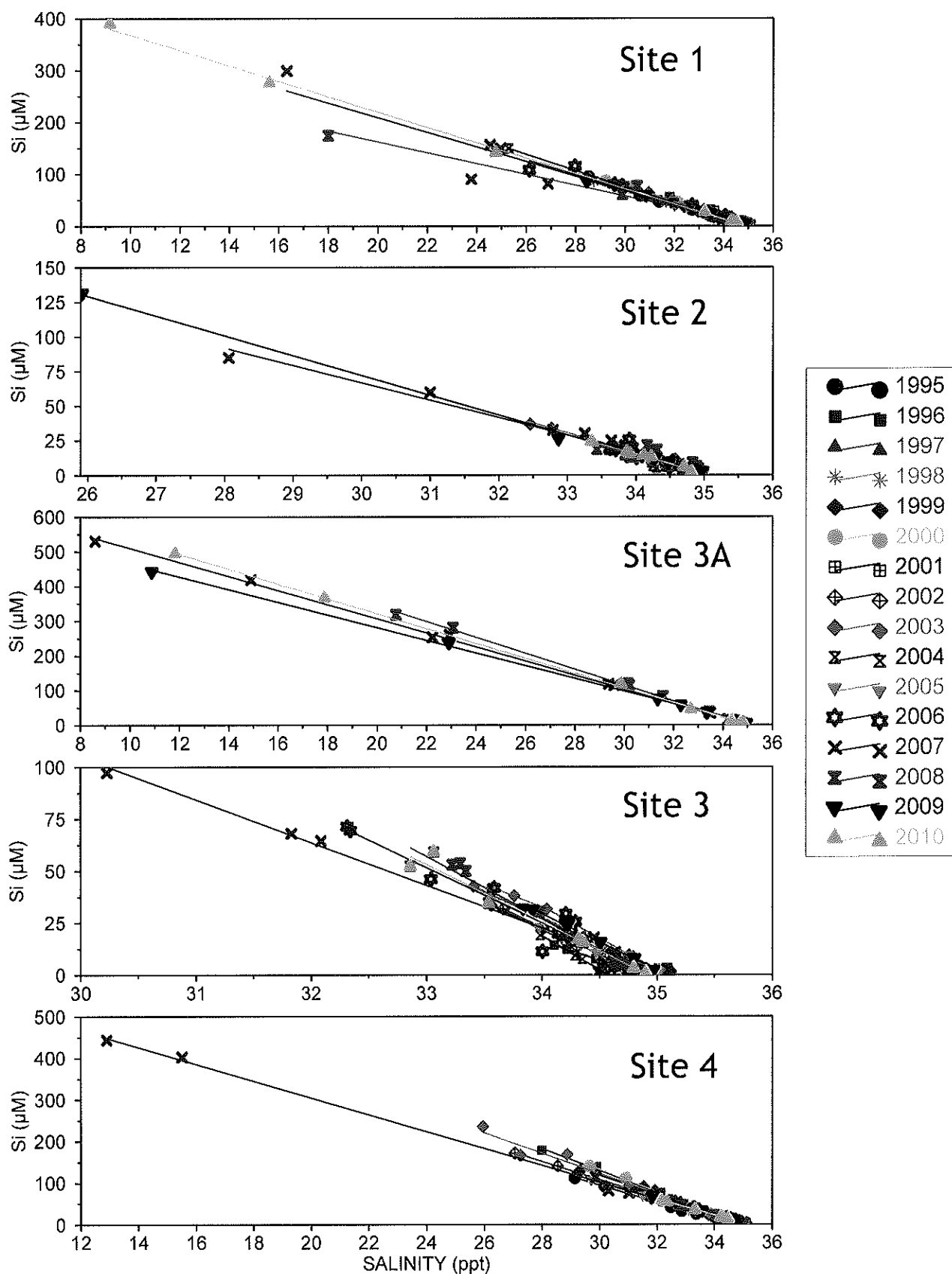


FIGURE 22. Mixing diagram showing yearly concentrations of silicate as functions of salinity from samples collected during annual monitoring surveys at five transect sites offshore of the Makena Resort (Site 3A since 2007). Note axis scale changes between sites. Straight lines are linear regressions through data points for each year. For sampling site locations, see Figure 1.

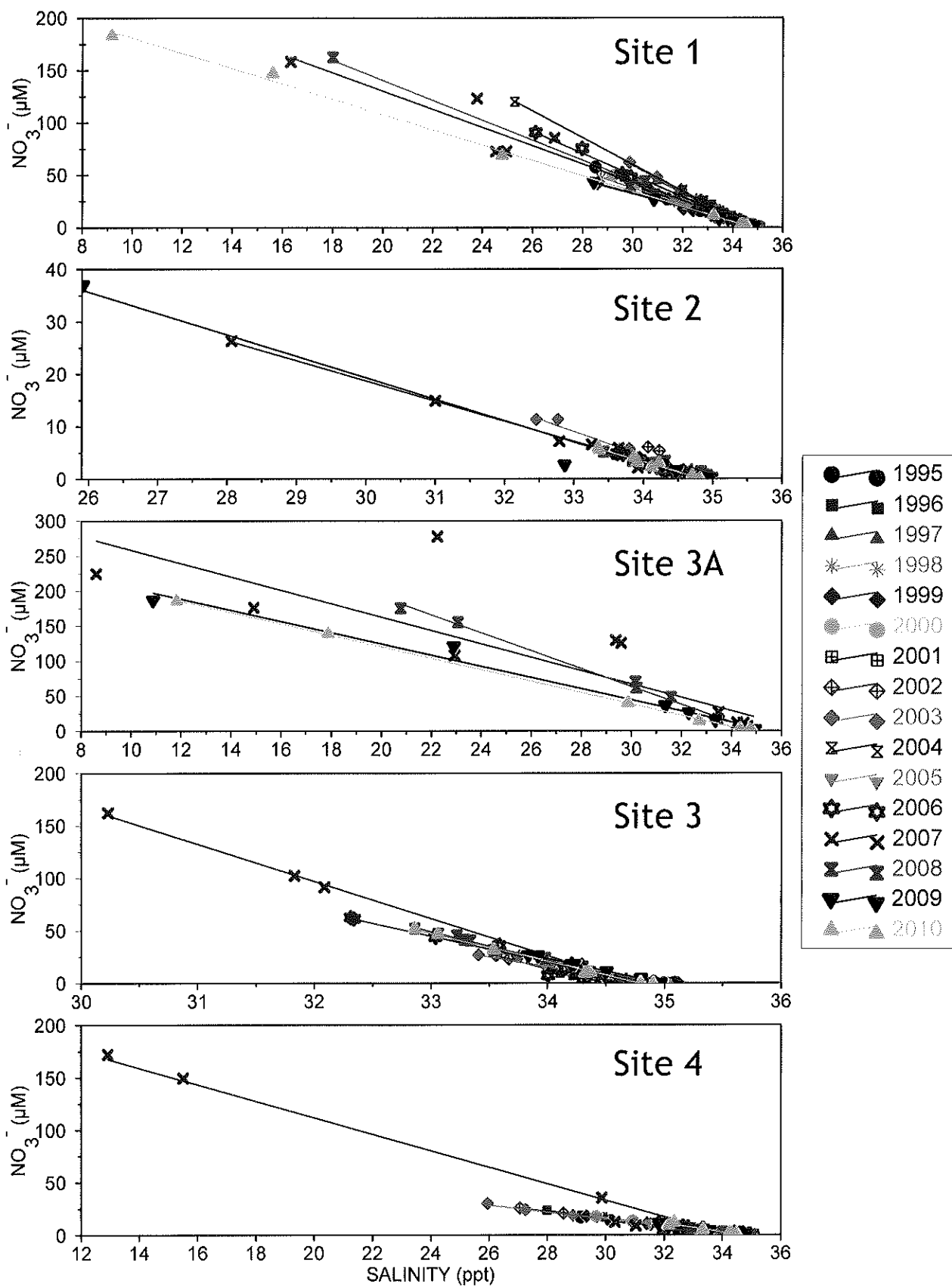


FIGURE 23. Mixing diagram showing yearly concentrations of nitrate as functions of salinity from samples collected during annual monitoring surveys at five transect sites offshore of the Makena Resort (Site 3A since 2007). Note axis scale changes between sites. Straight lines are linear regressions through data points for each year. For sampling site locations, see Figure 1.

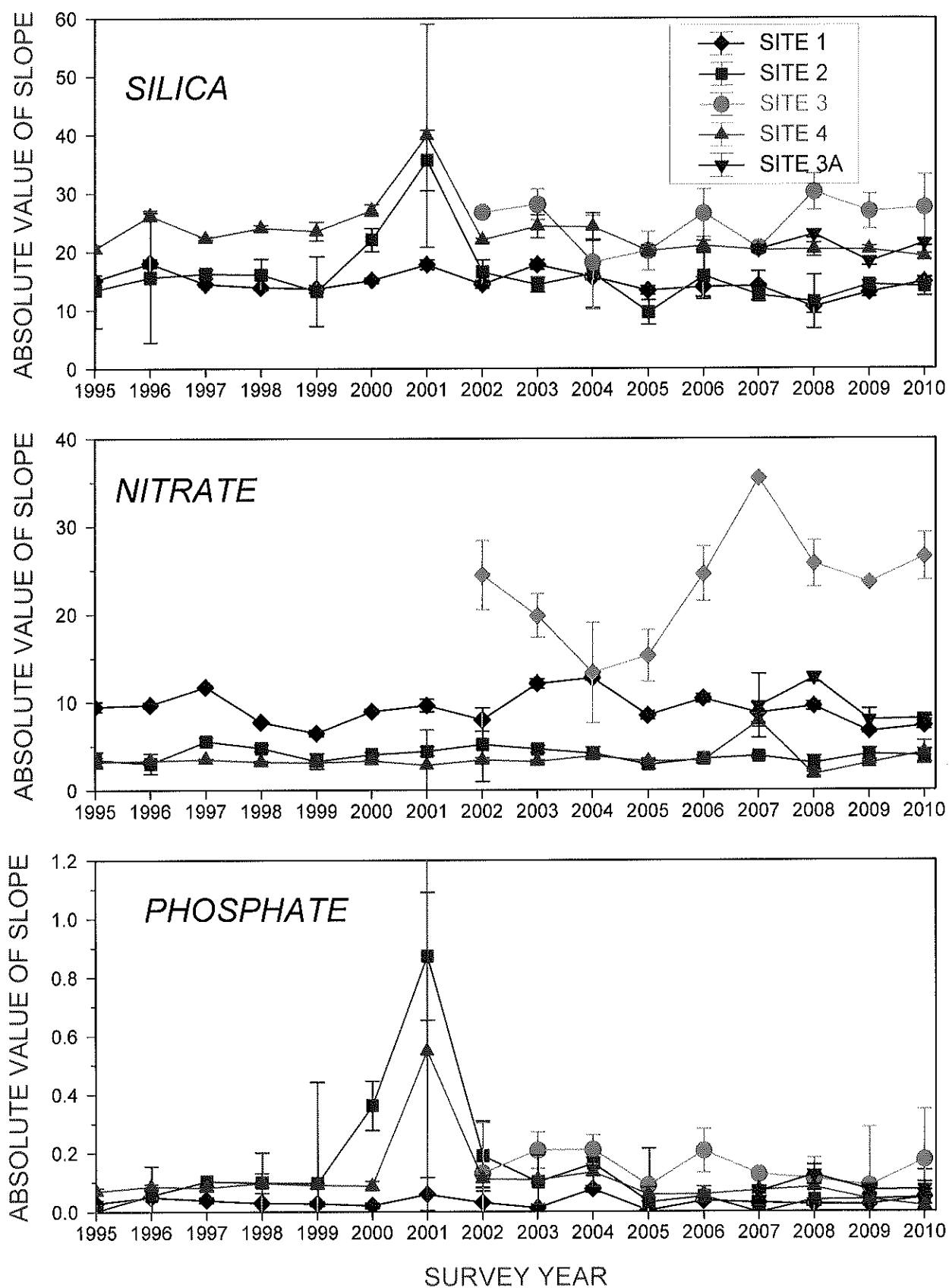


FIGURE 24. Time-course plots of absolute values of slopes of linear regressions of concentrations of silica, nitrate and phosphate as functions of salinity collected annually at each of the transect monitoring stations off the Makena Resort (Site 3A began in June 2007). Error bars are 95% confidence limits (Note error bar for Site 4 Phosphate is off scale). For locations of sampling transect sites, see Figure 1.

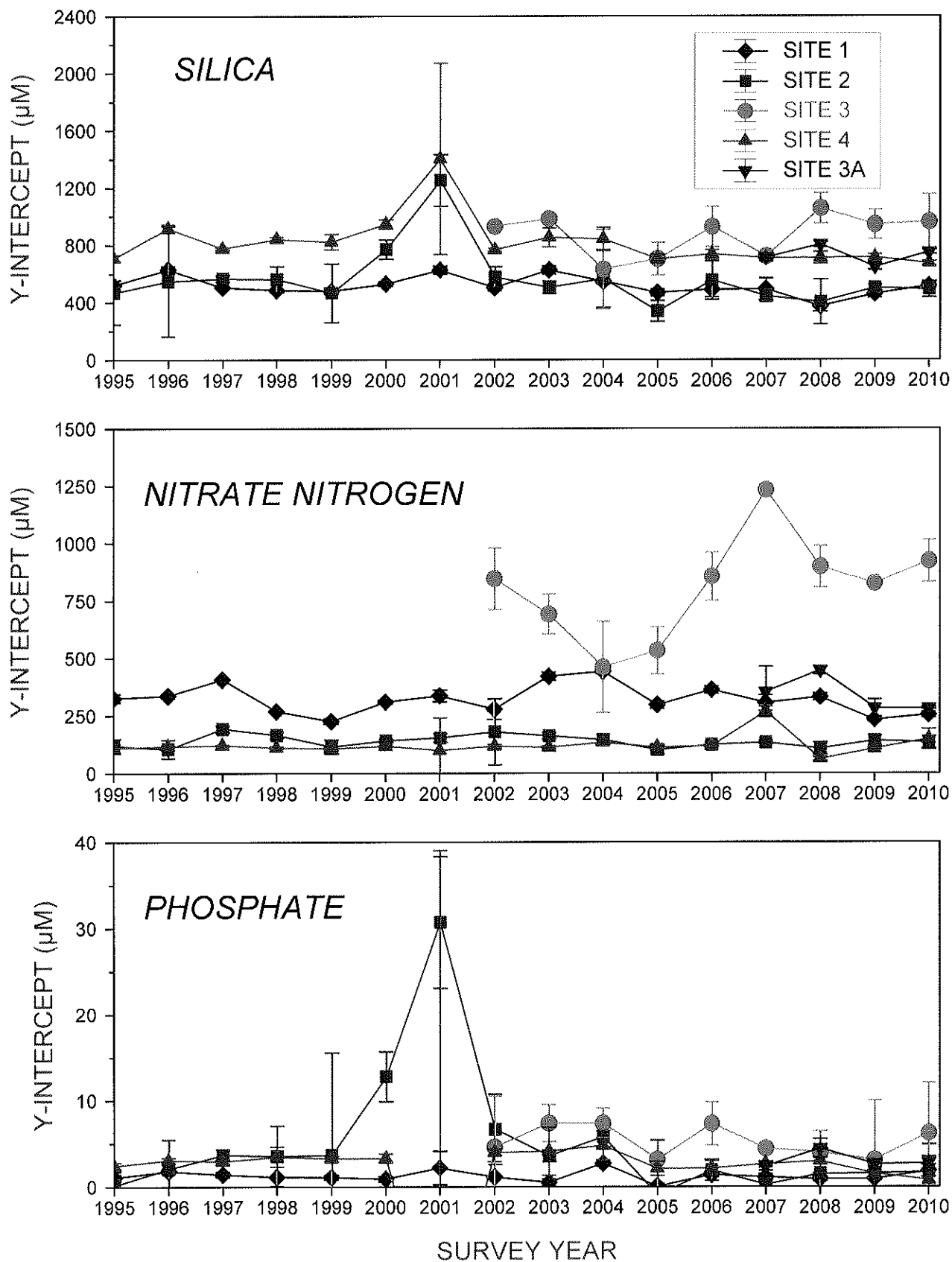


FIGURE 25. Time-course plots of Y-intercepts of linear regressions of concentrations of silica, nitrate and phosphorus as functions of salinity collected annually at each of the transect monitoring stations off the Makena Resort (Site 3A began in June 2007). Error bars are 95% confidence limits. For locations of sampling transect sites, see Figure 1.

