MARINE WATER QUALITY MONITORING

MAKENA GOLF COURSES, MAKENA, MAUI

WATER CHEMISTRY

REPORT 2001

Prepared for

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March 2002

EXHIBIT "A"

PURPOSE

One of the conditions (No. 10) of the Declaration of Conditions applicable to an Amendment of District Boundary from Agricultural to Urban dated April 17, 1998 requires the initiation and continued implementation of a Water Quality Monitoring Program offshore of the Makena Resort. The site fronts approximately 5.4 miles of coastline, and includes two 18-hole golf courses (North and South Courses) within the boundaries of the Makena Resort Development. The area is bounded by Papanui Stream (Nahuna Point) on the north and Puu Olai (Ahihi Bay) on the south. No part of the project involves direct alteration of the shoreline or nearshore marine environments.

The purpose of this report is to fulfill the stipulated requirement of the marine monitoring program. The primary goals of the program are twofold: 1) assess the degree that material from fertilizers and other materials that originate from human activities (e.g., anthropogenic materials) on land leach to groundwater, and 2) determine the fate of these materials within the nearshore zone. In terms of determining fate, do the anthropogenic materials 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 (estimated at twice per year). This strategy allows for determination of variations in effects from the golf course in both space (at different locations along the shoreline) and time. The following report presents the results of the ninth increment in the monitoring program, and contains data from water chemistry sampling conducted on December 2, 2001.

ANALYTICAL METHODS

Three survey sites directly downslope from the Makena Golf Course site were 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. 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. Survey site locations are depicted as transects perpendicular to the shoreline extending from the shoreline out to what is considered open coastal ocean. Survey Site 1 is located near the northern boundary of the project site off Nahuna Point; Survey Site 2 bisects the area off the center of the North course near Makena Landing, Site 3 is located at the southern boundary of the project offshore of Oneloa Beach, and Site 4 (Control) is located at the northern boundary of the 'Ahihi-kina'u natural area reserve offshore of the 1790 lava flow and approximately 1-2 miles south of the existing

Makena Golf courses (Figure 1). In the vicinity of Site 4, a few private residences exist near the shoreline with land use upslope of the survey site consisting primarily of cattle grazing.

All field work was conducted on December 2, 2001 using a small boat. Water samples were collected 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 transferred into a 1-liter polyethylene bottle until further processing. For nearshore samples, water samples were collected directly in 1-liter polyethylene bottles by divers swimming from the boat.

Environmental conditions during sample collection consisted of calm seas, light winds (0-10 knots) and sunny skies. Water samples were collected at stations along transects that extend from the highest wash of waves to approximately 125-200 meters (m) offshore at each site. Such a sampling scheme was 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 shoreline modification. With the exception of the two stations closest to the shoreline, 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 were also collected from six golf course irrigation wells (#'s 1, 2, 3, 4, 6, and 10) and 2 irrigation lakes located on the Makena Golf course property.

Subsamples for nutrient analyses were immediately placed in 125-milliliter (ml) acid-washed, triple rinsed, polyethylene bottles and stored on ice until returned to Honolulu. Water for other analyses was subsampled from 1-liter polyethylene bottles and kept chilled until analysis.

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 Water Quality Standards, Department of Health, State of Hawaii. These criteria include: total nitrogen (TN) which is defined as dissolved inorganic nitrogen plus dissolved organic nitrogen, nitrate + nitrite nitrogen (NO_3^- + NO_2^-, hereafter referred to as NO_3^-), ammonium (NH_4^+), total phosphorus (TP) which is defined as dissolved inorganic phosphorus plus dissolved 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 NH_4^+, PO_4^{3-}, and $NO_3^- + NO_2^-$ (hereafter termed NO_3^-) were performed 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 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 µM (0.14 µg/L) for NO_3^- and NH_4^+, 0.01 µM (0.31 µg/L) for PO_4^{3-}, 0.1 µM (1.4 µg/L) for TN and 0.1 µM (3.1 µg/L) for TP.

Turbidity was determined on 60-ml subsamples, and was measured in the field using a DRT-15CE Turbidimeter, and reported in nephelometric turbidity units (ntu, level of detection 0.01 ntu). 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 µg/L). Salinity was determined using an AGE Model 2100 laboratory salinometer with a precision of 0.0003‰.

Water temperature was measured in the field with a digital thermometer with a readability of 0.1°C. pH was determined using a field meter with combination electrode and a precision of 0.01 pH units.

Nutrient, turbidity, Chl *a* and salinity analyses were conducted by the University of Washington, School of Oceanography Marine Chemistry Laboratory, which possess the appropriate acceptability ratings from the U.S. EPA.

RESULTS

Horizontal Stratification

Table 1 shows results of all marine water chemical analyses for samples collected off Makena on December 2, 2001 reported in micromolar units (µM). Table 2 shows similar results presented in units of micrograms per liter (µg/L). Tables 3 and 4 show geometric means of ocean samples collected at the same sampling stations during the nine surveys to date; August 1995, February and October 1996, April 1997, March 1998, May and December 1999, December 2000 and December 2001. Table 5 shows water chemistry measurements (in units of µM and µg/L) for samples collected from irrigation wells located on the Makena Resort North Golf Course. Concentrations of twelve chemical constituents in surface and deep water samples are plotted as functions of distance from the shoreline in Figures 2 and 3. Figures 4-11 show nutrient concentrations plotted as a function of distance from the shoreline for each survey conducted to date.

Within a zone extending from the highest wash of waves to a distance of approximately 50 m offshore there are elevated concentrations of dissolved Si, NO_3^- and TN at Sites 1 and 2 (Figure 2, Tables 1 and 2). Salinity shows the opposite trend, with distinctly lower values within the nearshore zone (Figure 3). The greatest changes with respect to distance from the shoreline in the concentrations of dissolved Si, NO_3^-, TN and salinity was evident at Site 1 (Tables 1 and 2, Figures 2 and 3). Site 2 had similar patterns in dissolved nutrients and salinity but to a much lesser extent than Site 1 during the December 2001 survey. Horizontal gradients in PO_4^{3-} and TP were evident only at Site 2 during the December 2001 survey (Tables 1 and 2, Figure 2). No horizontal gradients were evident at Sites 3 or 4 as concentrations of Si, NO_3^-, PO_4^{3-}, TP and TN and salinity were relatively constant at offshore levels along the entire length of the transects (Figures 2 and 3, Tables 1 and 2).

The pattern of elevated Si, NO_3^- and PO_4^{3-} with corresponding low salinity is indicative of groundwater entering the ocean near the shoreline. Low salinity groundwater, which contains high concentrations of Si, NO_3^-, and PO_4^{3-} (see values for well waters in Table 5), often percolates to the ocean near the shoreline, resulting in a distinct zone of mixing in the nearshore region. During the December 2001 survey, horizontal gradients at Sites 1 and 2 were steepest within 50 m of the shoreline. Beyond 50 m of the shoreline, concentrations were low and consistent at all four transects (Tables 1 and 2; Figures 2 and 3). Concentrations of PO_4^{3-} were higher along the entire transect at Site 2 compared to the other three sites during December 2001 (Figure 2). Hence, there is not a good correlation between NO_3^- and PO_4^{3-} at Site 1.

Dissolved nutrient constituents that are not associated with groundwater input (NH_4^+, TON, TOP) did not show the same horizontal gradients as Si and NO_3^-. With the exception of TOP at Site 2, concentrations of TOP and TON in surface waters were essentially constant along the entire length of each transect and of the same magnitude among transects (Figure 2, Tables 1 and 2). Elevated levels of TOP were detected within 5 m of the shoreline at Site 2 (Figure 2 and Tables 1 and 2). Concentrations of NH_4^+ varied widely among the transects and within each transect, however, no distinct horizontal gradients are evident (relative to NO_3^- and Si) The highest concentrations of NH_4^+ were measured at Site 3, while in the offshore samples at Site 1, NH4+ was undetectable (Figure 2, Tables 1 and 2).

Surface concentrations of turbidity and Chl *a* were highest near the shoreline and decreased with increasing distance offshore at all four sites (Figure 3). Among the four sites, values for turbidity were highest at Sites 1 and 2 (Tables 1 and 2).

Surface water temperature varied by only 0.9 °C among all the transects during the December 2001 survey. Within any one transect the maximum variation was only 0.6 °C (Tables 1 and 2). There was a slight pattern of coolest temperatures at the shoreline and

higher temperatures offshore (Figure 3). Temperature at Site 1, was approximately 0.2 °C warmer compared to the other 3 sites during December 2001 (Figure 3).

Approximately two months prior to the December 1999 survey, a severe flash flood originating in the ranch lands upslope of the project site traversed through the golf courses and entered the ocean at Site 2 (Makena Landing). Water in the area remained turbid for a substantial period of time, but was only slightly more turbid during the December 2001 survey than at the other three sampling site. The higher levels of turbidity at Site 2 near the shoreline is most likely the result of resuspended terrigenous material in sandy nearshore zone. Beyond the nearshore zone (within 5 m from shore), turbidity at Site 2 is not substantially higher than at the other three stations. While there was a period of time when suspended sediment remained within the water column of the embayment where Makena Landing is located, at present tidal and wave action has largely flushed introduced sediment from the area.

Vertical Stratification

In many areas of the Hawaiian Islands, input of low salinity groundwater to the nearshore ocean creates a distinct buoyant surface lens that persists for some distance from shore. 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 and 3 and Tables 1 and 2 show concentrations of water chemistry constituents with respect to vertical stratification. During the December 2001 survey, vertical stratification, as revealed by different nutrient concentrations in the surface layer compared to the subsurface waters, was not distinctly apparent at any of the sites (Figures 2 and 3, Tabes 1 and 2). Physical processes associated with wind and waves were sufficient to completely mix the water column at these sites during the December 2001 survey.

In general, there were differences between surface and deep water concentrations of NH_4^+, however, these differences were not consistent at any of the four sites (Figure 2). Vertical gradients in the concentrations of TOP and TON were minor during the December 2001 survey at all four sites (Figure 2). In most cases, turbidity and Chl *a* were higher in the surface water compared to the deep samples. Temperature measured in surface and deep water showed differences , however, the variation was small and no apparent trend with distance offshore was evident (Figure 3, Tables 1 and 2).

Temporal Comparison of Monitoring Results

Figures 4-11 show concentrations of water chemistry constituents from surface samples at all four sites during the nine monitoring surveys. Examination of these plots reveals noticeable changes in water chemistry over time, with several distinct trends. With respect to groundwater efflux, similar patterns of Si, NO_3^-, PO_4^{3-} and salinity are evident for all nine surveys at Sites 1and 2 (Figures 4-7). At Site 2 concentrations of PO_4^{3-} were distinctly higher during December1999 and 2000 than all other survey dates (Figure 6). At Site 3, groundwater efflux was absent during all surveys except February 1996 (Figures 8 and 9). At Site 4, groundwater input to the nearshore area was nearly undetectable during the October 1996 and December 2001 surveys and very small during the March 1998 survey compared to the other survey dates (Figures 10 and 11).

Variations in other constituents over time were not apparent except in a few cases. Concentrations of NH_4^+ were higher during December 2001 and May 1999 at Site 2 and May 1999 at Site 3 compared to the other surveys at these sites (Figures 6 and 8). NH_4^+ was lower during the October 1996 and December 1999 survey at Site 4 (Figure 10). Chl *a* was comparatively higher at all sites during May 1999 compared to the other survey dates while turbidity at Site 1 during December 2001 and Decmeber1999 (Figures 5, 7, 9 and 11). At all four sites, a seasonal trend was evident for temperature with coolest temperatures during the February 1996, March 1998 and December 1999 surveys and warmest temperatures during the October 1996 survey (Figures 5, 7, 9 and 11).

It is important to note that in no case is there an indication of progressively increasing concentrations of nutrients or other water chemistry constituents over time. Hence, it does not appear that input of materials as a result of leaching of golf course fertilizers, or any other source of nutrient subsidy, is increasing over time. In fact, at Site 1 where there has been peak concentrations of NO_3^- at the shoreline since the inception of the program, the highest concentration of 15 µM is almost 4-fold lower than the highest value of 57 µM measured during the initial survey in August 1995.

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 12 shows plots of concentrations of four chemical constituents (Si, NO_3^-, PO_4^{3-}, NH_4^+) as functions of salinity for the samples collected at each site in December 2001. Figures 13 and

14 show the same type of plot with data grouped by site for all surveys to date. Each graph also shows conservative mixing lines that are constructed by connecting the end member concentrations of open ocean water and groundwater from irrigation well No.4 located on the North Course of the Makena Resort. An additional mixing line was constructed from open ocean water and water collected from an irrigation lake that was fed by irrigation wells 2, 3 and 4, as well as effluent from the Maui Prince Hotel sewage treatment plant. To construct the mixing lines for each site in Figures 13 and 14, ocean data from each site was used as the endpoint.

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. Most of the data points for Si from the December 2001 survey fall on both conservative mixing lines. Data points from the shoreline samples at Site 2 lie slightly above the line prescribed by the other data points (Figure 12). Such a pattern suggests that the groundwater endmembers (irrigation well No. 4 or the irrigation lake) is close in composition to groundwater downslope from the golf courses. Hence, the use of irrigation water as an endpoint appears to provide a valid representation of the effects of golf course operation on unaltered groundwater that enters the ocean following flow through the golf courses.

The plots of NO_3^- versus salinity show that data points from each transect appear to lie in a distinct grouping. Nearly all of the data points from Site 1with salinities less than 34.5‰ fall well above the conservative mixing line (Figure 12). As NO_3^- is the form of nitrogen most common in fertilizer mixes and sewage effluent, and is the most mobile form of nitrogen, the position of data points above the mixing line suggests that there is an input of NO_3^- to the ocean from activities on land other than natural groundwater input. The only excursion of data points from the mixing line occurs at Site 1, which is located directly downslope from the boundary between the Makena and Wailea Golf Courses. It is possible that the apparent subsidy of NO_3^- is a result of leaching of golf course fertilizers to the groundwater lens. However, it is important to note that in addition to the nearby golf courses, there are numerous houses that are not connected to the County sewage system, and instead rely on septic systems or cesspools. In addition, there are lawns and landscaped areas in the vicinity of Site 1. Thus, it is possible that the subsidy of NO_3^- in nearshore waters may be associated

with leaching of nutrients from sewage disposal systems and fertilization of these residential features, as well from leaching of golf courses fertilizers. The nearly uniform elevation of NO_3^- near the shoreline at Site 1 over the six-year extent of the monitoring program suggests that the subsidy is from a very consistent source.

Data points for NO_3^- from Sites 2, 3 and 4 fall on the conservative mixing lines, indicating that groundwater mixing with ocean water in these areas is lower in magnitude than at Site 1. As Sites 2 and 3 are located directly downslope from the Makena Golf Courses, it appears likely that the subsidy of NO_3^- at Site 1 is not completely derived from fertilizer leaching from the golf courses.

Linear regression of NO_3^- concentrations as a function of salinity for the present survey has a Y-intercept (concentration at a salinity equal to that of well water) of 333 µM at Site 1. Compared to the averaged concentration of NO_3^- measured in six irrigation wells for this survey (133 µM), there appears to be a subsidy to groundwater of about 200 µM. Thus, the concentration of NO_3^- in groundwater entering the ocean at Site 1 is increased by nearly 300% compared to the NO_3^- concentration in groundwater that is not affected by leaching from the various sources on land.

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 since 1989. Correlation coefficients of NO_3^- versus salinity are significant ($p<0.05$) for each monitoring survey, indicating that over the last nine years (1992-2001) there appears to have been a significant increase of NO_3^- in nearshore waters 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 overlap in the makai-mauka direction landward of ocean sampling Site 1, the increased concentrations of NO_3^- may be a result of leaching of fertilizer materials from the combined golf courses to groundwater that enters the ocean in the sampling area. However, as described above, there are other sources of nutrient subsidies such as sewage disposal systems from residences and residential landscaping that may also be the causal factors for the nutrient subsidies.

While there appears to be an increase in the concentration of NO_3^- in groundwater at Site 1, it does not appear that there has been any adverse effect to the biota offshore of this area. Because of the linear relationship of the concentrations of NO_3^- as functions of salinity, there is no indication of uptake of this material in 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 nutrients entering the ocean through groundwater efflux appear to be dispersed solely by

physical mixing processes. As a result, it does not appear that the increased nutrients are causing any 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. Inspection of the region during the monitoring surveys indicates that indeed, there are no areas where excessive algal growth is presently occurring. The averaged concentration of Chl *a* off of Site 1, is not substantially higher than that of the other 3 sites. In past surveys, Chl *a* at Site 1 has not been higher than any of the other sites and often was less. The lack of upward concavity of the line prescribed by the data points of NO_3^- versus salinity in Figure 1 indicate that there is little or no detectable uptake of NO_3^- in nearshore water. Continued monitoring will be necessary to see if this trend continues.

It is also important to note that there is no subsidy of NO_3^- at Site 2 (Makena Landing), which was the area impacted by the flash flood in 1999. While turbidity in this area was affected on a sustained basis (at least for the past year), there is no increase in the form of nitrogen associated with golf course fertilization or any other form of nutrient subsidy.

The other form of dissolved inorganic nitrogen, NH_4^+, does not show a linear pattern of distribution with respect to salinity (Figure 12). Many of the samples with 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^+ appears to be generated by natural biological activity in the ocean waters off Makena. It is also interesting to note that the array of data points for NH_4^+ is completely different than that of NO_3^-. While there is a significant subsidy of NO_3^- at Site 1 above the other three sampling sites, the distribution of NH_4^+ at Site 1 forms a distinct pattern below the predominant data clusters from the other stations. Such a pattern suggests that there are different processes affecting

composition of water at Site 1 relative to the other areas, and that the source of the subsidy of NO_3^- is not coupled with a similar source of NH_4^+. Another point of interest is that the conservative mixing line from irrigation lake 10, composed of well water and treated sewage effluent, has substantially higher NH_4^+ than the water from irrigation well 4 (Figure 12).

PO_4^{3-} is also a major component of fertilizer, and sewage effluent. However, PO_4^{3-} is usually not found to leach to groundwater to the extent of NO_3^-, owing to a high absorptive affinity of phosphorus in soils. Data points for PO_4^{3-} from Site 1 fall well below the mixing lines, while data points from Site 2 fall distinctly above both mixing lines (Figure 12). This is in contrast to NO_3^-, where only data points from Site 1 fell above the mixing line. As with NH_4^+, the lack of consistency between the patterns of NO_3^- and PO_4^{3-} between Sites 1 and 2 suggests that there are different processes affecting the relative subsidies of PO_4^{3-} and NO_3^- at the different survey sites. The elevated NO_3^- at Site 1 is not reflected in similar subsidies of PO_4^{3-}. At Site 2, where there is no apparent subsidy of NO_3^-, but elevated concentrations of PO_4^{3-} that may be associated with the residual suspended sediment loads that originated in the flash flood during December 1999.

Figures 13 and 14 show mixing plots for the same four nutrients at each site over the seven year course of the Makena monitoring program. Also shown are conservative mixing lines from well water collected during the initial sampling event in 1995 and the most recent event in 2001. While there are several obvious deviations from the general patterns during some years (e.g. NO_3^- at site 3 in 1996), the overall trends show relatively little variation. In no case is there a consistent increase in nutrient subsidies with time. At site 1, the increased concentrations of NO_3^- relative to groundwater appear to be consistent since the origination of the monitoring program in 1995.

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 3 million gallons of groundwater input per mile per day (wet). As it is difficult to estimate groundwater and surface water discharge, both wet and dry standards are considered below. 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 nine samples collected to date from each sampling station, 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. Eleven samples collected in the December 2001 survey exceeded the 10% criteria for NO_3^- under dry conditions, while ten samples exceeded the 10% criteria under wet conditions (Table 1). From the preceding discussion of conservative mixing, it is apparent that natural input of groundwater to the nearshore zone can substantially raise the concentrations of NO_3^-. Indeed, no samples from Sites 3 or 4, where groundwater efflux was undetectable, exceeded the DOH criteria for NO_3^-. Thus, it appears that input of natural groundwater can result in ocean water quality measurements that can be interpreted to exceed DOH standards.

In addition, results from the December 2001 survey indicated that twenty-seven measurements of NH_4^+, four measurements of TN and three measurements of TP exceeded the 10% DOH criteria under dry conditions. When compared under wet conditions, nineteen samples of NH_4^+, three measurements of TN and one measurement of TP exceeded the standards. Dry condition standards were exceeded for turbidity twelve times (four under wet conditions) and ten times for Chl *a* (twice under wet conditions).

Tables 3 and 4 show geometric means of samples collected at the same locations during the nine increments of the monitoring program at all four sites. Also shown in these tables are 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^+, TN and Chl *a*, numerous dry and wet standards were exceeded. Only six dry and two wet standard was exceeded for TP. Twenty-one cases of turbidity exceeded the dry standards (4 cases exceed the wet standards).

Site 4 is considered a control transect, in that it is not located offshore of a golf course. However, it can be seen in Tables 3-4 that the number of samples that exceed geometric mean criteria at Site 4 are comparable to Sites 1 and 2, and less than Site 3, all of which are located downslope from the Makena courses. Hence, it appears that the golf courses cannot be attributed as the sole (or even major) factor causing water quality to exceed geometric mean standards.

SUMMARY

- The ninth phase of water chemistry monitoring of the nearshore ocean off the Makena Golf Course was carried out on December 2, 2001. Fifty ocean water samples were collected on three transects spaced along the project ocean frontage and one transect located outside of the project area. Site 1 was located at the northern boundary of the project, Site 2 was located near the central part of the North Golf Course, Site 3 was located near the southern boundary of the project, and Control Site 4 was located to the south of Makena Resort. Transects extended from the shoreline out to the open 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 two irrigation lakes located on the North Course of the Makena Golf Course.

- Water chemistry constituents that occur in high concentration in groundwater (Si, NO_3^- and PO_4^{3-}) displayed distinct horizontal gradients with high concentrations nearest to shore and decreasing concentrations moving seaward. Groundwater input was greatest at Sites 1and 2, and markedly reduced at Sites 3 and 4. As Site 4 was not located in the vicinity of any golf course, it is apparent that groundwater input is not solely dependent on land usage.

- Vertical stratification of the water column was not evident at any survey sites during December 2001. Vertical and horizontal patterns of distribution indicate that physical mixing processes generated by wind, waves and currents were sufficient for complete mixing of the water column within 100 - 200 m of the shoreline.

- Distinctly high concentrations of turbidity were detected in samples collected at Sites 1 and 2 during December 2001. Site 2 is located at the point where sediment laden storm water runoff entered the ocean following a flash flood in October 1999. Normal processes of circulation (tidal exchange, wave mixing) apparently were not sufficient over the year following the storm to flush suspended sediment from the area of Sites 1 and 2. However, during the most recent survey in 2001, turbidity levels had returned to pre-storm levels indicating that most of the storm-bourne sediment had been flushed from the area near Makena Landing.

- Most water chemistry constituents that do not occur in high concentrations in groundwater did not display any recognizable horizontal or vertical trends with the exception of constituents at Site 2, as mentioned above.

- Comparison of the nine surveys conducted to date reveal some differences in the influx of groundwater at each site over the seven-year course of monitoring. However, there does not appear to be any progressive trends of increasing (or decreasing) inputs to the nearshore ocean over time. An apparent seasonal trend was present for temperature at all four sites with cooler temperatures in winter and warmest temperatures in fall.

- Scaling nutrient concentrations to salinity indicates that there was a significant subsidy of NO_3^- to the nearshore ocean at Site 1. The subsidy appears to nearly triple the concentration of NO_3^- in unsubsidized groundwater flowing to the ocean from the project site. The area shoreward of Site 1 includes an overlap of the southern part of the Wailea Gold Course and the northern part of the Makena North Course. In addition, residential development in the region may utilize cesspools or septic systems which may cause leaching of nutrients to groundwater that reaches the shoreline in the area of Site 1. Similar subsidies of NO_3^- were not evident at Sites 2 and 3, off the Makena Courses, or at Site 4, located beyond the influence of the golf course. The significant correlation between concentration of NO_3^- and salinity indicates that the additional NO_3^- is entering the ocean as a component of groundwater that is reaching the ocean at the shoreline. There is no subsidy of PO_4^{3-} corresponding to the subsidy of NO_3^- at Site 1.

- At Sites 2, 3 and 4, concentrations of NH_4^+ in nearshore waters do not appear to be a result of activities on land, but rather from biological activity within the marine environment. At Site 1, however, concentrations of NH_4^+ are substantially lower than at the other stations. Such a pattern indicates that there are not corresponding subsidies to groundwater of NH_4^+ similar to subsidies of NO_3^-.

- Comparing water chemistry parameters to DOH standards revealed that numerous measurements of NO_3^-, a few measurements of NH_4^+, TP and TN, and several measurements of Chl *a* exceeded the DOH "not to exceed more than 10% of the time" criteria for dry and wet conditions of open coastal waters. With the exception of NH_4^+, no samples from Site 3, where groundwater entering the ocean was not detected, exceeded the DOH standards during December 2001. 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 which was far from any golf course influence.

- The next phase of the Makena Golf Course monitoring program is scheduled for summer of 2002.

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TABLE 1. Water chemistry measurements from ocean water samples collected in the vicinity of the Makena Golf Course on December 2, 2001. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit; NS = sample lost. 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.

SITE	NO.	DFS (m)	PO4 (µM)	NO3 (µM)	NH4 (µM)	Si (µM)	TOP (µM)	TON (µM)	TP (µM)	TN (µM)	TURB (NTU)	SALT (‰)	CHL a (µg/L)	TEMP deg.C)	pH
DOH "DRY" 10% STD				**0.71**	**0.36**				**0.96**	**12.86**	**0.50**		**0.50**	*	**
2% STD				**1.43**	**0.64**				**1.45**	**17.86**	**1.00**		**1.00**		
DOH "WET" 10% STD				**1.00**	**0.60**				**1.29**	**17.85**	**1.25**		**0.90**	*	**
2% STD				**1.78**	**1.07**				**1.93**	**25.00**	**2.00**		**1.75**		
MAK-1-	1-S	0	0.20	15.72	0.33	31.38	0.15	7.66	0.35	23.71	1.30	33.456	0.58	25.6	8.21
	2-S	2	0.14	13.55	0.17	28.58	0.14	9.20	0.28	22.92	1.26	33.624	0.44	25.7	8.21
	3-S	5	0.17	8.00	0.17	20.02	0.19	13.09	0.36	21.26	0.78	34.179	0.46	25.5	8.20
	3-D	5	0.21	7.28	0.45	18.15	0.20	10.06	0.41	17.79	0.67	34.262	3.13	25.8	8.19
	4-S	10	0.14	1.73	0.01	8.02	0.21	6.48	0.34	8.21	0.67	34.798	0.53	26.0	8.19
	4-D	10	0.15	1.91	0.32	8.57	0.24	7.29	0.38	9.51	0.61	34.764	0.36	25.8	8.19
	5-S	50	0.13	1.02	0.43	5.60	0.21	6.80	0.34	8.25	0.49	34.930	NS	25.6	8.15
	5-D	50	0.18	0.12	0.32	3.37	0.28	7.09	0.45	7.54	0.31	35.043	0.66	25.6	8.13
	6-S	100	0.08	BDL	0.06	2.44	0.20	6.02	0.28	6.08	0.30	35.097	0.23	25.7	8.15
	6-D	100	0.11	BDL	BDL	3.18	0.20	5.65	0.30	5.65	0.21	35.083	0.23	25.8	8.14
	7-S	125	0.04	BDL	BDL	2.63	0.19	5.17	0.23	5.17	0.18	35.084	0.26	26.0	8.14
	7-D	125	0.11	BDL	BDL	2.44	0.19	5.57	0.30	5.57	0.14	35.088	0.24	25.9	8.14
MAK-2-	1-S	0	0.29	1.29	0.64	11.58	0.99	8.20	1.29	10.13	2.71	34.814	0.58	25.7	8.14
	2-S	2	0.38	1.37	0.81	13.41	1.64	9.55	2.01	11.73	1.72	34.815	0.57	25.4	8.14
	3-S	5	0.24	1.00	0.61	8.35	0.58	6.26	0.81	7.87	0.91	34.898	0.35	25.4	8.14
	3-D	5	0.28	0.85	1.08	9.09	0.78	8.80	1.06	10.74	0.88	34.917	0.40	25.4	8.15
	4-S	10	0.14	0.41	0.61	5.14	0.34	5.59	0.48	6.62	0.47	35.006	0.30	25.3	8.15
	4-D	10	0.23	0.46	0.86	5.14	0.43	6.46	0.65	7.79	0.46	34.995	0.33	25.2	8.15
	5-S	50	0.12	0.32	0.50	3.12	0.29	5.49	0.41	6.31	0.56	35.072	0.31	25.2	8.14
	5-D	50	0.25	0.34	1.32	3.30	0.34	9.07	0.60	10.74	0.45	35.056	0.41	25.5	8.13
	6-S	100	0.08	0.10	0.06	2.47	0.29	9.92	0.36	10.08	0.32	35.095	0.25	25.5	8.15
	6-D	100	0.06	0.12	0.23	2.93	0.29	8.39	0.35	8.74	0.31	35.058	0.24	25.5	8.14
	7-S	150	0.10	0.08	0.28	2.56	0.35	8.64	0.45	9.00	0.26	35.086	0.54	25.5	8.16
	7-D	150	0.09	0.07	0.26	3.48	0.37	9.88	0.46	10.22	0.24	35.079	0.77	25.6	8.15
	8-S	200	0.09	0.11	0.07	2.29	0.25	7.69	0.34	7.87	0.13	35.087	0.29	25.8	8.15
	8-D	200	0.10	0.13	0.07	2.38	0.25	8.27	0.35	8.48	0.12	35.070	0.29	25.8	8.15
MAK-3-	1-S	0	0.20	0.44	1.17	3.23	0.41	8.60	0.61	10.22	0.29	35.090	0.44	25.2	8.16
	2-S	2	0.18	0.46	0.82	3.23	0.28	6.02	0.46	7.31	0.27	35.082	0.37	25.2	8.16
	3-S	5	0.16	0.40	1.17	3.13	0.26	6.91	0.42	8.48	0.21	35.079	0.26	25.2	8.16
	3-D	5	0.11	0.43	1.27	3.22	0.26	6.39	0.37	8.09	0.28	35.080	0.23	25.3	8.15
	4-S	10	0.19	0.40	1.26	3.13	0.27	6.12	0.46	7.79	0.24	35.078	0.23	25.0	8.16
	4-D	10	0.18	0.41	0.86	3.13	0.27	6.52	0.44	7.79	0.25	35.082	0.23	25.3	8.16
	5-S	50	0.16	0.33	1.26	2.67	0.25	5.93	0.41	7.53	0.13	35.090	0.24	25.4	8.14
	5-D	50	0.20	0.22	1.35	2.39	0.26	5.52	0.46	7.09	0.15	35.085	0.25	25.3	8.15
	6-S	100	0.11	0.19	0.58	2.39	0.27	5.41	0.39	6.18	0.14	35.092	0.24	25.5	8.15
	6-D	100	0.11	0.19	0.32	2.48	0.26	5.89	0.36	6.40	0.13	35.075	0.23	25.5	8.15
	7-S	150	0.03	0.24	0.37	2.39	0.22	5.09	0.25	5.70	0.14	35.085	0.22	25.5	8.14
	7-D	150	0.08	0.17	0.38	2.48	0.25	4.98	0.33	5.53	0.12	35.080	0.25	25.2	8.15
MAK-4-	1-S	0	0.11	0.47	0.75	5.66	0.24	6.71	0.34	7.93	0.78	35.043	0.91	25.2	8.07
	2-S	2	0.11	0.38	0.93	5.11	0.26	6.58	0.36	7.89	0.53	35.030	0.46	25.1	8.06
	3-S	5	0.11	0.25	0.15	3.55	0.20	5.95	0.31	6.36	0.41	35.062	0.21	25.1	8.05
	3-D	5	0.11	0.33	0.32	3.55	0.21	6.14	0.33	6.79	0.52	35.059	0.39	25.3	8.05
	4-S	10	0.12	0.30	0.33	3.92	0.21	6.12	0.33	6.75	0.51	35.062	0.24	25.1	8.04
	4-D	10	0.11	0.28	0.44	3.28	0.21	5.72	0.32	6.44	0.54	35.071	0.26	25.3	8.06
	5-S	50	0.08	0.18	0.32	3.10	0.24	7.55	0.32	8.05	0.34	35.089	0.22	25.3	8.12
	5-D	50	0.07	0.11	0.24	3.10	0.33	8.02	0.39	8.37	0.47	35.118	0.27	25.4	8.13
	6-S	100	0.10	0.13	0.19	2.55	0.22	5.29	0.32	5.61	0.29	35.096	0.67	25.3	8.15
	6-D	100	0.21	0.38	0.77	3.42	0.32	5.94	0.53	7.09	0.31	35.104	0.27	25.3	8.14
	7-S	150	0.21	0.37	1.21	2.86	0.27	5.91	0.48	7.48	0.23	35.100	0.28	25.4	8.15
	7-D	150	0.13	0.19	0.55	2.40	0.24	5.05	0.37	5.79	0.15	35.092	0.27	25.4	8.15

* Shall vary no more that 1 °C from "ambient conditions"

** Shall not deviate more than 0.5 units from a value of 8.1

TABLE 2. Water chemistry measurements from ocean water samples (in µg/L) collected in the vicinity of the Makena Golf Course on December 2, 2001. Abbreviations as follows: DFS=distance from shore;S=surface; D=deep; BDL=below detection limit; NS = sample lost. 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.

SITE	NO.	DFS (m)	PO4 (µg/L)	NO3 (µg/L)	NH4 (µg/L)	Si (µg/L)	TOP (µg/L)	TON (µg/L)	TP (µg/L)	TN (µg/L)	TURB (NTU)	SALT (‰)	CHL a (µg/L)	TEMP (deg.C)	pH
DOH "DRY" 10% STD				**10.00**	**5.00**				**30.00**	**180.0**	**0.50**		**0.50**	*	**
2% STD				**20.00**	**9.00**				**45.00**	**250.0**	**1.00**		**1.00**		
DOH "WET" 10% STD				**14.00**	**8.50**				**40.00**	**250.00**	**1.25**		**0.90**	*	**
2% STD				**25.00**	**15.00**				**60.00**	**350.00**	**2.00**		**1.75**		
MAK-1-	1-S	0	6.31	220.08	4.62	881.8	4.67	107.23	10.98	331.94	1.30	33.456	0.58	25.6	8.21
	2-S	2	4.32	189.73	2.37	803.1	4.31	128.79	8.63	320.89	1.26	33.624	0.44	25.7	8.21
	3-S	5	5.30	111.99	2.44	562.5	5.77	183.27	11.08	297.70	0.78	34.179	0.46	25.5	8.20
	3-D	5	6.51	101.91	6.34	510.1	6.20	140.86	12.71	249.11	0.67	34.262	3.13	25.8	8.19
	4-S	10	4.30	24.17	0.11	225.3	6.38	90.66	10.68	114.94	0.67	34.798	0.53	26.0	8.19
	4-D	10	4.51	26.70	4.46	240.9	7.33	102.00	11.84	133.16	0.61	34.764	0.36	25.8	8.19
	5-S	50	4.18	14.27	6.04	157.3	6.49	95.18	10.67	115.49	0.49	34.930	NS	25.6	8.15
	5-D	50	5.50	1.72	4.53	94.7	8.55	99.30	14.05	105.55	0.31	35.043	0.66	25.6	8.13
	6-S	100	2.62	BDL	0.78	68.6	6.16	84.34	8.78	85.12	0.30	35.097	0.23	25.7	8.15
	6-D	100	3.28	BDL	BDL	89.5	6.08	79.05	9.36	79.05	0.21	35.083	0.23	25.8	8.14
	7-S	125	1.29	BDL	BDL	73.9	5.96	72.42	7.25	72.42	0.18	35.084	0.26	26.0	8.14
	7-D	125	3.27	BDL	BDL	68.7	5.96	77.94	9.23	77.94	0.14	35.088	0.24	25.9	8.14
MAK-2-	1-S	0	9.14	18.09	8.93	325.3	30.79	114.78	39.93	141.80	2.71	34.814	0.58	25.7	8.14
	2-S	2	11.71	19.16	11.40	376.8	50.73	133.70	62.45	164.26	1.72	34.815	0.57	25.4	8.14
	3-S	5	7.33	14.03	8.59	234.8	17.86	87.61	25.19	110.22	0.91	34.898	0.35	25.4	8.14
	3-D	5	8.68	11.96	15.15	255.3	24.25	123.19	32.93	150.30	0.88	34.917	0.40	25.4	8.15
	4-S	10	4.19	5.77	8.53	144.4	10.65	78.32	14.84	92.62	0.47	35.006	0.30	25.3	8.15
	4-D	10	6.99	6.46	12.06	144.3	13.21	90.50	20.20	109.01	0.46	34.995	0.33	25.2	8.15
	5-S	50	3.73	4.52	6.99	87.6	8.97	76.86	12.70	88.36	0.56	35.072	0.31	25.2	8.14
	5-D	50	7.88	4.77	18.55	92.7	10.66	126.98	18.54	150.30	0.45	35.056	0.41	25.5	8.13
	6-S	100	2.38	1.40	0.87	69.5	8.90	138.92	11.28	141.19	0.32	35.095	0.25	25.5	8.15
	6-D	100	1.93	1.65	3.20	82.4	8.88	117.51	10.81	122.37	0.31	35.058	0.24	25.5	8.14
	7-S	150	3.05	1.09	3.91	72.1	10.98	121.01	14.03	126.01	0.26	35.086	0.54	25.5	8.16
	7-D	150	2.93	0.97	3.70	97.8	11.33	138.34	14.27	143.01	0.24	35.079	0.77	25.6	8.15
	8-S	200	2.82	1.54	1.03	64.3	7.64	107.65	10.46	110.22	0.13	35.087	0.29	25.8	8.15
	8-D	200	3.04	1.86	1.04	66.8	7.78	115.83	10.82	118.72	0.12	35.070	0.29	25.8	8.15
MAK-3-	1-S	0	6.14	6.19	16.41	90.7	12.68	120.41	18.82	143.01	0.29	35.090	0.44	25.2	8.16
	2-S	2	5.57	6.45	11.55	90.7	8.61	84.33	14.18	102.33	0.27	35.082	0.37	25.2	8.16
	3-S	5	5.01	5.64	16.42	88.1	7.98	96.67	12.99	118.72	0.21	35.079	0.26	25.2	8.16
	3-D	5	3.44	6.02	17.83	90.6	8.01	89.41	11.45	113.26	0.28	35.080	0.23	25.3	8.15
	4-S	10	5.90	5.65	17.70	88.0	8.29	85.67	14.19	109.01	0.24	35.078	0.23	25.0	8.16
	4-D	10	5.45	5.72	12.07	87.9	8.26	91.27	13.71	109.06	0.25	35.082	0.23	25.3	8.16
	5-S	50	5.00	4.59	17.71	75.0	7.65	83.07	12.65	105.37	0.13	35.090	0.24	25.4	8.14
	5-D	50	6.12	3.10	18.91	67.2	8.08	77.30	14.20	99.29	0.15	35.085	0.25	25.3	8.15
	6-S	100	3.42	2.66	8.14	67.2	8.52	75.75	11.94	86.54	0.14	35.092	0.24	25.5	8.15
	6-D	100	3.31	2.67	4.48	69.8	7.92	82.44	11.23	89.58	0.13	35.075	0.23	25.5	8.15
	7-S	150	0.95	3.42	5.12	67.2	6.95	71.33	7.90	79.86	0.14	35.085	0.22	25.5	8.14
	7-D	150	2.40	2.36	5.33	69.7	7.88	69.74	10.28	77.44	0.12	35.080	0.25	25.2	8.15
MAK-4-	1-S	0	3.27	6.64	10.54	159.1	7.41	93.90	10.69	111.07	0.78	35.043	0.91	25.2	8.07
	2-S	2	3.27	5.36	13.01	143.6	8.00	92.15	11.26	110.52	0.53	35.030	0.46	25.1	8.06
	3-S	5	3.37	3.52	2.12	99.9	6.13	83.35	9.50	88.99	0.41	35.062	0.21	25.1	8.05
	3-D	5	3.48	4.59	4.52	99.9	6.60	85.95	10.08	95.06	0.52	35.059	0.39	25.3	8.05
	4-S	10	3.80	4.26	4.60	110.2	6.39	85.65	10.19	94.51	0.51	35.062	0.24	25.1	8.04
	4-D	10	3.47	3.87	6.17	92.2	6.48	80.05	9.95	90.09	0.54	35.071	0.26	25.3	8.06
	5-S	50	2.47	2.47	4.52	87.1	7.36	105.74	9.83	112.73	0.34	35.089	0.22	25.3	8.12
	5-D	50	2.02	1.58	3.31	87.1	10.14	112.25	12.16	117.15	0.47	35.118	0.27	25.4	8.13
	6-S	100	3.12	1.76	2.64	71.7	6.93	74.10	10.05	78.50	0.29	35.096	0.67	25.3	8.15
	6-D	100	6.48	5.37	10.76	96.0	9.83	83.17	16.31	99.29	0.31	35.104	0.27	25.3	8.14
	7-S	150	6.48	5.12	16.89	80.4	8.41	82.75	14.89	104.76	0.23	35.100	0.28	25.4	8.15
	7-D	150	4.01	2.68	7.74	67.4	7.55	70.66	11.56	81.08	0.15	35.092	0.27	25.4	8.15

* Shall vary no more that 1 °C from "ambient conditions"

** Shall not deviate more than 0.5 units from a value of 8.1

TABLE 3. Geometric mean data from water chemistry measurements (in µM) off the Makena Golf Course collected since August 1995 (N=9). 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.

SITE	NO.	DFS (m)	PO4 (µM)	NO3 (µM)	NH4 (µM)	Si (µM)	TOP (µM)	TON (µM)	TP (µM)	TN (µM)	TURB (NTU)	SALT (‰)	CHL a (µg/L)	TEMP (deg.C)	pH
DOH GM "DRY" STD				**0.25**	**0.14**				**0.52**	**7.86**	**0.20**		**0.15**	*	**
DOH GM "WET" STD				**0.36**	**0.25**				**0.64**	**10.71**	**0.50**		**0.30**		
MAK-1-	1-S	0	0.22	29.40	0.22	54.83	0.24	8.54	0.48	40.87	0.33	30.809	0.72	25.2	8.14
	2-S	2	0.17	20.00	0.23	38.72	0.25	8.04	0.43	29.39	0.28	32.226	0.68	25.3	8.15
	3-S	5	0.14	8.19	0.14	19.21	0.25	7.83	0.41	19.22	0.24	33.220	0.61	25.3	8.15
	3-D	5	0.14	6.83	0.27	16.97	0.25	7.15	0.41	17.27	0.23	33.420	0.75	25.3	8.14
	4-S	10	0.11	2.56	0.12	8.15	0.25	7.09	0.37	10.70	0.21	34.314	0.40	25.4	8.13
	4-D	10	0.11	2.24	0.17	7.43	0.26	6.80	0.37	9.89	0.22	34.388	0.45	25.4	8.13
	5-S	50	0.11	1.67	0.14	5.62	0.25	6.71	0.37	8.93	0.17	34.562	0.29	25.6	8.13
	5-D	50	0.11	0.27	0.12	2.75	0.27	7.40	0.38	7.90	0.13	34.795	0.32	25.5	8.14
	6-S	100	0.10	0.58	0.13	4.52	0.27	6.92	0.38	8.89	0.14	34.590	0.29	25.5	8.12
	6-D	100	0.09	0.08	0.09	2.32	0.26	7.08	0.37	7.36	0.11	34.810	0.23	25.5	8.15
	7-S	125	0.09	0.26	0.10	3.37	0.25	6.50	0.36	7.51	0.13	34.695	0.21	25.7	8.14
	7-D	125	0.10	0.04	0.12	1.91	0.26	6.77	0.37	7.01	0.10	34.823	0.19	25.6	8.15
MAK-2-	1-S	0	0.23	3.49	0.40	21.28	0.35	8.50	0.64	12.95	1.08	33.984	0.69	25.4	8.13
	2-S	2	0.23	3.34	0.31	18.58	0.37	8.60	0.66	12.73	0.81	33.925	0.77	25.4	8.13
	3-S	5	0.21	2.97	0.33	15.00	0.31	7.74	0.55	11.40	0.58	34.060	0.60	25.4	8.13
	3-D	5	0.22	2.83	0.48	15.56	0.33	8.47	0.58	12.25	0.59	34.081	0.85	25.4	8.13
	4-S	10	0.17	1.71	0.26	10.50	0.29	7.31	0.48	9.58	0.41	34.349	0.43	25.3	8.14
	4-D	10	0.17	1.28	0.36	8.74	0.31	7.48	0.50	9.50	0.32	34.481	0.53	25.4	8.14
	5-S	50	0.14	1.10	0.26	7.70	0.29	7.30	0.46	9.09	0.36	34.503	0.38	25.4	8.13
	5-D	50	0.13	0.27	0.26	3.76	0.30	8.90	0.45	9.69	0.26	34.766	0.47	25.5	8.13
	6-S	100	0.12	0.52	0.23	4.88	0.28	7.94	0.41	9.11	0.20	34.634	0.32	25.6	8.13
	6-D	100	0.10	0.17	0.22	2.92	0.27	7.38	0.39	7.89	0.15	34.784	0.35	25.5	8.14
	7-S	150	0.11	0.27	0.27	3.86	0.28	7.75	0.41	8.46	0.16	34.728	0.33	25.6	8.14
	7-D	150	0.09	0.10	0.25	2.59	0.30	8.23	0.41	8.70	0.14	34.806	0.31	25.5	8.15
	8-S	200	0.11	0.19	0.26	2.87	0.29	7.40	0.40	8.20	0.13	34.838	0.27	25.7	8.15
	8-D	200	0.10	0.06	0.22	1.99	0.30	7.85	0.41	8.23	0.11	34.875	0.32	25.7	8.16
MAK-3-	1-S	0	0.11	0.34	0.25	3.03	0.29	7.23	0.42	8.60	0.30	34.766	0.34	25.3	8.16
	2-S	2	0.11	0.29	0.28	2.81	0.29	7.06	0.42	8.07	0.26	34.810	0.29	25.3	8.16
	3-S	5	0.11	0.26	0.28	2.95	0.27	6.80	0.39	8.03	0.20	34.778	0.22	25.3	8.16
	3-D	5	0.11	0.24	0.26	3.09	0.27	7.10	0.39	8.42	0.22	34.770	0.24	25.4	8.16
	4-S	10	0.10	0.18	0.28	2.41	0.28	7.42	0.40	8.07	0.17	34.828	0.20	25.3	8.16
	4-D	10	0.11	0.15	0.28	2.39	0.28	7.30	0.40	7.87	0.18	34.826	0.20	25.3	8.16
	5-S	50	0.09	0.11	0.27	2.14	0.28	6.89	0.38	7.43	0.14	34.840	0.21	25.4	8.15
	5-D	50	0.10	0.10	0.34	2.19	0.28	7.06	0.39	7.67	0.16	34.837	0.21	25.4	8.15
	6-S	100	0.08	0.07	0.24	2.08	0.28	7.03	0.37	7.44	0.13	34.825	0.16	25.4	8.15
	6-D	100	0.08	0.05	0.23	2.04	0.28	6.83	0.37	7.21	0.13	34.847	0.18	25.3	8.16
	7-S	150	0.07	0.05	0.25	1.93	0.27	6.71	0.35	7.11	0.10	34.847	0.18	25.5	8.15
	7-D	150	0.09	0.03	0.22	1.92	0.29	6.82	0.39	7.17	0.10	34.836	0.20	25.4	8.16
MAK-4-	1-S	0	0.37	7.75	0.33	66.02	0.22	6.36	0.66	18.67	0.41	30.063	0.69	24.9	8.03
	2-S	2	0.32	5.83	0.28	50.41	0.25	6.81	0.60	15.93	0.37	31.742	0.71	25.0	8.02
	3-S	5	0.15	1.01	0.18	11.87	0.25	7.12	0.42	9.09	0.22	34.162	0.35	25.0	8.05
	3-D	5	0.15	0.84	0.22	10.89	0.24	6.87	0.41	8.57	0.20	34.238	0.40	25.0	8.06
	4-S	10	0.14	0.73	0.23	9.44	0.25	7.01	0.40	8.34	0.22	34.373	0.28	25.0	8.06
	4-D	10	0.13	0.48	0.25	7.83	0.24	7.32	0.39	8.59	0.20	34.428	0.28	25.0	8.06
	5-S	50	0.11	0.36	0.21	5.67	0.27	7.98	0.39	8.85	0.16	34.618	0.25	25.1	8.09
	5-D	50	0.10	0.22	0.17	3.95	0.29	8.13	0.40	8.60	0.16	34.772	0.26	25.2	8.10
	6-S	100	0.10	0.19	0.17	4.11	0.27	7.52	0.39	8.00	0.13	34.761	0.21	25.2	8.11
	6-D	100	0.11	0.16	0.18	2.92	0.28	7.82	0.40	8.32	0.11	34.795	0.21	25.3	8.12
	7-S	150	0.09	0.08	0.11	2.24	0.29	7.39	0.39	7.79	0.10	34.834	0.16	25.3	8.13
	7-D	150	0.09	0.10	0.15	2.18	0.28	7.34	0.38	7.72	0.10	34.843	0.16	25.3	8.14

* Shall vary no more that 1 °C from "ambient conditions"

** Shall not deviate more than 0.5 units from a value of 8.1

TABLE 4. Geometric mean data (in µg/L) from water chemistry measurements (in µM) off the Makena Golf Course collected since August 1995 (N=9). 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.

SITE	NO.	DFS (m)	PO4 (µg/L)	NO3 (µg/L)	NH4 (µg/L)	Si (µg/L)	TOP (µg/L)	TON (µg/L)	TP (µg/L)	TN (µg/L)	TURB (NTU)	SALT (‰)	CHL a (µg/L)	TEMP (deg.C)	pH
DOH GM "DRY" STD				**3.50**	**2.00**				**16.00**	**110.0**	**0.20**		**0.15**	*	**
DOH GM "WET" STD				**5.00**	**3.50**				**20.00**	**150.00**	**0.50**		**0.30**		
MAK-1-	1-S	0	6.80	411.70	3.00	1540.2	7.40	119.60	14.80	572.40	0.33	30.809	0.72	25.2	8.14
	2-S	2	5.20	280.10	3.20	1087.6	7.70	112.60	13.30	411.60	0.28	32.226	0.68	25.3	8.15
	3-S	5	4.30	114.70	1.90	539.6	7.70	109.60	12.60	269.10	0.24	33.220	0.61	25.3	8.15
	3-D	5	4.30	95.60	3.70	476.7	7.70	100.10	12.60	241.80	0.23	33.420	0.75	25.3	8.14
	4-S	10	3.40	35.80	1.60	228.9	7.70	99.30	11.40	149.80	0.21	34.314	0.40	25.4	8.13
	4-D	10	3.40	31.30	2.30	208.7	8.00	95.20	11.40	138.50	0.22	34.388	0.45	25.4	8.13
	5-S	50	3.40	23.30	1.90	157.9	7.70	93.90	11.40	125.00	0.17	34.562	0.29	25.6	8.13
	5-D	50	3.40	3.70	1.60	77.2	8.30	103.60	11.70	110.60	0.13	34.795	0.32	25.5	8.14
	6-S	100	3.00	8.10	1.80	127.0	8.30	96.90	11.70	124.50	0.14	34.590	0.29	25.5	8.12
	6-D	100	2.70	1.10	1.20	65.2	8.00	99.10	11.40	103.00	0.11	34.810	0.23	25.5	8.15
	7-S	125	2.70	3.60	1.40	94.7	7.70	91.00	11.10	105.10	0.13	34.695	0.21	25.7	8.14
	7-D	125	3.00	0.50	1.60	53.7	8.00	94.80	11.40	98.10	0.10	34.823	0.19	25.6	8.15
MAK-2-	1-S	0	7.10	48.80	5.60	597.8	10.80	119.00	19.80	181.30	1.08	33.984	0.69	25.4	8.13
	2-S	2	7.10	46.70	4.30	521.9	11.40	120.40	20.40	178.20	0.81	33.925	0.77	25.4	8.13
	3-S	5	6.50	41.50	4.60	421.4	9.60	108.40	17.00	159.60	0.58	34.060	0.60	25.4	8.13
	3-D	5	6.80	39.60	6.70	437.1	10.20	118.60	17.90	171.50	0.59	34.081	0.85	25.4	8.13
	4-S	10	5.20	23.90	3.60	294.9	8.90	102.30	14.80	134.10	0.41	34.349	0.43	25.3	8.14
	4-D	10	5.20	17.90	5.00	245.5	9.60	104.70	15.40	133.00	0.32	34.481	0.53	25.4	8.14
	5-S	50	4.30	15.40	3.60	216.3	8.90	102.20	14.20	127.30	0.36	34.503	0.38	25.4	8.13
	5-D	50	4.00	3.70	3.60	105.6	9.20	124.60	13.90	135.70	0.26	34.766	0.47	25.5	8.13
	6-S	100	3.70	7.20	3.20	137.1	8.60	111.20	12.60	127.50	0.20	34.634	0.32	25.6	8.13
	6-D	100	3.00	2.30	3.00	82.0	8.30	103.30	12.00	110.50	0.15	34.784	0.35	25.5	8.14
	7-S	150	3.40	3.70	3.70	108.4	8.60	108.50	12.60	118.40	0.16	34.728	0.33	25.6	8.14
	7-D	150	2.70	1.40	3.50	72.8	9.20	115.20	12.60	121.80	0.14	34.806	0.31	25.5	8.15
	8-S	200	3.40	2.60	3.60	80.6	8.90	103.60	12.30	114.80	0.13	34.838	0.27	25.7	8.15
	8-D	200	3.00	0.80	3.00	55.9	9.20	109.90	12.60	115.20	0.11	34.875	0.32	25.7	8.16
MAK-3-	1-S	0	3.40	4.70	3.50	85.1	8.90	101.20	13.00	120.40	0.30	34.766	0.34	25.3	8.16
	2-S	2	3.40	4.00	3.90	78.9	8.90	98.80	13.00	113.00	0.26	34.810	0.29	25.3	8.16
	3-S	5	3.40	3.60	3.90	82.9	8.30	95.20	12.00	112.40	0.20	34.778	0.22	25.3	8.16
	3-D	5	3.40	3.30	3.60	86.8	8.30	99.40	12.00	117.90	0.22	34.770	0.24	25.4	8.16
	4-S	10	3.00	2.50	3.90	67.7	8.60	103.90	12.30	113.00	0.17	34.828	0.20	25.3	8.16
	4-D	10	3.40	2.10	3.90	67.1	8.60	102.20	12.30	110.20	0.18	34.826	0.20	25.3	8.16
	5-S	50	2.70	1.50	3.70	60.1	8.60	96.50	11.70	104.00	0.14	34.840	0.21	25.4	8.15
	5-D	50	3.00	1.40	4.70	61.5	8.60	98.80	12.00	107.40	0.16	34.837	0.21	25.4	8.15
	6-S	100	2.40	0.90	3.30	58.4	8.60	98.40	11.40	104.20	0.13	34.825	0.16	25.4	8.15
	6-D	100	2.40	0.70	3.20	57.3	8.60	95.60	11.40	100.90	0.13	34.847	0.18	25.3	8.16
	7-S	150	2.10	0.70	3.50	54.2	8.30	93.90	10.80	99.50	0.10	34.847	0.18	25.5	8.15
	7-D	150	2.70	0.40	3.00	53.9	8.90	95.50	12.00	100.40	0.10	34.836	0.20	25.4	8.16
MAK-4-	1-S	0	11.40	108.50	4.60	1854.5	6.80	89.00	20.40	261.40	0.41	30.063	0.69	24.9	8.03
	2-S	2	9.90	81.60	3.90	1416.0	7.70	95.30	18.50	223.10	0.37	31.742	0.71	25.0	8.02
	3-S	5	4.60	14.10	2.50	333.4	7.70	99.70	13.00	127.30	0.22	34.162	0.35	25.0	8.05
	3-D	5	4.60	11.70	3.00	305.9	7.40	96.20	12.60	120.00	0.20	34.238	0.40	25.0	8.06
	4-S	10	4.30	10.20	3.20	265.2	7.70	98.10	12.30	116.80	0.22	34.373	0.28	25.0	8.06
	4-D	10	4.00	6.70	3.50	219.9	7.40	102.50	12.00	120.30	0.20	34.428	0.28	25.0	8.06
	5-S	50	3.40	5.00	2.90	159.3	8.30	111.70	12.00	123.90	0.16	34.618	0.25	25.1	8.09
	5-D	50	3.00	3.00	2.30	111.0	8.90	113.80	12.30	120.40	0.16	34.772	0.26	25.2	8.10
	6-S	100	3.00	2.60	2.30	115.4	8.30	105.30	12.00	112.00	0.13	34.761	0.21	25.2	8.11
	6-D	100	3.40	2.20	2.50	82.0	8.60	109.50	12.30	116.50	0.11	34.795	0.21	25.3	8.12
	7-S	150	2.70	1.10	1.50	62.9	8.90	103.50	12.00	109.10	0.10	34.834	0.16	25.3	8.13
	7-D	150	2.70	1.40	2.10	61.2	8.60	102.80	11.70	108.10	0.10	34.843	0.16	25.3	8.14

* Shall vary no more that 1 °C from "ambient conditions"

** Shall not deviate more than 0.5 units from a value of 8.1

TABLE 5. Water chemistry measurements in µM and µg/L (shaded) from irrigation wells and two irrigation lakes collected in the vicinity of the Makena Golf Course in December 2001. BDL=below detection limit; NS = sample lost. For sampling site locations, see Figure 1.

WELL	PO4 (µM)	PO4 (µg/L)	NO3 (µM)	NO3 (µg/L)	NH4 (µM)	NH4 (µg/L)	Si (µM)	Si (µg/L)	TOP (µM)	TOP (µg/L)	TON (µM)	TON (µg/L)	TP (µM)	TP (µg/L)	TN (µM)	TN (µg/L)	SALINITY (ppt)
1	2.19	67.91	125.53	1757.48	BDL	BDL	527.32	14818	1.12	34.61	73.04	1022.54	3.31	102.52	198.57	2780.02	NS
2	2.45	75.95	147.08	2059.14	BDL	BDL	713.17	20040	1.27	39.35	74.84	1047.77	3.72	115.30	221.92	3106.91	1.461
3	2.86	88.80	138.78	1942.92	BDL	BDL	727.71	20449	1.36	42.22	79.27	1109.77	4.23	131.02	218.05	3052.69	1.466
4	2.24	69.58	116.55	1631.69	BDL	BDL	678.26	19059	1.63	50.66	77.04	1078.57	3.88	120.24	193.59	2710.20	1.655
6	2.27	70.31	150.43	2106.08	BDL	BDL	567.93	15959	1.50	46.51	57.43	803.97	3.77	116.82	207.86	2910.05	1.153
10	2.81	87.23	119.05	1666.70	0.22	3.10	662.96	18629	1.37	42.36	72.85	1019.91	4.18	129.59	192.12	2689.71	1.649
IL 10	18.25	565.79	50.19	702.72	25.11	351.52	672.56	18899	10.76	333.44	188.33	2636.62	29.01	899.24	263.63	3690.86	1.393
IL-B	0.16	5.01	11.60	162.43	2.59	36.26	217	6104	2.47	76.51	100.04	1400.49	2.63	81.52	114.23	1,599	1.664

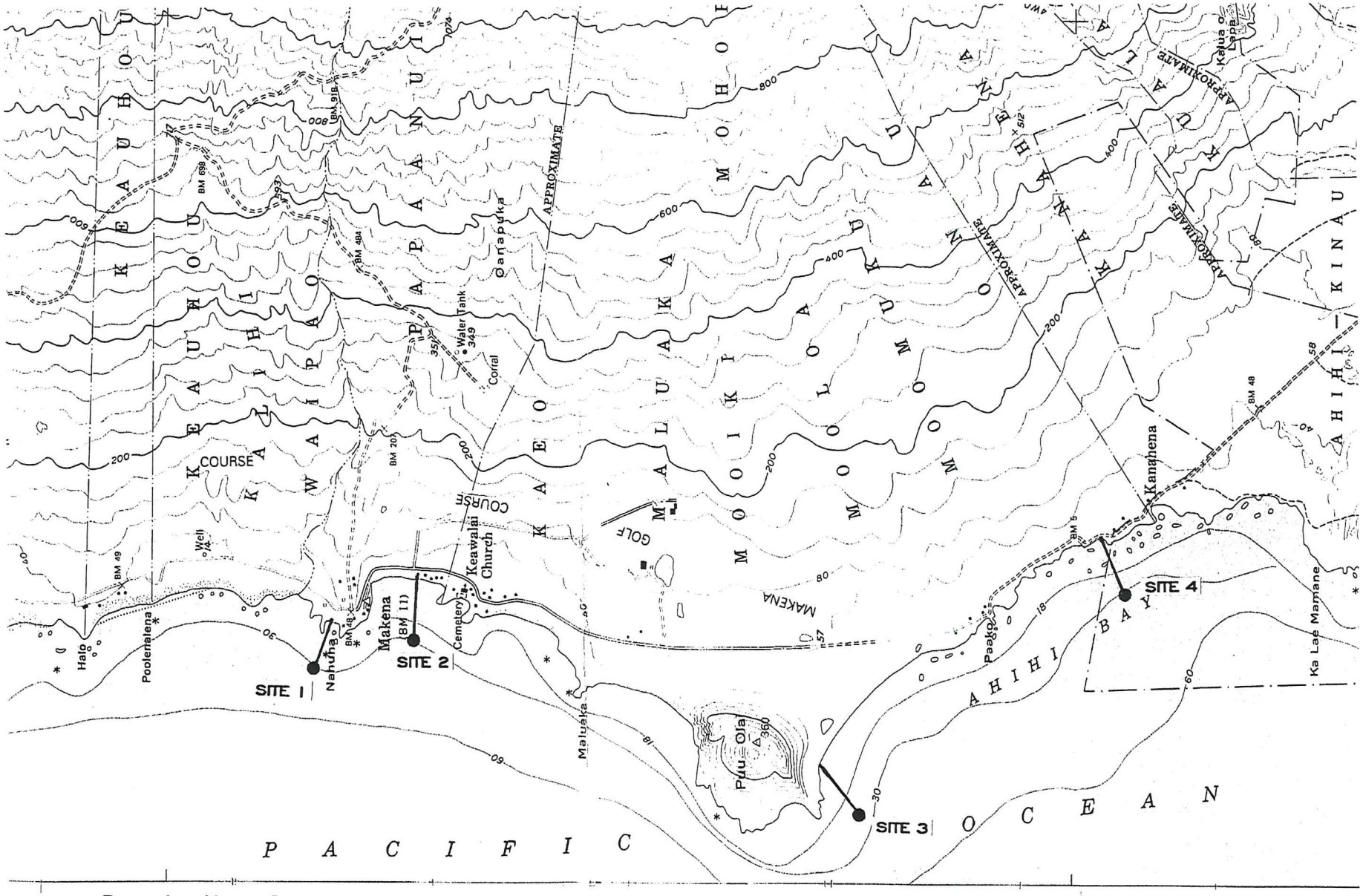

FIGURE 1. MAP OF SOUTHWEST SCHORELINE OF MAUI SHOWING LOCATIONS OF FOUR WATER SAMPLING TRANSECTS SITES. SITES 1-3 LIE OFF THE NORTH AND SOUTH MAKENA GOLF COURSES. SITE 4 IS A CONTROL TRANSECT OFF THE AHIHI-KINAU NATURAL RESERVE AREA.

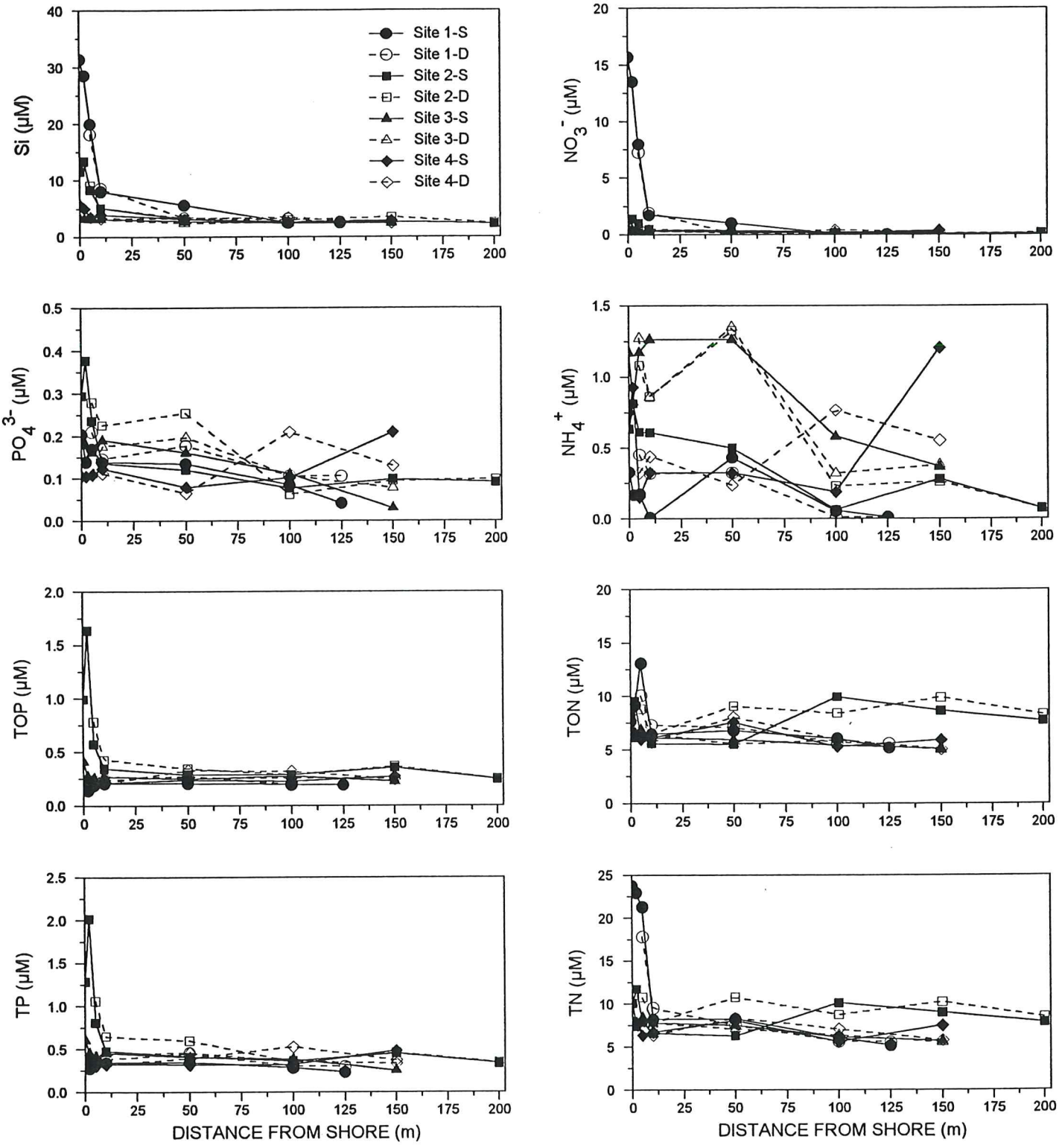

FIGURE 2. Plots of dissolved nutrients in surface (S) and deep (D) samples collected on December 2, 2001 as a function of distance from the shoreline in the vicinity of Makena Golf Course. For site locations, see Figure 1.

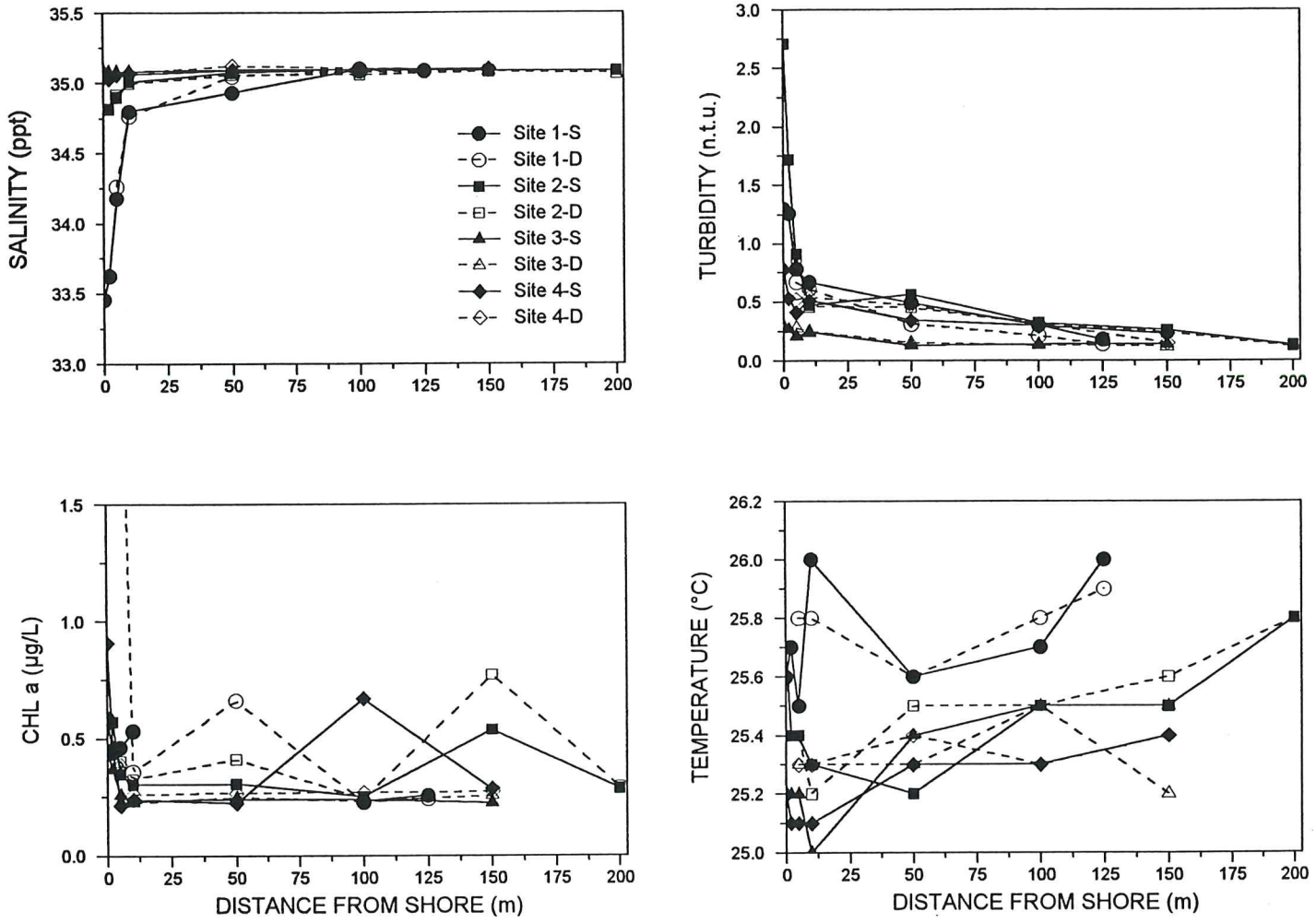

FIGURE 3. Plots of water chemistry constituents in surface (S) and deep (D) samples collected on December 2, 2001 as a function of distance from the shoreline in the vicinity of Makena Golf Course. For site locations, see Figure 1.

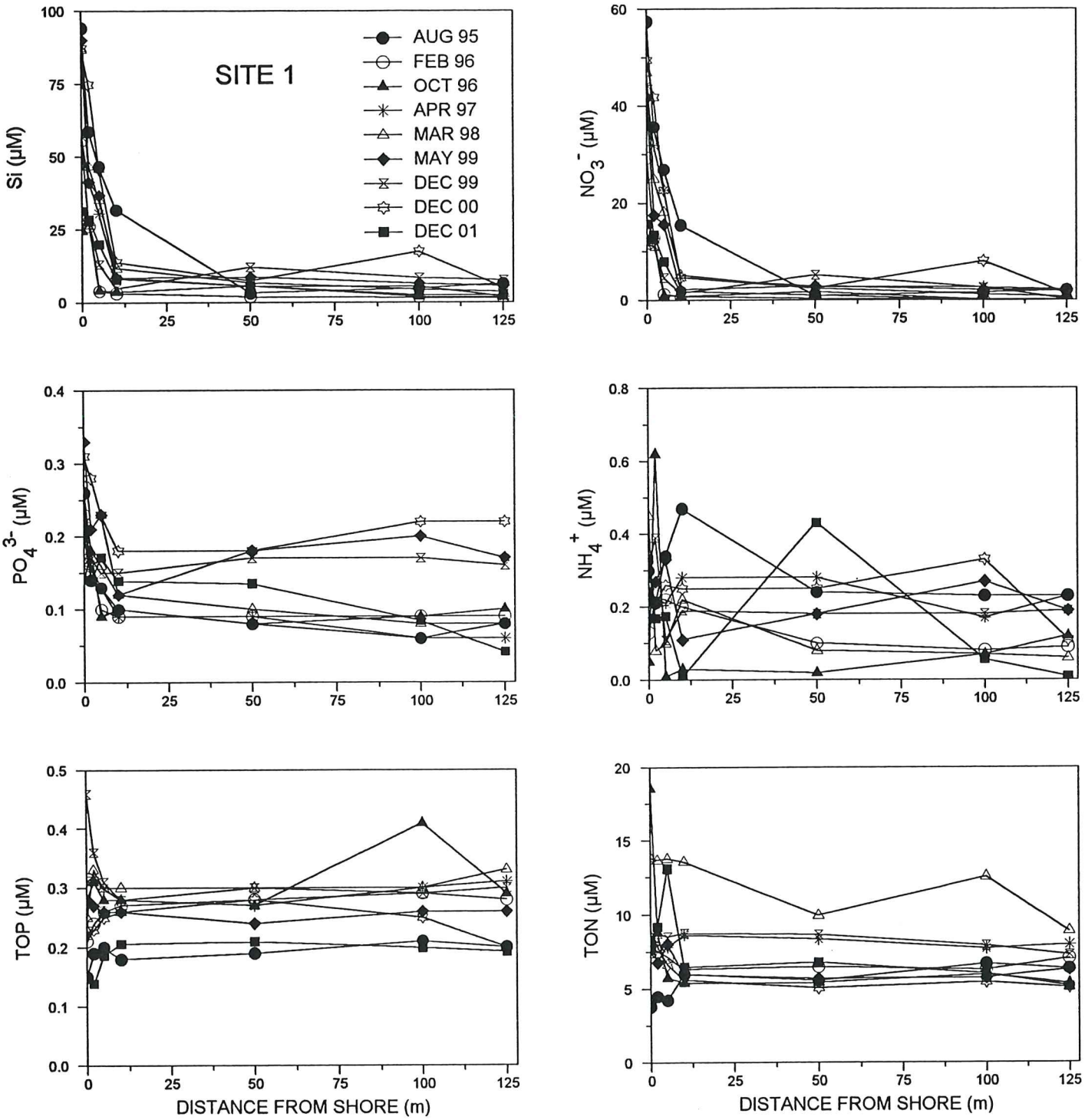

FIGURE 4. Plots of dissolved nutrient constituents in surface water samples as a function of distance from the shoreline at Site 1 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. For location of Site 1, see Figure 1.

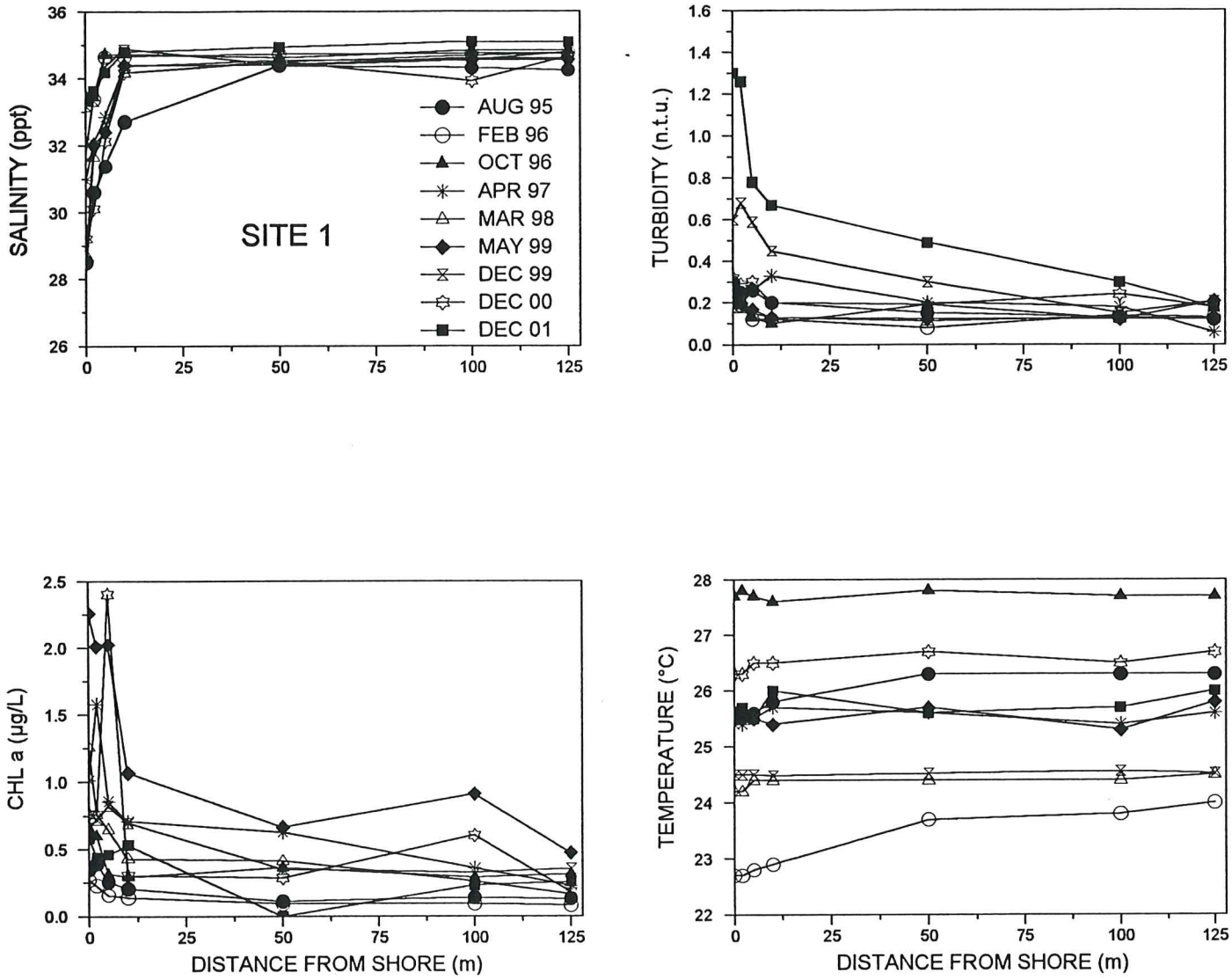

FIGURE 5. Plots of water chemistry constituents in surface water samples as a function of distance from the shoreline at Site 1 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. For location of Site 1, see Figure 1.

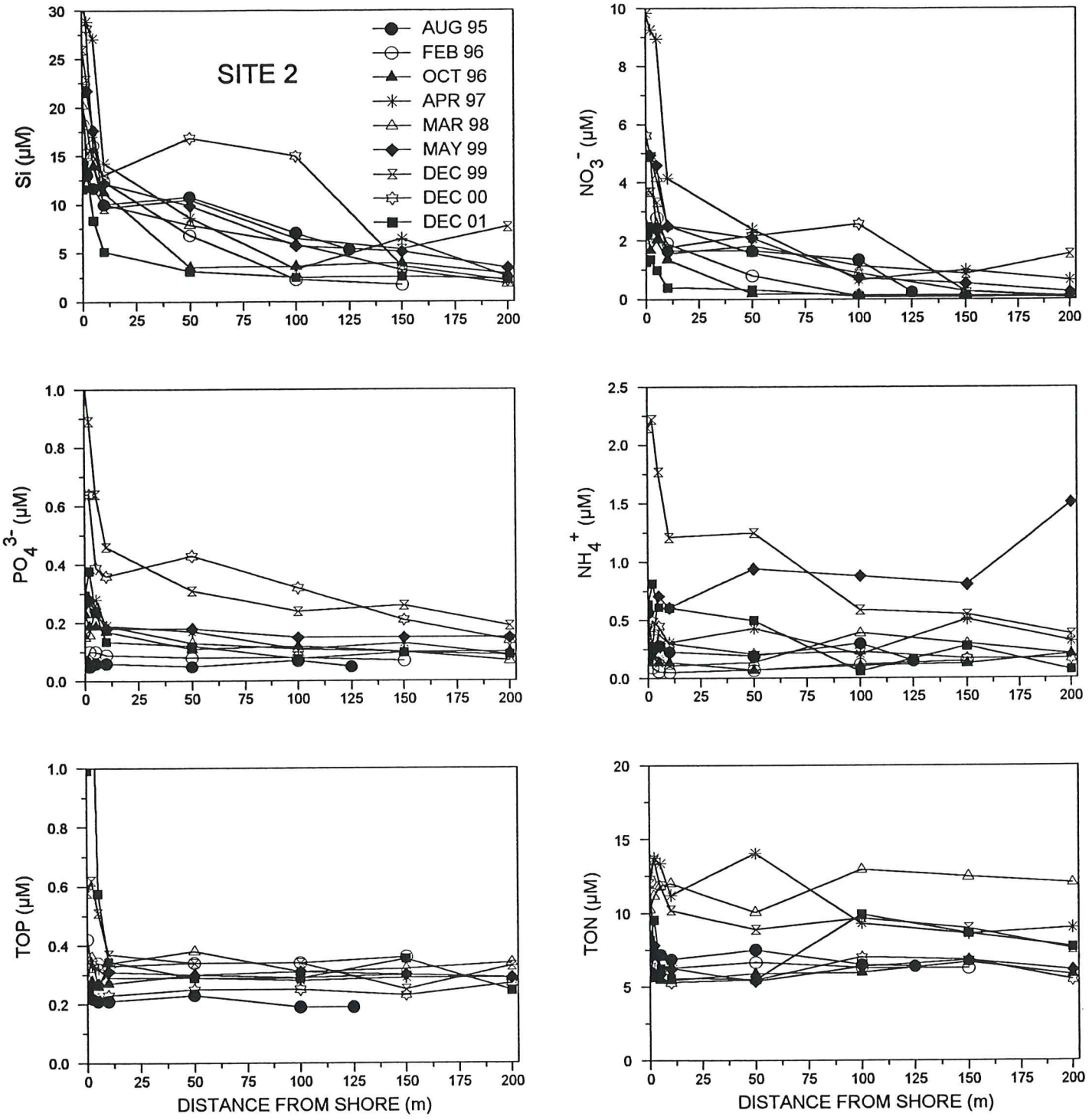

FIGURE 6. Plots of dissolved nutrient constituents in surface water samples as a function of distance from the shoreline at Site 2 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. Note: transect sampling extended to 200 m from shoreline after February 1996. For location of Site 2, see Figure 1.

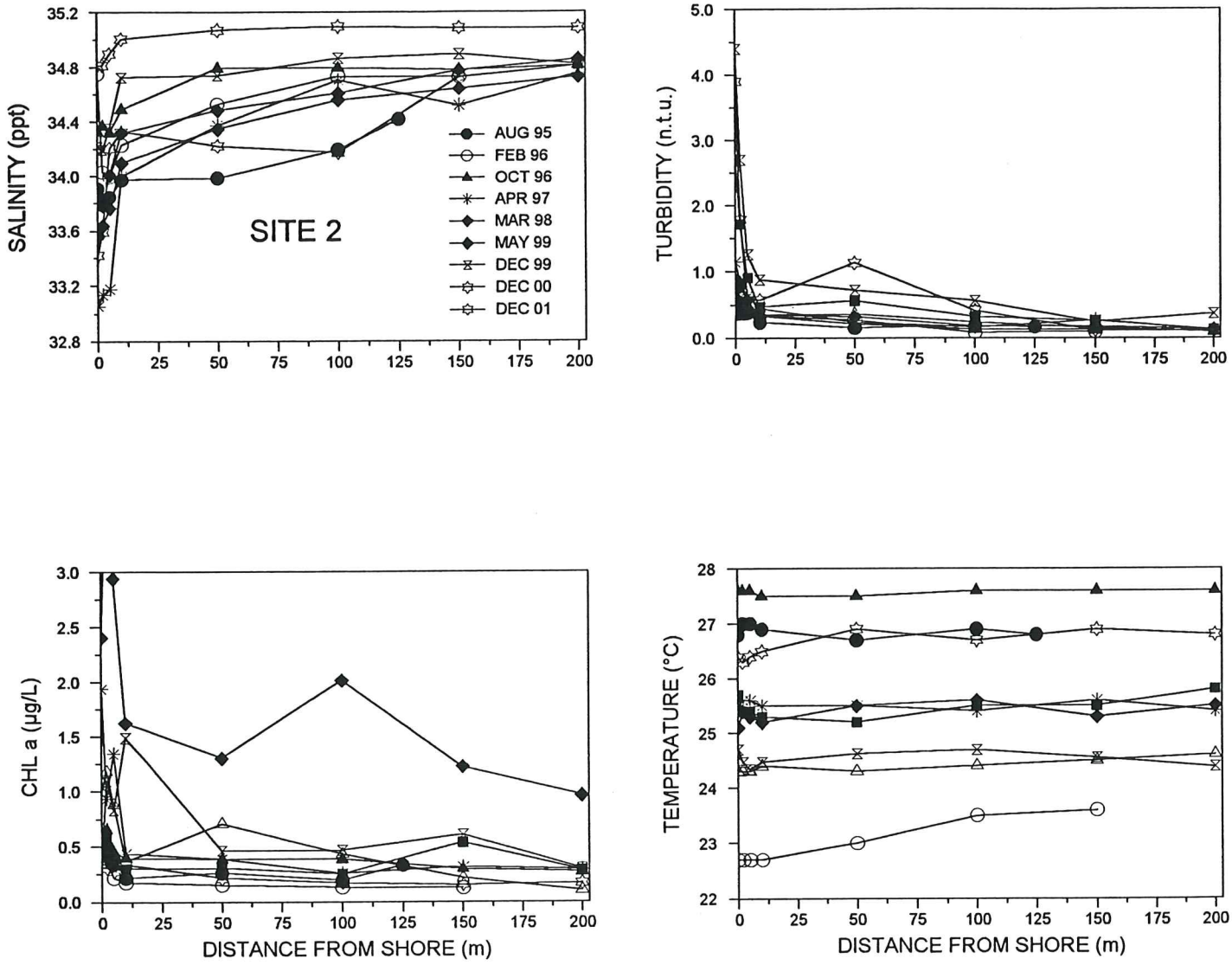

FIGURE 7. Plots of water chemistry constituents in surface water samples as a function of distance from the shoreline at Site 2 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. Note: transect sampling extended to 200 m from shoreline after February 1996. For location of Site 2, see Figure 1.

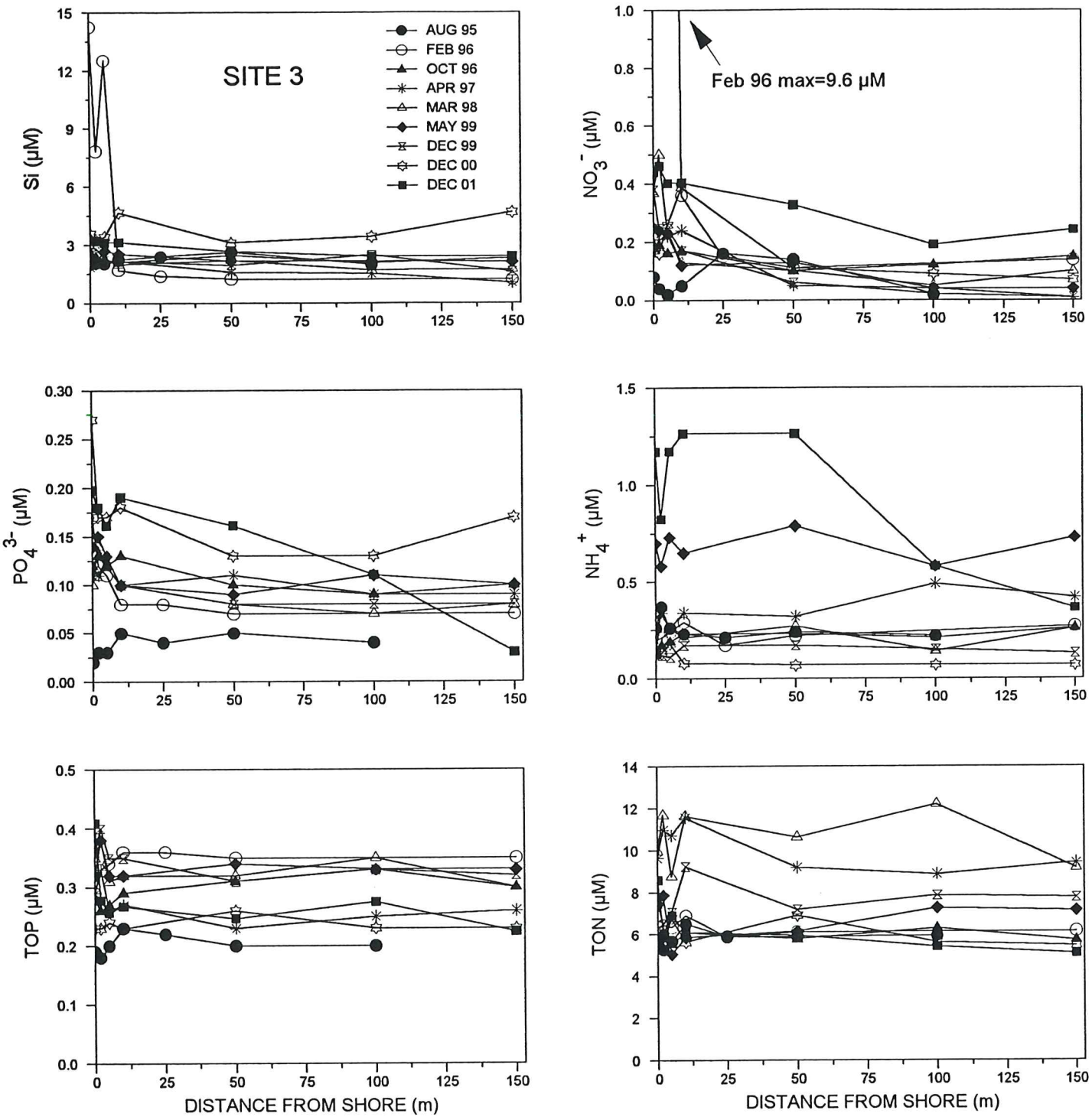

FIGURE 8. Plots of dissolved nutrient constituents in surface water samples as a function of distance from the shoreline at Site 3 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. For location of Site 3, see Figure 1.

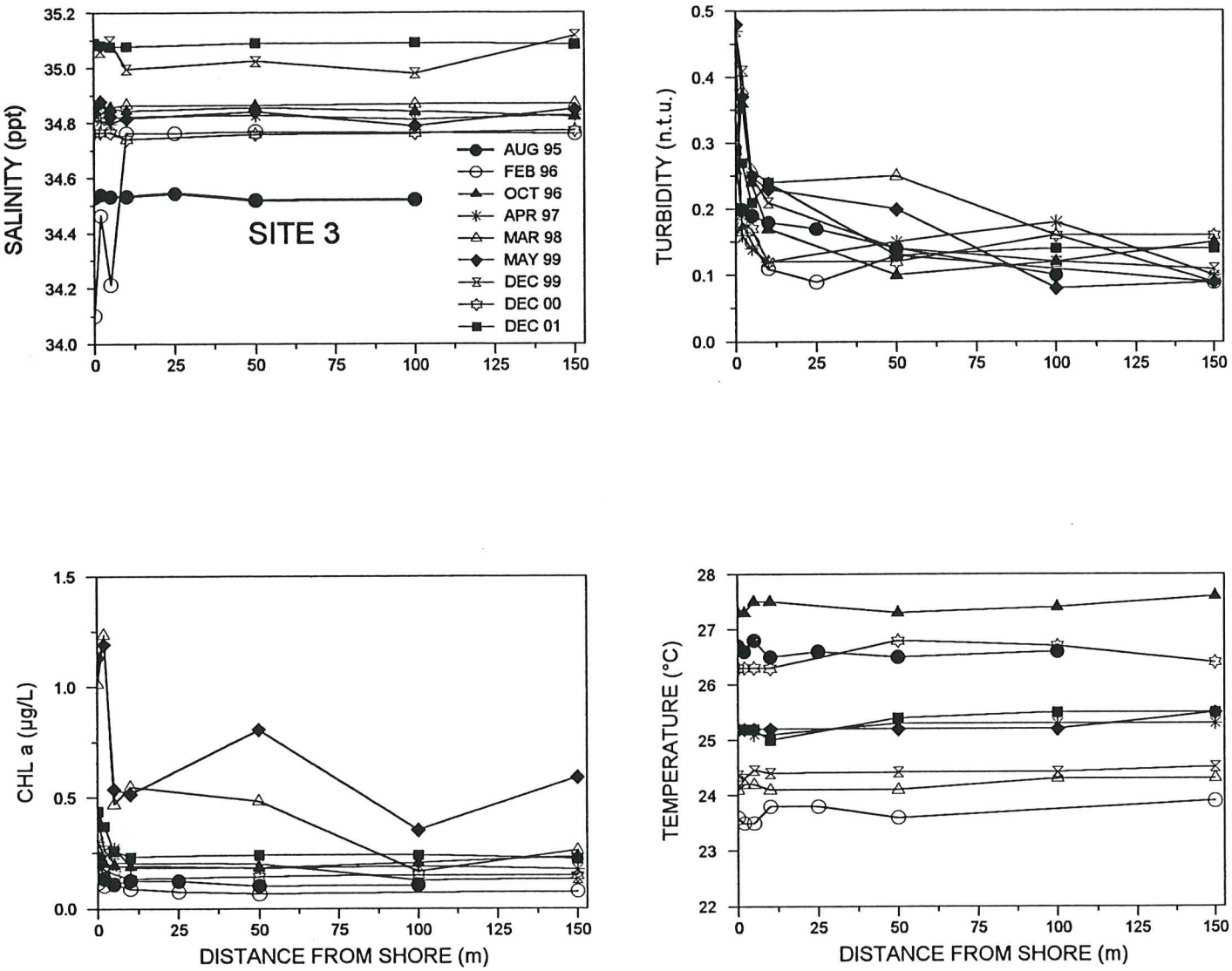

FIGURE 9. Plots of water chemistry constituents in surface water samples as a function of distance from the shoreline at Site 3 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. For location of Site 3, see Figure 1.

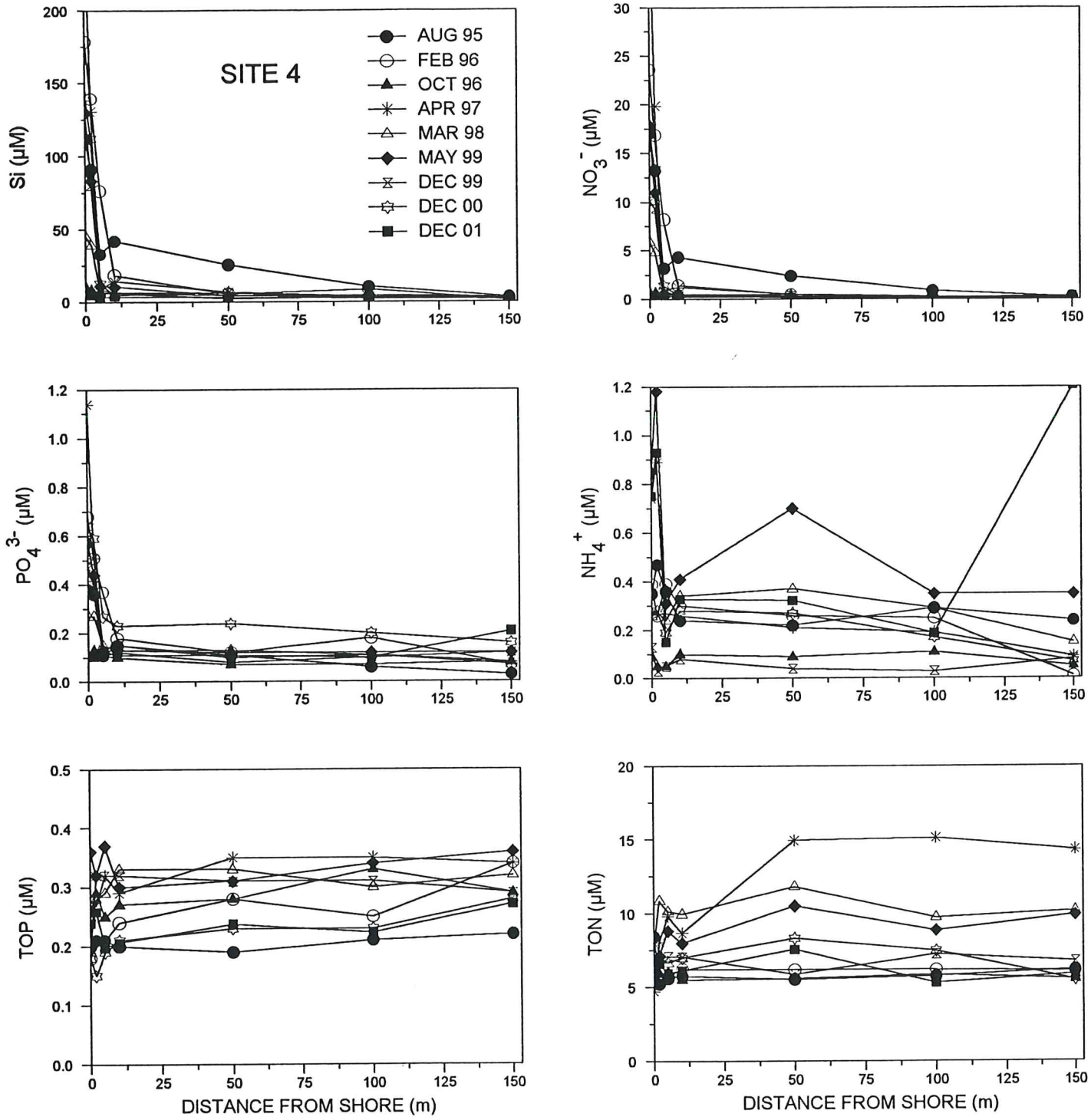

FIGURE 10. Plots of dissolved nutrient constituents in surface water samples as a function of distance from the shoreline at Site 4 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. For location of Site 4, see Figure 1.

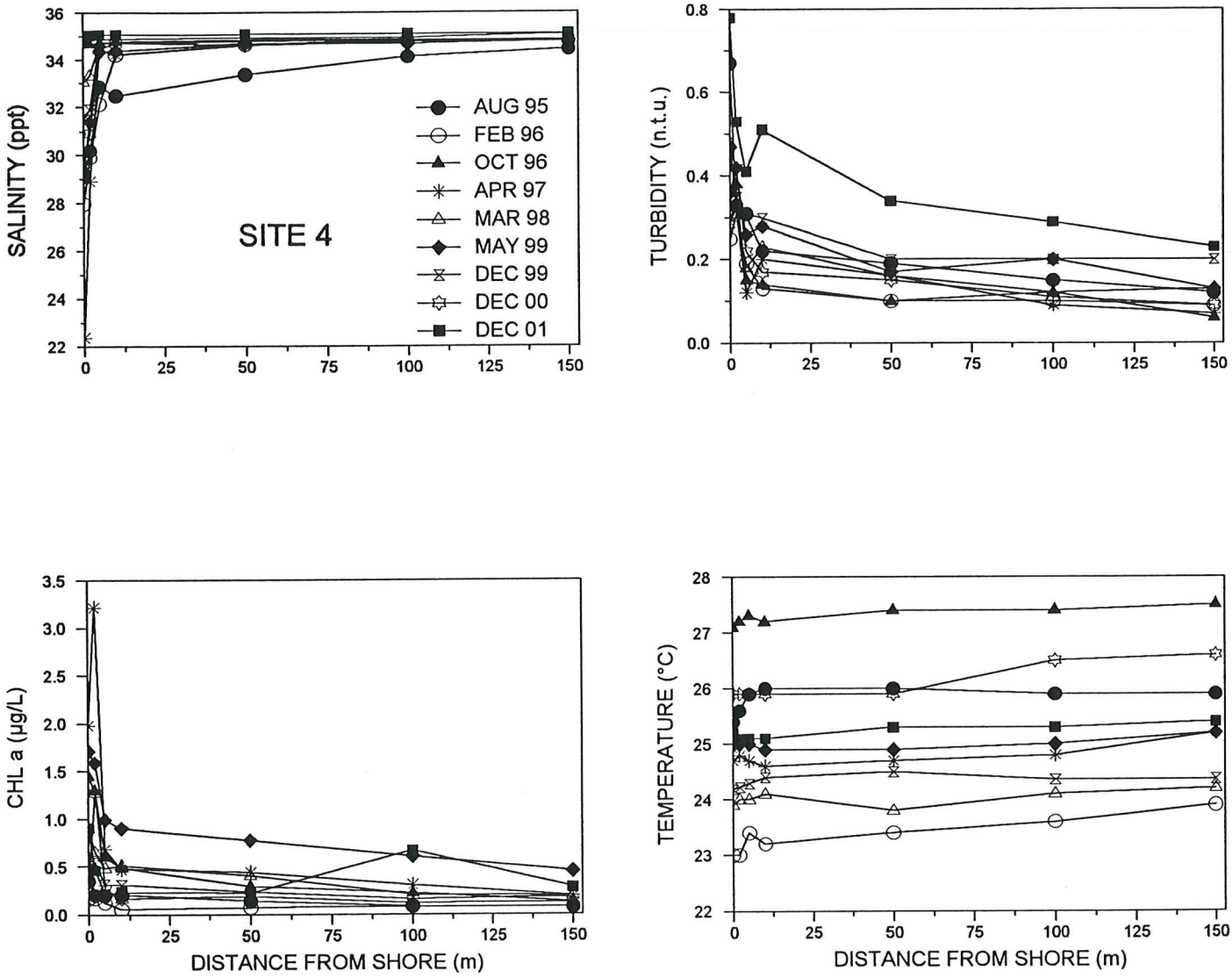

FIGURE 11. Plots of water chemistry constituents in surface water samples as a function of distance from the shoreline at Site 4 offshore of the Makena Golf Course for monitoring surveys conducted since August 1995. For location of Site 4, see Figure 1.

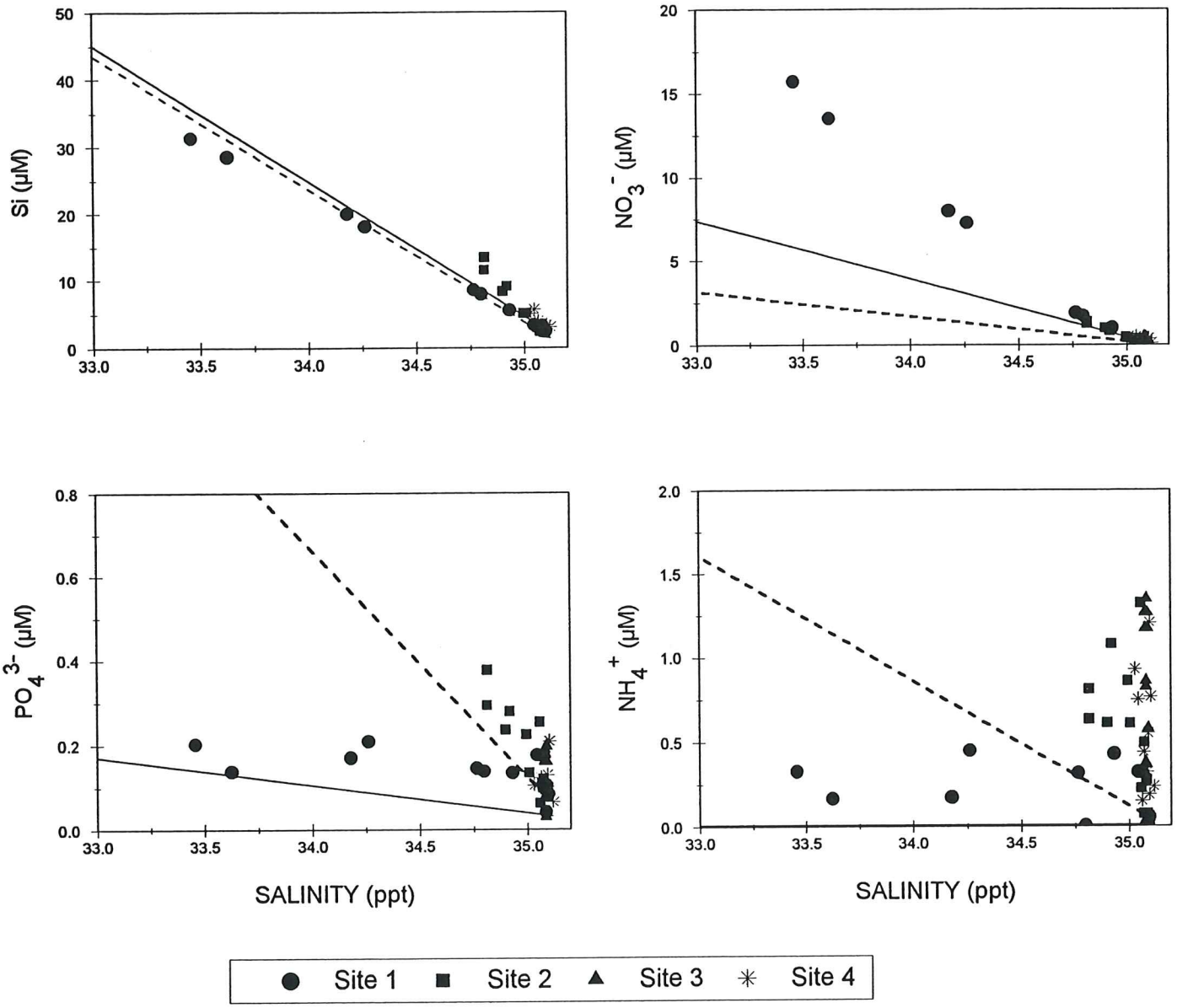

FIGURE 12. Mixing diagram showing concentration of dissolved nutrients from samples collected offshore of the Makena Golf Course on December 2, 2001 as functions of salinity. Solid line in each plot is conservative mixing line constructed by connecting the concentrations in open coastal water with water from a golf course irrigation well. Dotted line is mixing line constructed from open coastal water with water from irrigation lake 10 used to feed both North and South courses. For sampling site locations, see Figure 1.

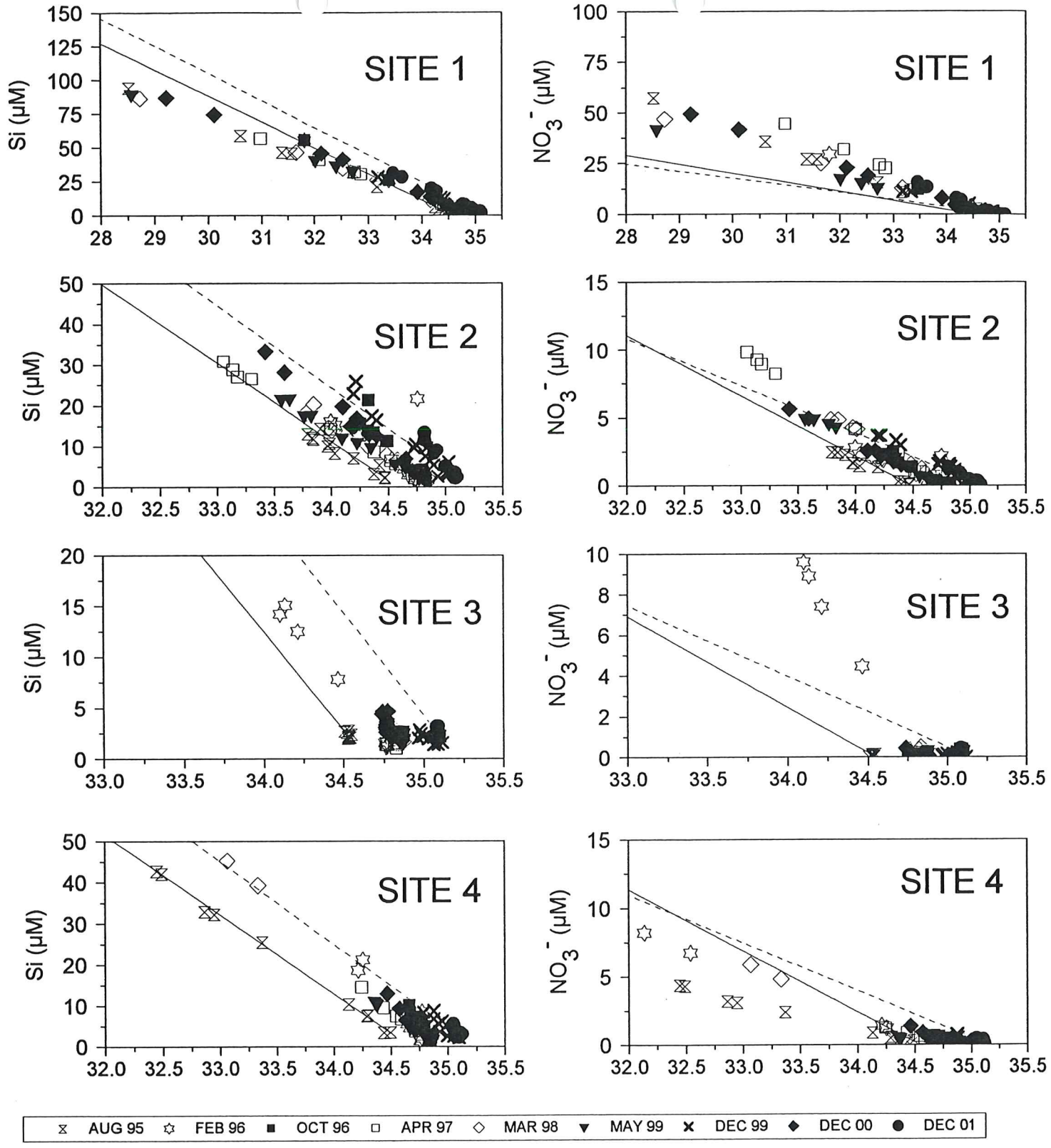

FIGURE 13. Silicate and nitrate, plotted as a function of salinity for all samples collected during surveys at four sites offshore of the Makena Golf Course. Straight lines in each plot are conservative mixing lines and were constructed by connecting the concentration in open coastal water and water from golf course irrigation wells located near each site (see text). Solid lines are mixing lines for initial survey (August 1995). Dashed lines are mixing lines from current survey. Note axis scales are different for each site. For site locations, see Figure 1.

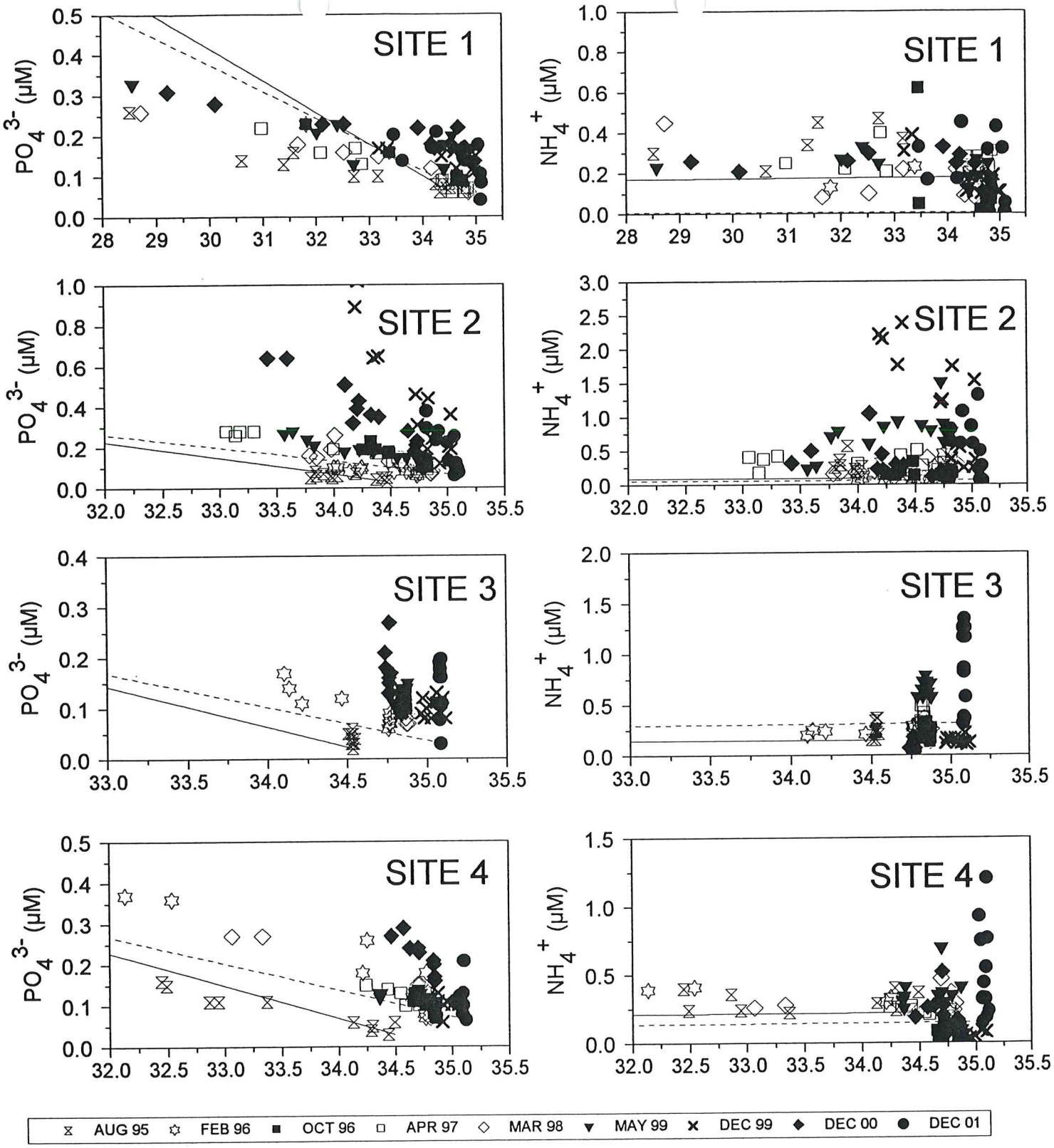

FIGURE 14. Phosphate and ammonium, plotted as a function of salinity for all samples collected during surveys at four sites offshore of the Makena Golf Course. Straight lines in each plot are conservative mixing lines and were constructed by connecting the concentration in open coastal water and water from golf course irrigation wells located near each site (see text). Solid lines are mixing lines for initial survey (August 1995). Dashed lines are mixing lines from current survey. Note axis scales are different for each site. For site locations, see Figure 1.