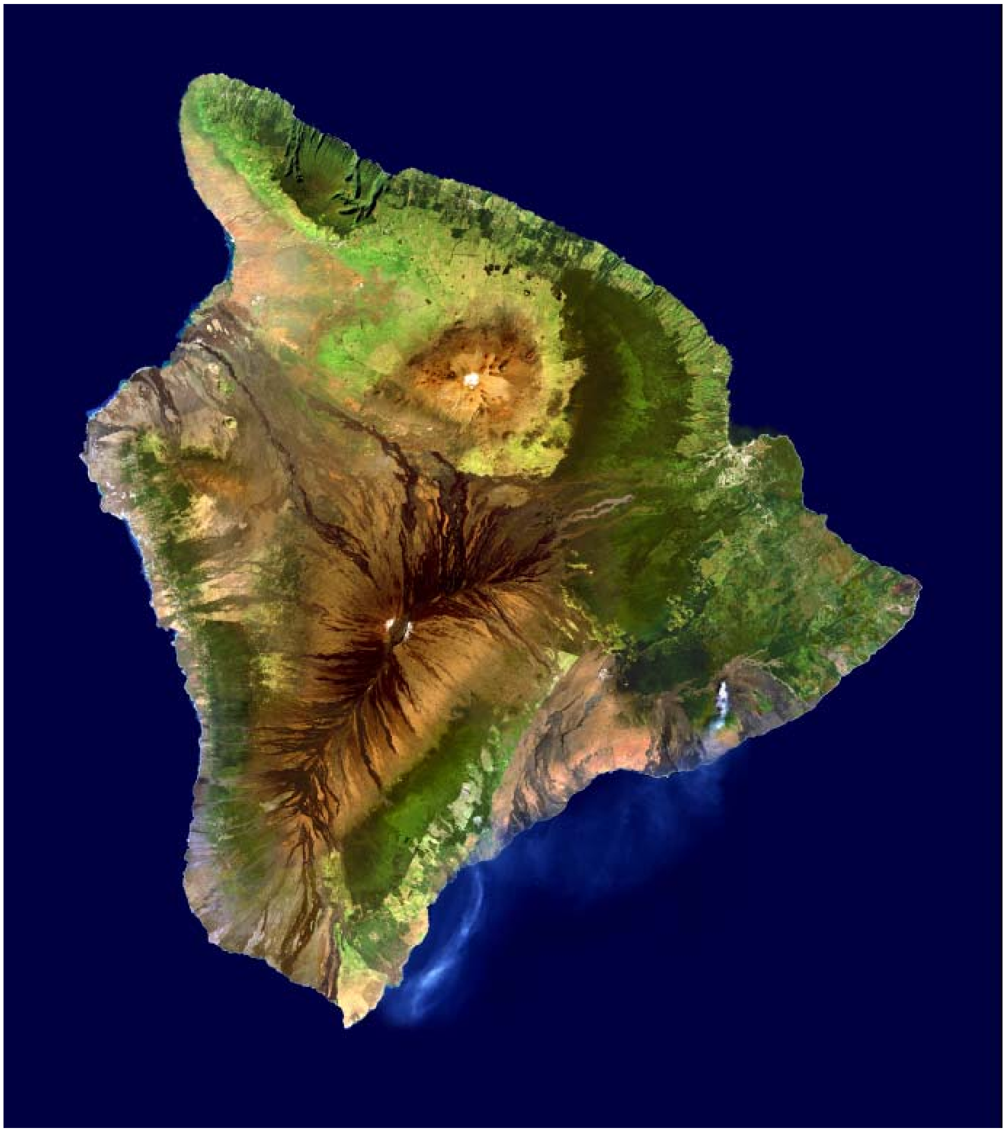
# A Review of Coastal Monitoring Data for Developments in West Hawai`i



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## I. EXECUTIVE SUMMARY

The West Hawai`i Coastal Monitoring Task Force was established in 1990 with the charge to develop coastal monitoring guidelines for West Hawai`i. In 1992, these guidelines were published and intended to provide minimum components of a coastal monitoring program to be implemented by developers, government agencies, and other interested or concerned groups (West Hawai`i Coastal Monitoring Task Force 1992). The guidelines incorporated concepts of sustainable development and limits to acceptable change in coastal waters of West Hawai`i. These guidelines also provided a mechanism for identifying "unacceptable" change in West Hawaiian coastal waters so that corrective action could be taken and waters would then be in compliance with Hawai`i Department of Health (HDOH) water quality standards.

In 2004, the County of Hawai`i contracted the Marine Science Department at the University of Hawai`i at Hilo to evaluate monitoring data from development projects in West Hawai`i for spatial and temporal trends and to evaluate whether developments were in compliance with HDOH water quality standards (HDOH 2004). Monitoring reports from 13 development projects were reviewed to evaluate water quality, microbiological, biological, geological, and physical data collected during these projects. Only three of the development projects [Waikoloa, Natural Energy Laboratory of Hawai`i (NELHA), and Hokuli`a] contained sufficient data over a sufficient duration to evaluate temporal trends for water quality and compliance with HDOH water quality standards (HDOH 2004); none of the other developments even came close to having sufficient data for these types of analyses. Thus, we used water quality data from Waikoloa, NELHA, and Hokuli`a to evaluate effects of resort/residential development on coastal water quality.

Four classes of waters [groundwater, anchialine ponds, coastal waters (estuaries, embayments, open coastal waters), oceanic water] were sampled for water quality parameters [i.e., nutrients, chlorophyll *a* (Chl *a*), turbidity, bacterial indicators of human waste] during monitoring projects for developments in West Hawai`i. Of these four classes, only coastal and oceanic waters are regulated for water quality by HDOH. Most of the parameters regulated for coastal waters (nutrients, Chl *a*, turbidity) were consistently measured during monitoring projects. However, fewer of the regulated parameters were sampled for oceanic waters. Nitrate ($NO_3^-$) and ammonium ($NH_4^+$) were the only parameters consistently sampled in coastal waters at development sites, whereas total nitrogen (TN), total phosphorus (TP), and Chl *a* were not consistently sampled. Similarly, fecal coliform and enterococci, two standard indicator bacteria of human waste contamination that HDOH regulates for in inland and marine recreational waters, were sampled at only three developments.

The only biological parameter regulated by HDOH is Chl *a*; however, the West Hawai`i Coastal Monitoring Task Force (1992) recommended that corals, fish, macroinvertebrates, macroalgae, benthic substrate characteristics, marine mammals, and turtles be monitored in coastal waters of West Hawai`i. Chl *a*, corals/benthic substrate cover, macroinvertebrates, and fish were the most commonly sampled biological parameters at the developments. Turtle data were only presented in one report. Overall, biological data were not collected consistently during the development projects so trend analysis was not possible.

Sediment analyses and sea/weather conditions were the geological and physical parameters lacking from most development project monitoring reports. Sediment analyses and monitoring for Class II beaches, marine pools, protected coves, and reef flats and communities are required by HDOH (HDOH 2004). Only two development projects in West Hawai`i conducted sediment analysis. Sea/weather conditions were recommended to be included in all coastal water quality measurements by the West Hawai`i Coastal Monitoring Task Force (1992). Water circulation, current meter, drogue, and wind velocity measurements were not presented in any of the reports and only in rare instances were weather conditions mentioned.

Anchialine ponds were examined at six of the 13 developments reviewed. Within the United States, these unique habitats are only found in Hawai`i. Currently, anchialine ponds are not protected by the State of Hawai`i for preservation or water quality. Investigations have documented the decline of water quality and biological integrity of anchialine ponds adjacent to developments (Brock 1985; Brock et al. 1987). However, no HDOH water quality standards exist for anchialine ponds. Inorganic nutrients [$NO_3^-$, $NH_4^+$, phosphate ($PO_4^{3-}$)] were primarily sampled in these ponds, while TN, TP, and Chl *a* were not consistently measured. Sediment analyses were not carried out for anchialine ponds, although it was recommended by the West Hawai`i Coastal Monitoring Task Force (1992). Additionally, water quality data from anchialine ponds at Waikoloa and Hokuli`a were compared to previous measurements at Kaloko-Honokohau National Historic Park (KAHO) to evaluate effects of development on water quality in these ponds. Anchialine ponds at both Waikoloa and Hokuli`a have nutrient concentrations that were >70% higher than concentrations reported for KAHO. Nutrient concentrations in the ponds at both Waikoloa and Hokuli`a were often higher than concentrations measured in highly polluted rivers and estuaries. It is estimated that nutrient concentrations in the anchialine ponds at Waikoloa have more than doubled since the resort's development. Likely sources of nutrients to these ponds are irrigation water enriched with treated sewage used to water development grounds (Waikoloa), dry fertilizers applied to golf courses (Waikoloa), and remnant nutrients from historical agriculture and cattle grazing (Hokuli`a).

Historical water quality analyses from Waikoloa and Hokuli`a revealed that nitrogen water quality parameters have significantly increased at both developments over the past ten years. Specifically, TN and dissolved organic nitrogen (DON) concentrations increased 49% and 107%, respectively, at Waikoloa from 1991 to 2002. At Hokuli`a, all nutrient parameters showed significant increases in concentrations from 1991 to 2001, with $NO_3^-$ concentrations exhibiting the largest concentration increase of 410%. Nutrient concentrations were more elevated at low salinities, suggesting that nutrients originate from freshwater sources like fertilizers, irrigation water, or waste water. These elevated nutrient concentrations may lead to algal blooms in West Hawai`i, which may be comprised of exotic and/or harmful species. In Maui County, frequent exotic algal blooms from elevated nutrients in the coastal waters have resulted in the loss of millions of dollars annually from potential revenue in property values and income from hotel and rental properties (West Maui Watershed Management Advisory Committee 1997; Davidson et al. 2003). Tens of thousands of dollars have also been spent to remove algae from beaches (West Maui Watershed Management Advisory Committee 1997; Davidson et al. 2003).

Phosphorus and nitrogen concentrations in open coastal waters at Waikoloa, NELHA, and Hokuli`a often exceeded HDOH water quality standards. $PO_4^{3-}$ concentrations were out of compliance 68% (±22), 64% (±33), and 23% (±29) of the time at Waikoloa, NELHA, and Hokuli`a, respectively. $PO_4^{3-}$ values were 1 to 5 times higher than HDOH standards. $NO_3^-$ concentrations were out of compliance 73% (±24), 86% (±14), and 39% (±39%) of the time at Waikoloa, NELHA, and Hokuli`a, respectively. $NO_3^-$ concentrations were up to 16 times higher than HDOH standards. Paradoxically, control sites at Waikoloa and Hokuli`a developments often had higher nutrient concentrations than sampling sites at the development itself. Results from these analyses are consistent with historical temporal trends for these sites, suggesting that conditions in West Hawai`i may be developing for extreme environmental degradation, possibly resulting in algal blooms like those in West Maui.

Our primary conclusion is that the West Hawai`i Coastal Monitoring Task Force guidelines (1992), which were sound and appropriate for the time, have not been adequately implemented and development monitoring projects have not been scientifically evaluated. From our review of the development projects' monitoring reports, **three major recommendations** are made to Hawai`i County. **1)** Guidelines from the West Hawai`i Coastal Monitoring Task Force (1992) need to be revised, amplified, enhanced, adhered to, and enforced. Guidelines for environmental reports need to be provided to developers prior to application. **2)** A county-wide coastal water monitoring program needs to be developed to monitor long-term environmental changes at existing and future developments, as well as, other identified sites in West Hawai`i. This program will provide crucial data for evaluation of environmental conditions and impacts on coastal resources and water quality. We suggest that the program be directed by Hawai`i County and funded from fees charged to existing and future resorts and developments in West Hawai`i. **3)** Hawai`i County needs to develop an anchialine pond protection/management program. This program would include a) an enforcement policy of no net loss of ponds on both public and private lands, b) conducting an island-wide inventory of anchialine ponds, and c) establishing water quality standards for ponds. Without development of an anchialine protection/ management program, anchialine ponds will most likely disappear within the next two decades (Brock and Kam 1997).

## II. INTRODUCTION

The Hawai`i County Comprehensive Development Strategy Report prepared by the Hawai`i Island Economic Development Board in 1998 states that:

*Hawai`i County and its residents keenly appreciate the beauty and fragility of the islands, and agree that protection of the environment is a primary goal and significant cultural value. The county's limited resources and its dependence on the visitor industry mandate that economic development go in tandem with conservation and preservation of the environment. County residents largely recognize that the scenic beauty and pristine environment is a mainstay of the successful visitor industry component of the economy.*

Wise stewardship of Hawai`i has always mandated protection of the marine environment as a primary goal, and it has become an increasing challenge in the coastal zone of West Hawai`i, as it has faced unprecedented development during the later decades of the 20$^{th}$ century. During the past 25 years, the population of Kailua-Kona more than doubled and in the decade from 1980 to 1990, the resident population of Hawai`i Island experienced 30% growth. This was also a decade of explosive resort development in West Hawai`i. In response to concern about degradation of the marine environment from extensive coastal development, the West Hawai`i Coastal Monitoring Task Force was formed and a workshop convened in December 1990. One goal was for guidelines to be produced and a monitoring program established to describe existing conditions and assess potential impacts of coastal development on coastal resources. The Task Force consisted of 18 knowledgeable and interested individuals representing federal, state, and county agencies, community organizations, the University of Hawai`I (UH), and several private consulting firms. Of the PhD scientists in the group, the majority were professional environmental consultants. Dr. Walter Dudley, UH-Hilo Professor, was a member of the Task Force and the only University scientist who did not also work for a private consulting firm.

An additional Task Force workshop and several Task Force working group meetings were held during the following year, and in April 1992 a set of "Monitoring Protocol Guidelines" was published (Appendix I). The guidelines were intended to provide "the minimum components of a coastal monitoring program" to be implemented by "coastal developers, government agencies and other interested and concerned groups." The guidelines were also developed "with the clear understanding that specific projects" might "require additional monitoring to assess the potential impacts of these projects." The proposed coastal monitoring program was to be an "on-going, dynamic monitoring effort to assess the environmental characteristics of the coastal area over time" thereby producing time series data for future analysis. Furthermore, the guidelines incorporated "concepts of sustainable development......and limits of acceptable change" implying that "unacceptable" change would be identified and corrective action taken.

The 1992 Monitoring Protocol also served as the basic guidelines for "development of more detailed regional or site specific monitoring programs." The monitoring program was designed to provide data for use by government agencies, university scientists, public and private coastal developers, and the general public. The data were also to be made available for coastal ecosystem research and public education programs.

The protocol called for control stations to be established in "undeveloped or minimally developed" coastal areas. Any deviation from the protocols would only be allowed with a "scientific rationale." Finally, the "Monitoring/Survey Protocols" clearly listed five objectives: 1) develop a data base of existing conditions, 2) quantify natural variability of parameters in an area, 3) define long-term trends through on-going monitoring, 4) define potential impacts resulting from specific types of coastal projects, uses, and activities, and 5) develop resource management tools necessary for protection, preservation, and enhancement of coastal resources.

This report is an evaluation of compliance with these Monitoring/Survey Protocols and examination of whether or not each objective was met. Long-term trends found in the monitoring data available are described. Recommendations are made for future monitoring/survey guidelines.

## III. HAWAI`I DEPARTMENT OF HEALTH (HDOH) WATER QUALITY STANDARDS

### A. Definitions of Water Types (HDOH 2004)

1. Anchialine ponds: bodies of coastal standing waters that have no surface connection to ocean, but clearly display both tidal fluctuations and salinity ranges characteristic of fresh and brackish water, indicating subsurface connections to the water table and ocean.
2. *Brackish waters: water with dissolved inorganic ion concentrations (salinity) >0.5 ppt and <32 ppt (see Section IV, E, on recommendations for changing *brackish waters* definition.).
3. *Coastal waters: waters surrounding the islands from the coast to a point 3 miles offshore (see Section IV, E, on issues surrounding definition of wet and dry season for open coastal waters).
4. Coastal wetlands: natural or man-made ponds and marshes having variable salinity, basin limits, and permanence.
5. Ditches/flumes: fresh waters flowing continuously in artificial channels.
6. Elevated wetlands: natural freshwater wetlands located above 100 m elevation.
7. *Embayment: marine waters that are land-confined and physically protected with restricted openings to open coastal waters. Restricted opening is defined by the ratio of the total bay volume to the cross-sectional entrance area of seven hundred to one or greater (see Section IV, E, on issues surrounding definition).
8. Estuary: brackish coastal waters contained in a well-defined basin with continuous or seasonal surface connection to the ocean.
9. Flowing springs/seeps: perennial freshwater flows not in distinct channels. Water trickles over rock surfaces.
10. Flowing waters: fresh waters flowing unidirectionally down altitudinal gradients.
11. Fresh waters: waters with a dissolved inorganic ion concentration of <0.5 ppt.
12. Oceanic waters: marine waters outside the 183 m depth contour (600 ft or 100 fathom).
13. Intermittent streams: fresh water flowing in defined natural channels only during part of the year or season.
14. Low wetlands: freshwater wetlands located below 100 m elevation.
15. Reservoirs: standing fresh water in an artificial impoundment.
16. Saline/salt waters: water with dissolved inorganic ion concentration greater than 32 ppt.
17. Saline lakes: standing waters with salinities ranging from brackish to hypersaline, located in a well-defined natural basin, and lacking a natural surface connection to the ocean.
18. Standing waters: waters of variable size, depth, and salinity that have little or no flow and are usually contained in well-defined basins.
19. Streams: seasonal or continuous water flowing unidirectional down altitudinal gradients.

### B. Classification of State Waters (HDOH 2004)

1. Inland Waters***:*** can be fresh, brackish, or saline
    - a. *Inland Fresh Waters*
        - 1) Flowing waters: streams, springs/seeps, ditches/flumes

2) Standing waters: freshwater lakes, reservoirs
3) Wetlands: elevated wetlands (bogs, marshes, swamps), lowland wetlands (marshes, swamps)

b. *Inland Brackish and Saline Waters*

1) Standing waters: anchialine ponds, saline lakes
2) Wetlands: coastal wetlands (marshes, swamps)
3) Estuaries: natural estuaries (spring- and stream-fed), developed estuaries

2. Marine Waters*:* can be embayments, open coastal waters, or oceanic waters

**C. Classification of Water Uses (HDOH 2004)**

1. Inland Waters:

a. *Class 1*: These waters are to remain in their natural state as much as possible with minimum pollution from humans. Waste discharge into these areas is prohibited.

1) Class 1a: These waters are protected for scientific and educational purposes. These waters serve as areas for native organisms to breed, baseline reference for environmental quality (chemical, biological, geological), aesthetic enjoyment, and other uses that are compatible with protection of these waters.

2) Class 1b: These waters are protected to ensure that they can be used for domestic water supply, food processing, breeding areas for native organisms, baseline reference for environmental quality (chemical, biological, geological), scientific and educational purposes, compatible recreation, and aesthetic enjoyment.

b. *Class 2*: These waters are protected for their recreational, agricultural, industrial, and navigational uses. These uses must also be compatible with the protection and proliferation of fish, shellfish, and wildlife in these areas, as well as the recreational uses of these waters. Discharge into these waters must be treated and fall within the State's water quality standards. No new treated sewage discharge shall be permitted within estuaries. The same applies for new industrial discharges, with the exception of:

1) Acceptable non-contact thermal discharge and drydock
2) Stormwater discharge associated with industrial activities that meet basic water quality criteria for all water bodies (Section III, E)
3) Discharge covered by a National Pollutant Discharge Elimination System general permit

2. Marine Waters:

a. *Class AA*: These waters are to remain in their natural pristine state with minimum pollution or alteration of water quality from any human-caused source or actions. These waters include water less than 18 m depth within a defined reef area and waters up to a distance of 300 m offshore (depth greater than 18 m).

b. *Class A*: These waters are for recreational use and aesthetic enjoyment. Additional uses of these waters must be compatible with protection and proliferation of fish, shellfish, and wildlife, as well as recreation in these waters. Discharge into these areas must be treated and compatible with the water quality criteria for Class A waters. No new sewage or industrial discharge shall be permitted with the exception of:

1) Stormwater discharge associated with industrial activities that meet basic water quality criteria for all water bodies (Section III, E)
2) Discharge covered by a National Pollutant Discharge Elimination System general permit

3. Marine Bottom Ecosystems:

a. *Class I*: These ecosystems are to remain in their natural pristine state with minimum pollution from human sources. Passive human uses of these ecosystems are permitted such as non-consumptive scientific research and education (demonstration, observation, or monitoring).
b. *Class II*: Uses for Class II ecosystems include propagation of fish, shellfish, and wildlife, as well as recreation. Actions that may permanently modify, alter, consume, or degrade the marine bottoms (i.e., dams, landfills, harbors, etc.) must be approved by the director of HDOH.

**D. Criteria for Listing Surface Waters (HDOH 2003)**

Criteria listed below were created to evaluate total daily maximum loads (TMDL) for sediment and nutrient inputs to coastal waters (Table 1). They are not the general protocol used by HDOH to monitor coastal water quality (personal communication HDOH). General monitoring protocols need to be developed by HDOH to evaluate water quality compliance with HDOH standards. Critical to these protocols is the establishment of the number of samples that need to be collected to evaluate water quality compliance and the time over which these samples should to be collected must be specified.

1. Listing Priority 1: Water bodies will be listed if the criteria for conventional pollutants (i.e., total suspended sediments, nutrients) are exceeded under the following conditions:

a. Water bodies must be sampled at least 10 times and the geometric mean of the data must exceed the geometric mean of the criterion.
b. For tidally-influenced water bodies (e.g., estuaries, coastal waters), samples must be distributed either on a transect or randomly over the extent of the water body or section of the water body sampled.
c. To evaluate whether the pollutant exceeds the criterion 10% of the time, a sample size of at least 100 is needed. To evaluate whether the pollutant exceeds the criterion 2% of the time, a sample size of at least 500 is needed.

2. Listing Priority 2: Water bodies can be listed even if all the data requirements under Listing Priority 1 are not met under the following conditions:

a. At least 10 samples per site were collected, but wet and dry season were combined because insufficient samples were collected to evaluate wet and dry seasons separately.
b. The majority of the samples (5-9 of the values) exceed the geometric mean for the criterion by a factor 2 or more.

c. Calculations with a sample size of 50 to 90 exceed the 10% criterion.
d. Calculations with a sample size of 250 to 450 exceed the 2% criterion.

3. Listing Priority 3: These water bodies are considered a high priority for additional monitoring.
a. < 5 samples are available for conventional pollutants.

**E. Water Quality Standards for All Waters (HDOH 2004)**

1. All waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants, including:
a. Materials that settle forming 'objectionable' sludge or bottom deposits
b. Floating debris, oil, grease, and scum
c. Substances that cause:
1) Water and/or fish to taste funny
2) Water to be an 'objectionable' color or turbidity
d. High or low temperatures
e. Biocides
f. Pathogenic organisms
g. Toxic, radioactive, corrosive, or other deleterious substances at levels or in combination to be toxic to humans, animals, plants or at sufficient levels to render the water body unusable
h. Substances or conditions that produce undesirable aquatic life
i. Soil particles resulting from erosion on land involved in earthworks

**F. Microbiology Standards**

HDOH follows United State Environmental Protection Agency (USEPA) regulations for enterococci and fecal coliforms, standard indicator bacteria used worldwide as indicators of human waste contamination of water sources ranging from drinking water to recreational waters (Table 1). However, in tropical environments, even in the absence of known fecal contamination, some indicators multiply creating problems for accurate counts in assays (Shibata et al. 2004). HDOH has a lower enterococci standard for monitoring beach water quality than other states and recently added *Clostridium perfringens* as a supplemental, more accurate indicator due to the formation of highly resistant spores (HDOH 2004).

1. Inland Recreational Waters:
a. Enterococcus content shall not exceed a geometric mean of 33 colony forming units/100 ml (CFUs) in not more than five samples which shall be spaced to cover a period between 25 and 30 days. No single sample shall exceed the single sample maximum of 89 CFUs/100 ml or the site-specific, one-sided, 82% confidence limit.
b. Fecal coliforms samples cannot exceed geometric mean of 200 CFUs/100 ml in 10 or more samples in a 30 day period. Not more than 10% of the samples shall exceed 400 CFUs/100 ml in the same 30 day period.

2. Marine Recreational Waters:

a. Within 300 m of the shoreline, including natural public bathing or wading areas, enterococcus content shall not exceed a geometric mean of 7 CFUs/100 ml in not more than five samples which shall be spaced to cover a period between 25 and 30 days. No single sample shall exceed the single sample maximum of 100 CFUs/100 ml or the site-specific, one-sided, 75% confidence limit. Federal standards for enterococci are 35 CFUs/100 ml (USEPA 1986).

Table 1. HDOH water quality standards (Chapter 11-54, 2004).

A. ESTUARIES

| Parameter | Standard | Cannot exceed 10% of time | Cannot exceed 2% of time |
|---|---|---|---|
| TN (μM) | 14.28 | 25.00 | 35.70 |
| $NH_4^+$ (μM) | 0.43 | 0.71 | 1.43 |
| $NO_3^-/NO_2^-$ (μM) | 0.57 | 1.78 | 2.50 |
| TP (μM) | 0.81 | 1.61 | 2.42 |
| Chl *a* (μg $L^{-1}$) | 2.00 | 5.00 | 10.00 |
| Turbidity (NTU) | 1.50 | 3.00 | 5.00 |
| pH | 7.0-8.6 | | |
| %Dissolved $O_2$ Saturation | 75 | | |
| Eh in upper 10 cm of sediments (mV) | <-100 | | |

B. EMBAYMENT (wet/dry seasons)

| Parameter | Standard | Cannot exceed 10% of time | Cannot exceed 2% of time |
|---|---|---|---|
| TN (μM) | *14.28/**10.71 | 25.00/17.85 | 35.70/25.00 |
| $NH_4^+$ (μM) | 0.43/0.25 | 0.93/0.61 | 1.43/1.07 |
| $NO_3^-/NO_2^-$ (μM) | 0.57/0.36 | 1.43/1.00 | 2.50/1.78 |
| TP (μM) | 0.81/0.65 | 1.61/1.29 | 2.42/1.94 |
| Chl *a* (μg $L^{-1}$) | 1.50/0.50 | 4.50/1.50 | 8.50/3.00 |
| Turbidity (NTU) | 1.5/0.40 | 3.00/1.00 | 5.00/1.50 |
| pH | 7.0-8.1 | | |
| %Dissolved $O_2$ Saturation | 75 | | |

*Wet: applies when the average fresh water inflow from the land equals or exceeds 1% of the embayment volume per day

**Dry: applies when the average fresh water inflow from the land is less than 1% of the embayment volume per day

Table 1. Continued.

C. OPEN COASTAL WATERS (wet/dry seasons)

| Parameter | Standard | Cannot exceed 10% of time | Cannot exceed 2% of time |
|---|---|---|---|
| TN (μM) | *10.71/**7.85 | 17.85/12.85 | 25.00/17.85 |
| $NH_4^+$ (μM) | 0.25/0.14 | 0.61/0.36 | 1.07/0.64 |
| $NO_3^-/NO_2^-$ (μM) | 0.36/0.25 | 1.00/0.71 | 1.78/1.43 |
| TP (μM) | 0.65/0.52 | 1.29/1.00 | 1.94/1.45 |
| Light Extinction Coefficient (k units) | 0.20/0.10 | 0.50/0.30 | 0.85/0.55 |
| Chl *a* (μg $L^{-1}$) | 0.30/0.15 | 0.90/0.50 | 1.75/1.00 |
| Turbidity (NTU) | 0.50/0.20 | 1.25/0.50 | 2.00/1.00 |
| pH | 7.0-8.1 | | |
| %Dissolved $O_2$ Saturation | 75 | | |

*Wet: applies when the open coastal waters receive more than 3 million gallons per day of fresh water discharge per shoreline mile
**Dry: applies when the open coastal waters receive less than 3 million gallons per day of fresh water discharge per shoreline mile

D. OCEANIC WATERS

| Parameter | Standard | Cannot exceed 10% of time | Cannot exceed 2% of time |
|---|---|---|---|
| TN (μM) | 3.57 | 5.71 | 7.14 |
| $NH_4^+$ (μM) | 0.07 | 0.13 | 0.18 |
| $NO_3^-/NO_2^-$ (μM) | 0.11 | 0.18 | 0.25 |
| TP (μM) | 0.32 | 0.58 | 0.81 |
| Chl *a* (μg $L^{-1}$) | 0.06 | 0.12 | 0.2 |
| Turbidity (NTU) | 0.03 | 0.1 | 0.2 |
| pH | 8.1 | | |
| %Dissolved $O_2$ Saturation | 75 | | |

Table 1. Continued.

E. KONA COAST (marine waters from Loa Point, South Kona District, clockwise to Mala`e Point, North Kona District, and all areas from the shoreline at mean lower low water to a distance 1000 m seaward, and in nearshore marine waters where the salinity is >32 ppt). These criteria are NOT applicable for Kawaihae and Honokohau Harbors.

| Parameter | Standard |
|---|---|
| TN (µM) | 7.14 |
| $NH_4^+$ (µM) | 0.18 |
| $NO_3^-/NO_2^-$ (µM) | 0.32 |
| TP (µM) | 0.40 |
| $PO_4^{3-}$ (µM) | 0.16 |
| Chl *a* (µg $L^{-1}$) | 0.30 |
| Turbidity (NTU) | 0.10 |
| pH | 7.0-8.1 |
| %Dissolved $O_2$ Saturation | 75 |

F. MICROBIOLOGY STANDARDS FOR INLAND WATERS

| Parameter | Standard | Cannot exceed 10% time |
|---|---|---|
| Fecal coliforms CFUs/100ml | 200 | 400 |
| Enterococci CFUs/100ml | 33 | * 89 |

* single sample, one sided, 82% confidence limit

G. MICROBIOLOGY STANDARDS FOR MARINE WATERS

| Parameter | Standard | Cannot exceed |
|---|---|---|
| Enterococci CFUs/100ml | 7 | *100 |

* single sample, one sided, 75% confidence limit

## IV. REVIEW OF WATER QUALITY PARAMETERS MEASURED IN WEST HAWAI`I

### A. Status of Water Quality Monitoring

A total of 13 developments have been sampled for water quality parameters in West Hawai`i. Water types sampled include: groundwater, anchialine ponds, coastal waters (estuaries, embayments, open coastal waters), and oceanic waters. Of these water types, only coastal and oceanic waters are regulated by the state of Hawai`i for water quality (personal communication with HDOH Clean Water and Safe Drinking Water branches). Coastal and oceanic waters are regulated for nutrients [total nitrogen (TN), ammonium ($NH_4^+$), nitrate ($NO_3^-$), total phosphorus (TP), and phosphate ($PO_4^{3-}$)], chlorophyll *a* (Chl *a*), turbidity, and light penetration (only for open coastal waters) (Table 1). There are different water quality standards for wet and dry seasons for embayments and open coastal waters. These seasons are defined by HDOH (Table 1). Special water quality criteria exist for coastal waters located on the west side of the Island of Hawai`i from Loa Point in the South Kona District to Mala`e Point in the North Kona District (Table 1, Figure 1). Of the 13 developments sampled for water quality in West Hawai`i, 12 developments fall into this 'Kona' coastal water category. Additionally, of the 13 developments sampled, only three, Waikoloa, Natural Energy Laboratory of Hawai`i (NELHA), and Hokuli`a, potentially have enough data to evaluate compliance with HDOH water quality standards. Waikoloa and Hokuli`a had 19 and 37 coastal water sites (estuarine and open coastal water), respectively, that could be evaluated for compliance (See Section V for analyses). NELHA had 12 open coastal water and 4 oceanic sites that could be evaluated for compliance (See Section V for analysis).

1. <u>Groundwater:</u> Groundwater was sampled at seven of the 13 developments. The number of wells sampled at a development ranged from one to 16, with water being sampled one to 473 times. Uses for the wells included drinking water, irrigation, sampling, and dust control. The salinity of the water in the wells ranged from fresh to brackish. Generally, these waters were analyzed for nutrients ($NO_3^-$, $NH_4^+$, $PO_4^{3-}$, TN, TP) and turbidity. Occasionally, these waters were sampled for Chl *a*. However, because most of the waters from these wells were saline, non-drinking groundwater, they are not regulated by the state of Hawai`i. Hence, there are no available criteria to evaluate them.

2. <u>Anchialine Ponds:</u> Anchialine ponds were examined for water quality at six of the 13 developments. The number of ponds sampled at each development varied from two to 11, with water being sampled one to 32 times at a particular pond. Because anchialine ponds are not regulated by the state of Hawai`i, we created our own water quality standards using historical water quality data from anchialine ponds at Kaloko-Honokohau National Historic Park (Table 2). We evaluated these ponds at the developments for nutrients (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$), Chl *a*, and turbidity (Table 2). We chose to assess the ponds using estuarine water criteria (Table 1) because they most closely represent the physiochemical (temperature, salinity, etc.) conditions found in anchialine ponds. Nutrients ($NO_3^-$, $NH_4^+$, and $PO_4^{3-}$) and turbidity are the primary water quality parameters that have been measured in the ponds. TN, TP, and Chl *a* were not consistently sampled for anchialine ponds.

3. Coastal Waters (Estuary and Open Coastal Waters): Coastal waters were sampled at 11 of the 13 developments. The number of sites sampled for water quality at each development ranged from eight to 67, with water being collected one to 32 times at a particular site. Coastal waters are regulated for nutrients (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$), Chl *a*, and turbidity by the state of Hawai`i (Table 1). Of these parameters regulated, most were consistently sampled at the coastal sites.

4. Oceanic Waters: Oceanic waters were sampled at one of the 13 developments. Four sites were sampled at this development, with water being collected from a particular site 12 to 480 times. Oceanic waters are regulated by the state of Hawai`i for nutrients (TN, $NH_4^+$, $NO_3^-$, TP), Chl *a*, and turbidity (Table 1). Of these parameters, $NO_3^-$ and $NH_4^+$, were consistently sampled at each site. The other remaining parameters (TN, TP, Chl *a*, turbidity) were not consistently sampled.

**B. Status of Microbiology Monitoring**

Monitoring reports from the 13 developments were reviewed for monitoring of fecal coliforms and enterococci. Only three developments monitored fecal coliforms and enterococci, Mauna Lani (Makaiwa Bay and Pauao Bay) and NELHA. These samples were collected from marine waters. Monitoring methods were not clearly outlined in the development monitoring reports and frequency of sampling for all developments was inadequate for analysis using HDOH compliance regulations (Table 1).

Recommendations

*Methods*: Microbiological water quality needs to be monitored consistently with each development permit issued. Standard procedures should be followed according to established and approved State of Hawai`i and USEPA enumeration methods for evaluation of *E. coli* and enterococci (Table 1). A thorough description of quality assurance/quality control and statistical analyses for all microbiological analyses is located in *Standard Methods for the Examination of Water and Wastewater* under Part 9000, Microbiological Examination.

The most recent publication to clearly elucidate the details of the newest improved methods for *E. coli* and enterococci evaluation are USEPA/821/R-97/004 (2000), Method 1600 (2002) and Method 1103.1 (2002). Messer and Dufour (1998) describe the membrane filtration procedure for enterococci enumeration in detail. Shibata et al. (2004) also clearly discuss the methods with detailed descriptions of procedures. Alternative methods became available in 2003 when USEPA approved IDEXX enterococci and *E. coli* tests, the only commercial microbiological tests included in *Standard Methods for Examination of Water and Wastewater,* 20$^{th}$ Edition (USEPA, 2003).

*Sampling frequency*: Frequency of sampling is a key factor in adequate evaluation of the conditions of the inland and marine recreational waters. In order to evaluate results with HDOH compliance regulations, sampling must occur at specified intervals consistently over a one month period. Sampling design should be consistent with water quality sampling frequency.

*Data analysis*: Data analysis should be consistent with HDOH microbiological analyses for geometric means of *E. coli* and enterococci. Clear directions are presented for analyses in *Standard Methods for Examination of Water and Wastewater*, $19^{th}$ Edition and subsequent editions.

Table 2. Water quality standards for anchialine ponds based on measured concentrations at Kaloko-Honokohau National Historic Park (Brock and Kam 1997). In this report, these values are referred to as National Park Service (NPS) standards.

| ANCHIALINE POND Parameter | Standard |
|---|---|
| TN (μM) | 23.18 |
| $NH_4^+$ (μM) | 0.51 |
| $NO_3^-/NO_2^-$ (μM) | 4.67 |
| TP (μM) | 1.32 |
| Chl *a* (μg $L^{-1}$) | 0.36 |
| Turbidity (NTU) | 0.26 |
| $PO_4^{3-}$ (μM) | 0.80 |

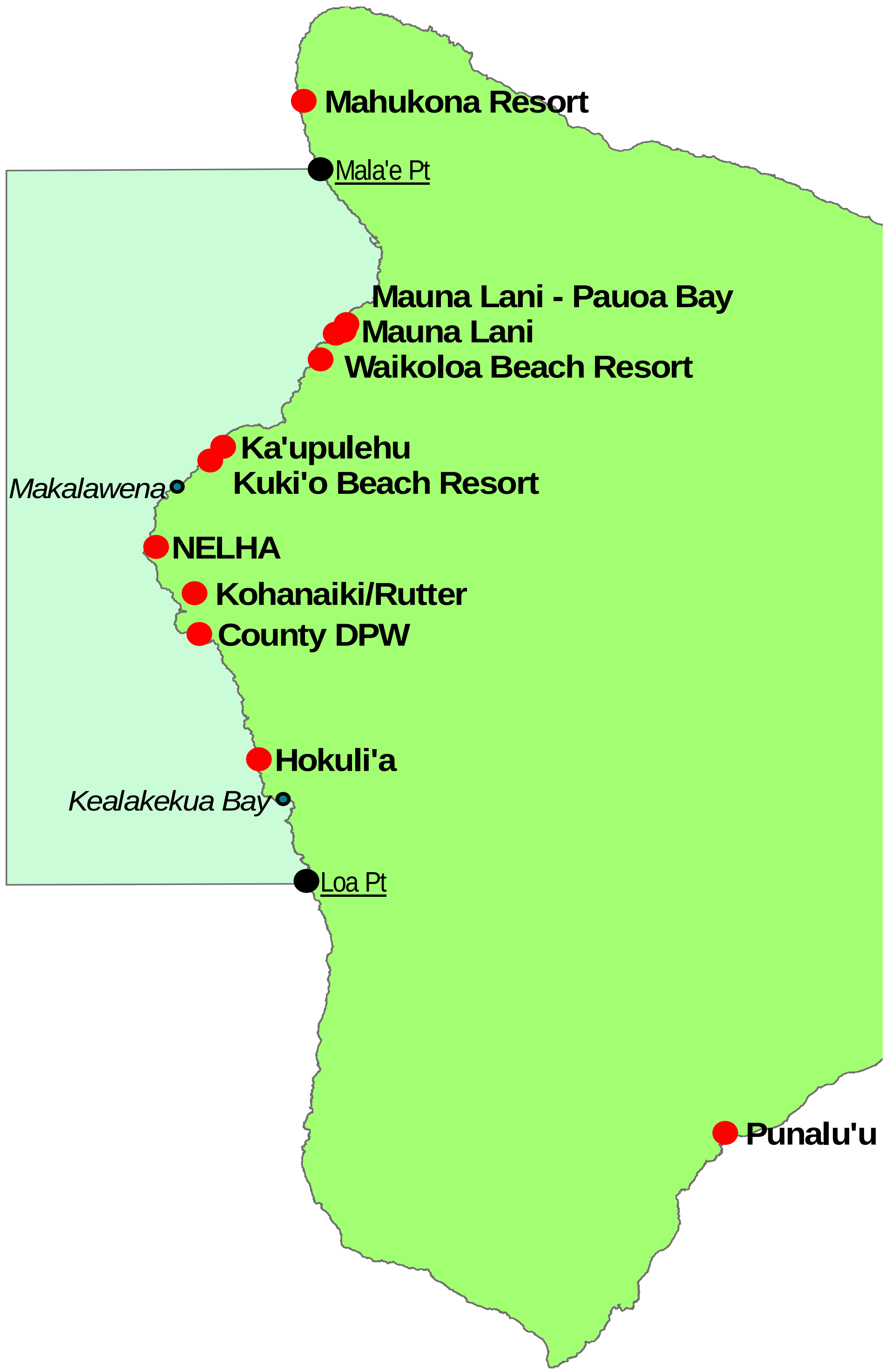



Figure 1. Development project locations in West Hawai`i. Control stations are in italics; Kona Coast waters, as designated in HDOH water quality criteria (Table 1), between Mala`e and Loa Points, are located within the enclosed area.

## C. Status of Biological Monitoring

In the 'Monitoring Protocol Guidelines', provided by the West Hawai`i Coastal Monitoring Task Force in 1992, several biological parameters and methods were recommended for use in monitoring projects. Six parameters [microbiology, Chl *a*, benthic substrate characteristics (including corals and macroalgae), macroinvertebrates, fishes, marine mammals, turtles] were recommended for biological monitoring using standard quadrat and transect methods for 'Marine Life' (Appendix I, pages 16-17) and similar recommendations for biological monitoring in 'Anchialine Ponds' (Appendix I, pages 18-19). The recommended methods are still relevant and should be implemented for any coastal development project (Appendix I). However, few of the recommended biological monitoring methods have been implemented consistently, and monitoring has not been conducted with sufficient frequency and duration to assess impacts and/or trends. Of the 13 development projects reviewed, none monitored all of the biological parameters (Table 3). The most consistently monitored biological parameter was Chl *a* (the only biological parameter with state regulated criteria), although two developments did not sample Chl *a* (Table 3). Nine development projects collected fish samples, seven sampled invertebrates and benthic substrate characteristics, and one collected data on marine turtles. Generally, data were not collected consistently so trend analysis was not possible.

Three development projects conducted biological monitoring projects of sufficient duration to analyze for trends, Waikoloa, NELHA, and Hokuli`a. Generally, development project monitoring projects did not collect data for biological parameters consistently or comparatively, except for Chl *a* measurements. For the Waikoloa project, only a single biological parameter (Chl *a*) was sampled**.** For the NELHA and Hokuli`a projects, fish and substrate samples were taken in addition to Chl *a*, but not sufficiently for a comparative temporal analysis. Analyses of Chl *a* measurements collected at Waikoloa, NELHA, and Hokuli`a demonstrated large variability in the data, with many measurements above the state-regulated criteria (Figures 2F, 5E, 6F, 7F, 8F). It is valuable to note that the lowest values for Chl *a* measurements were consistently taken at all stations at the beginning of the development monitoring period, suggesting a temporal increases in Chl *a* which is usually associated with increased nutrient loading.

Several development project reports provided adequate descriptions of biological conditions, including data on organism densities and benthic substrate coverage. These descriptions provide good baseline data for future comparisons. However, the present permit system does not provide a mechanism for long-term comparisons. Minimum permit requirements should include assessment of environmental conditions of all adjacent and potentially impacted areas, but a long-term monitoring program is needed for evaluation of trends and impacts (Section VI).

A comparison of the biological data collected during the various development monitoring projects demonstrated large spatial variability among sites. This is an expected result, considering the large range of physical and substrate conditions where sampling has been conducted (e.g., topographic complexity, percent coral cover, slope). Whereas, the spatial comparison of biological data provides an important view of the range of conditions expected on the western coast of Hawai`i, the more important data that would allow for trend analysis must be derived from a consistent monitoring program with established permanent sites. The establishment of a County Monitoring Program is the most practical means of determination of long-term trends and effects of developments (Section VI).

Fish and benthic monitoring has been conducted along the coast of West Hawai`i as part of the West Hawai`i Aquarium Program (WHAP), conducted by the Hawai`i Division of Aquatic Resources (DAR) and University of Hawai`i at Hilo (Tissot et al. 2004). WHAP has been integrated into a DAR monitoring program, which will hopefully continue to receive funding in future years. WHAP has provided excellent data for trend comparison to future development monitoring projects. The results from this program have provided data demonstrating spatial differences along the western coast and consistent temporal trends at sites with expected seasonal variation. Future monitoring projects need to be planned to take seasonal variation into account.

Marine turtle and marine mammal monitoring was also suggested in the West Hawai`i Coastal Monitoring Task Force monitoring protocols (1992). No marine mammal monitoring data were presented in reports and marine turtle data were included only in reports from Mauna Lani. Casual sightings were mentioned in other reports although no monitoring data were presented.

The most common sea turtle encountered around Hawai`i is the green sea turtle, *Chelonia mydas*. The green sea turtle is listed as a threatened species and protected in Hawai`i under state law, the federal Endangered Species Act, and listed under the Convention on International Trade of Endangered Species (CITES), making it illegal to import or export turtle products. It is illegal to kill, capture, or harass sea turtles. Although nesting grounds are mainly at French Frigate Shoals, turtles find foraging grounds around the Island of Hawai`i and are frequently observed basking on island beaches (Balazs and Chaloupka 2004). Turtles are often highly visible marine animals that attract visitors. The incidence of fibropapillomatosis (FP), a disease most commonly found in green sea turtles, has not been recorded along the west coast of Hawai`i (Aguirre and Lutz 2004), although in Kaneohe Bay, Oahu, the incidence of FP in 1991 in turtles was 92% (Balazs and Pooley 1991 cited in Aguirre and Lutz 2004). FP may soon become an indicator of ecosystem health for benthic ecosystems (Aguirre and Lutz 2004).

Recommendations: Review of biological data emphasized the need for comparative data that is consistently collected in order to assess conditions and impacts along the West Hawai`i coast. A coastal monitoring program coordinated by Hawai`i County would provide more consistent and useful data for environmental assessment, trend analysis, development impact determination, and evaluation of management strategies. Sampling/ monitoring methods should be employed for all biological parameters recommended in the 1992 Monitoring Protocol Guidelines.

Table 3. Biological parameters sampled during development monitoring projects in West Hawai`i. Parameters sampled include: microbiology (Micro), chlorophyll *a* (Chl *a*), benthic substrate (substrate coverage including corals and macroalgae), mobile invertebrates (Mobile inverts), reef fishes (Fishes), marine turtles, and marine mammals. "X" indicates data collection at the development. "-" indicates no data collection at the development.

| Development | Micro | Chl *a* | Benthic substrate | Mobile inverts | Fishes | Marine turtles | Marine mammals |
|---|---|---|---|---|---|---|---|
| Mahukona | - | X | X | X | X | - | - |
| Mauna Lani (Makaiwa Bay) | X | X | X | X | X | X | - |
| Mauna Lani (Pauoa Bay) | X | X | X | - | X | X | - |
| Mauna Lani (S. Kohala) | - | X | X | X | X | X | - |
| Waikoloa | - | X | - | - | - | - | - |
| Kaupulehu | - | X | X | X | X | - | - |
| Kukio Beach | - | X | - | - | X | - | - |
| NELHA | X | X | X | X | X | - | - |
| County DPW | - | X | - | - | - | - | - |
| Kohanaiki/Rutter | - | - | - | - | - | - | - |
| Hokuli`a | - | X | X | X | X | - | - |
| Punalu`u | - | X | X | X | X | - | - |

**D. Status of Sediment Monitoring**

Though coral reefs are recognized as structures built by animals and plants, it is rarely appreciated that over half of the material in most coral reef complexes is actually made up of sediments. These sediments can have a significant impact on coral reefs and can damage or kill corals and other reef organisms. Physical smothering of corals is the most obvious impact of increased sedimentation, but chemical effects of the sediment may also be important for long term patterns of nutrient cycling and ecosystem structure change. Because tropical soils are moderately to highly weathered and have a high iron content, it is likely that reefs will experience a higher than normal input of iron oxides from terrigenous sediments. Increased levels of iron oxides can potentially interfere with the biogeochemical cycling of important nutrients, especially phosphorus through adsorption/desorption kinetics. Furthermore, the presence of unconsolidated sediments can prevent the successful settlement of many hermatypic corals larvae. Hence, the sedimentology of a reef is an essential aspect of any thorough coral reef study.

Coral reefs are unique environments biologically, but they are also unique with respect to their sedimentology. They differ from virtually all other benthic marine sedimentary environments in that normal healthy coral reefs produce most of their own sediment. On coral reefs, well over 90% of the sediments come from the reef itself (*endogenous* sediments)(Dudley 1996), whereas most benthic marine environments accumulate sediments transported from elsewhere (*exogenous* sediments). In fact, most reefs produce far more sediment than they can accommodate internally. The excess is carried throughout the reef system and any remaining surplus is transported out of the reef environment to become beach material or transported into the deep sea. As a result, healthy coral reefs are important exporters of carbonate sediments to other marine environments and in Hawai`i are critical in maintaining the sand budget on most beaches.

The USEPA (USEPA, EMAP, 1995) lists the following qualities for which sediment should be analyzed: 1) grain size, 2) total organic carbon, 3) sediment chemistry, 4) benthic community structure, and 5) sediment toxicity.

The 1992 West Hawai`i Coastal Monitoring Program Monitoring Protocol Guidelines call for annual sampling of sediments for pre-selected toxic pollutants if there is no indication of contamination after the first samples are analyzed. Furthermore, it is noted that "catastrophic events may require more frequent data collection and analysis." Grain size analysis must be part of the sampling regime as contaminants have been shown to be concentrated in the fine grain size fractions due to their high surface area to volume ratio and high clay content.

HDOH water quality standards require that "no more than 50% of the grain size distribution of sediment shall be smaller than 0.125 mm in diameter" for all Class II beaches, for all marine pools, protected coves, and for all reef flats and reef communities (HDOH 2004). Furthermore "episodic deposits of flood-borne soil sediment shall not exceed....2 mm on living coral, ....5 mm on hard bottoms,.....[and] 10 mm on soft bottoms" for all reef flat and reef communities (HDOH 2004). Clearly sediment analysis is seen as an important component in any comprehensive marine monitoring program.

Synthesis of Monitoring Data: In spite of the importance of and requirements for carrying out sediment analysis, it is remarkable that grain size analysis was carried out in only two development monitoring projects conducted along the West Hawai`i coastal area (Table 4). These studies examined a total of only 19 sediment samples and sedimentary statistics were calculated for less than half of these samples. In another study, sediment was sampled following a heavy rainfall event in September of 2000 off the Hokuli`a development project (Brock 2000). In this case, only a single chemical analysis was carried out on a marine sediment sample created by actually mixing sediments from five different sampling sites. It was determined that these sediments most closely matched the composition of local soils and not material imported to the project development site. However, no mention was made of activities such as grading and grubbing at the site which might have led to increased soil erosion during the event, and no grain size analysis was carried out. At other sites along the Kona coast, a total of two samples were analyzed for percentage carbonate, two samples for pesticides and toxicity, and one sample was analyzed for elemental composition (Table 4).

Suggested Monitoring Protocol: It is recommended that sediment analysis be carried out as part of all coastal monitoring to include the sediment substrate of coral reef, and reef flat areas, marine pools, protected coves, and anchialine ponds. Such analyses should include, but not be limited to:

1) Grain size analysis of sediments
2) Statistical treatment of grain size analysis to include graphic mean, graphic standard deviation, and skewness
3) Percentage carbonate
4) Chemical analysis for pre-selected toxic pollutants as warranted

Following rainfall events, measurement of exogenous sediment depth and grain size should be carried out in the above mentioned areas, and following high surf overwash events, anchialine pond sediments should be analyzed. Measurements should be repeated annually or as warranted by extreme weather events as mentioned above or in the event of major development activity potentially impacting coastal areas.

Overall Recommendations: Marine sediments are useful indicators of the health of coral reef and other coastal environments. Sediments are also important as beach materials and as self-adjusting wave energy absorbers. Monitoring sediment composition and grain size distribution are a key element in any marine monitoring program and should be required.

Table 4. Development projects where sediment studies were carried out. "X" indicates the type of sediment analysis conducted. "-" indicates where data was not collected.

| Development | # Samples | Grain size | Statistics | % Carbonate | Toxins/pesticides analyses | Elemental analyses |
|---|---|---|---|---|---|---|
| Mahukona | - | - | - | - | - | - |
| Puako | - | - | - | - | - | - |
| Mauna Lani (Makaiwa Bay) | 2 | - | - | X | - | - |
| Mauna Lani (Pauoa Bay) | 7 | X | X | X | - | - |
| Mauna Lani (S. Kohala) | - | - | - | - | - | - |
| Waikoloa | 2 | - | - | - | X | - |
| Kaupulehu | - | - | - | - | - | - |
| Kukio Beach | - | - | - | - | - | - |
| NELHA | 7 | X | - | - | - | - |
| County DPW | - | - | - | - | - | - |
| Kohanaiki/Rutter | - | - | - | - | - | - |
| Hokuli'a | 1 | - | - | - | - | X |
| Punalu'u | - | - | - | - | - | - |

**E. Status of Physical Monitoring of Nearshore Waters**

The West Hawai`i Coastal Monitoring Program Guidelines (1992) recommend that water quality measurements for nearshore waters include "Sea/Weather Conditions." These are to include "visual observations of surface currents (speed and direction) and wind (speed and direction) during sampling, as well as, historical notes on immediate past weather conditions, i.e. incidents of high surf, rainfall, winds, etc." Where land inputs are significant "measurements should be taken at the 20 m depth contour using *in situ* current meters for at least a three month period." For nearshore water depths between 5 and 20 m, current measurements "are to be taken using surface drogues in conjunction with water quality sampling." Though land inputs of surface water in West Hawai`i tend to be highly episodic, significant groundwater input is constant, hence *in situ* current measurements are appropriate in this area (Mink and Lau 1993).

Synthesis of Monitoring Data: Clearly "Sea/Weather Conditions" can have a major influence on water quality measurements and should follow the recommended protocol. However, in none of the studies carried out in West Hawai`i was circulation actually measured. Neither current meter nor drogue studies were carried out. Wind velocities were not recorded and in only rare instances was mention given to past weather conditions. Lack of circulation and weather data is a serious weakness of all the water quality studies carried out.

Suggested Monitoring Protocol: It is recommended that "Sea and Weather Conditions" be included in all coastal monitoring of water quality. The parameters to be noted and/or measured should include:

1. Tidal state relative to the local datum, noting any local deviations from predicted tide state
2. Wind direction and speed
3. Surf conditions to include local significant wave height. In addition, buoy data on wave period and height, and swell direction and source should be included.
4. Circulation using moored current meters and/or drogues

Recommended Modification to Definition of *Brackish Waters:* HDOH water quality standards define *brackish waters* as having salinities between 0.5 and 32 ppt (Section III, A). The value of 32 ppt for the upper limit for brackish water is quite unusual, if not unique. Normally, the upper limit for brackish water is defined as either 25 ppt or 30 ppt, and in some cases is much lower, for example, the European Economic Community defines brackish water as "water with a salt concentration between 5 and 18 ppt" (75/440/EEC Annex II). Nowhere in the literature could a value as high as 32 ppt be found for the upper limit of *brackish waters*.

The dividing line between marine and brackish water has important implication for regulatory purposes. Using 32 ppt results in some marine waters being classified as estuarine thereby holding these waters to a lower standard on many criteria. It is recommended that 30 ppt be used as the upper limit for marine monitoring purposes and that brackish water be redefined as having salinities between 0.5 - 30 ppt.

Comment on Definition of Embayment and Conditions Defining Wet and Dry Seasons: In HDOH water quality standards (2004), an embayment is defined as marine water body that is land-confined and physically protected with restricted openings to open coastal waters (Section

III, A). Restricted opening is defined by the ratio of the total bay volume to the cross-sectional entrance area of seven hundred to one or greater. It is extremely difficult to identify an embayment given this definition because bathymetric data does not exist to evaluate the criteria. Additionally, there are water quality criteria for wet and dry seasons in embayments. Conditions delineating the two seasons are based on freshwater flow into the water body. A majority of the streams in Hawai`i are not gaged and so determination of freshwater flow into a coastal area is difficult. Open coastal waters also have wet and dry season water quality standards (Table 1). Like an embayment, wet and dry seasons for open coastal waters are based on freshwater flow into the water body (Table 1). Again, it is difficult to measure these conditions because most Hawaiian streams are not gaged for stream flow and many of the existing United States Geological Survey (USGS) stream gages in Hawai`i State and Island are being closed due to lack of federal and state funding (personal communication with USGS). It is recommended that wet and dry seasons be defined consistently across water bodies. We suggest that the definition for wet and dry season conditions in streams (wet season: November-April; dry season: May-October) be used for all water bodies because it is the simplest of all definitions to determine (HDOH 2004).

**F. Status of Anchialine Pond Monitoring**

Anchialine (from the Greek *anchialos*, meaning near the sea) ponds are found exclusively in the tropics and subtropics. They are characterized by a lack of surface connection to the sea, yet having measurable salinities and a damped tidal fluctuation (Hothuis 1973). The ponds are restricted to highly porous substrates such as recent lava flows or limestone adjacent to the sea. These unique habitats, though small in number, are widely distributed globally, being reported from the Sinai Peninsula of the Red Sea, Funafuti Atoll in the western Pacific (Hothuis 1973), Ascension Islands and the Azores in the Atlantic. Localities with the most numerous anchialine ponds are Fiji, Ryukyus, and the Hawaiian Islands, where they have been reported on the islands of Oahu, Maui, Molokai, and Hawai`i. Hawai`i is the only state in the United States with natural anchialine ponds ecosystems. The Hawaiian archipelago's geographic isolation provides for a greater percentage of anchialine endemic species, and therefore the highest level of biodiversity of anchialine-associated species as compared to any other Indo-Pacific region. This combination of geographic rarity and high levels of endemism and biodiversity establishes anchialine ponds as exceptional and valuable ecosystems.

A few anchialine ponds have been discovered on Oahu and 23 have been mapped on Maui near Cape Kinau (Brock 1985). Hawai`i Island has by far the largest number of anchialine ponds and of the estimated 520 ponds on the island, more than 70% occurred along a 53 km continuous section of the Kona coast (Brock et al. 1987).

Anchialine pond organisms fall into two classes, i.e. epigeal and hypogeal species. The epigeal fauna are found in the well-illuminated (sunlit) part of the anchialine system. The hypogeal organisms occur not only in the illuminated part of the system, but also in the interconnected water table below. These species are primarily decapod crustaceans, some of which are known only from the anchialine biotope (Brock 1985).

The Hawaiian anchialine pond ecosystem is dominated by a characteristic assemblage of organisms including crustaceans (shrimps, amphipods), fishes, mollusks, a hydroid, sponges, polychaetes, tunicates, aquatic insects, algae and aquatic macrophytes. Of the species of hypogeal shrimp found in anchialine ponds worldwide, three are known only from Hawai`i, opae‘ula - *Halocaridina rubra*, *Metabetaeus lohena*, and *Procaris hawaiana*. These hypogeal shrimps are usually found in waters with salinities between 2 and 30 ppt and temperatures between 22 and 30°C. When vertical stratification occurs in ponds, the shrimp move through these gradients with impunity, thus implying euryhalinity (Brock 1985).

Most striking and abundant of the Hawaiian hypogeal shrimps is *H. rubra*. It frequently occurs in densities exceeding hundreds of individuals per square meter in a given pond on a rising tide (Brock 1985). Depending on pond depth, shrimp display a tidally linked migration, emerging form the rock interstices with the incoming tide to feed in the pond, and later returning via the interstices to the subterranean labyrinth with the falling tide (Brock 1985). Nothing is known of the population size of these hypogeal shrimp in subterranean interstitial waters. Shrimp have also been recorded to have higher abundances during night hours versus daylight hours, indicating a preference for nocturnal activity (Chai 1993). *M. lohena,* about twice the size of *H. rubra,* is an active predator upon *H. rubra* (Hothuis 1973). At a maximum, *M. lohena* may occur in densities of approximately one per 100 *H. rubra*. Fishes may also be a part of the fauna of the Hawaiian anchialine habitat, but usually their occurrence in a pond signals the lack of hypogeal shrimp.

Probably the most unique aspect of the anchialine pond flora are the bright orange carbonate producing cyanophyta communities (*Schizothrix calcicola*). Their presence usually indicates a normal, healthy pond system (Brock 1985).

<u>Environmental Degradation:</u> A number of possible causes of anchialine pond degradation include: 1) development resulting in pond infilling, 2) development resulting in excessive nutrient loading, 3) recreation near ponds resulting in use as refuse receptacles, 4) use of ponds for cultivation of fishes, and 5) recreation in ponds resulting in bathing. Ponds have apparently been used for bathing since ancient times, but only recently have chemical impacts from soap, shampoo, and suntan lotion been added to the ponds. To this list could be added 6) reduced salinity of pond waters as a result of enhanced fresh water input from landscaping activities.

Perhaps one of the greatest impacts to the biota of anchialine ponds comes through the introduction of exotic fishes to these systems. Fish species prey on the resident crustaceans, particularly the shrimps. Being small and red, opae‘ula are an “ideal” food for many fish, both native and exotic. In general, ponds located in heavily populated areas have some common attributes: populations of exotic fishes, sediment dominated by mud, establishment of macroalgae. Without the presence of *H. rubra*, macroalgae overgrow the *Schizothrix* causing major changes in the appearance of the pond and ultimately leading to a system dominated by mud bottom and exotic fishes. *H. rubra* may be considered a keystone species maintaining the benthic community of anchialine ponds (Bailey-Brock and Brock 1993).

Though the Hawaiian Islands have the greatest number of anchialine ponds, many of them have been seriously disturbed by introduced exotic species (Brock 1985; Bailey-Brock and Brock 1993) such that the anchialine habitat and usual complement of native species are now rare on the islands. A 1985 study (Brock) noted loss of eight out of 23 ponds from 1972 to 1985 on the Kona coast as a result of natural infilling with sand from beach overwash, choking with alien vegetation, and intentional infilling during development. Furthermore, ten of 17 ponds studied showed a loss of native species over the same period as a result of the introduction of fish or habitat deterioration. It is also possible that ponds may be further threatened by a reduction of salinity. All 14 ponds monitored for salinity in both 1972 and 1985 showed a marked reduction in salinity (approximate 25%). It is hypothesized that the reduction is the result of an increase in fresh water infiltration probably from activities related to landscaping and maintenance of nearby vegetation. At least 130 ponds were destroyed in 1985 during the construction of the Waikoloa Resort (Brock et al. 1987). A more recent study (Belt Collins 2000) of ponds at Mauna Lani (TMK 6-8-22:09) found that only 5 of 14 ponds inventoried in 1989 remained. Of the five ponds recorded, the three largest are partially filled with sediments, leaves, and detritus. Of 300 ponds on Hawai`i Island surveyed by Acly in 2002, 43% no longer contain visible shrimp populations. Brock (Personal Communication in Acly 2003) estimated that more than 95% of the anchialine habitat has been lost over the past 20 years.

Synthesis of Development Projects' Monitoring Data

*Water quality assessment:* To assess water quality in anchialine ponds in West Hawai`i, we compiled water quality data from reports for Waikola from 1991 to 2002 and Hokuli`a from 1991 to 2001. Because anchialine ponds are not regulated by the State of Hawai`i, water quality standards were created using historical water quality data from anchialine ponds at Kaloko-Honokohau National Historic Park (NPS standards; Brock and Kam 1997). Criteria were created for TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$, Chl *a*, and turbidity (Table 2). These parameters were selected based on those regulated by HDOH for estuarine waters (Table 1). Criteria for estuarine waters were selected because these waters most closely represent the physiochemical (temperature, salinity, etc.) conditions found in anchialine ponds. These water quality data were then entered and geometric means for the parameters were calculated and compared to NPS standards (Figure 2). Additionally, frequency of non-compliance with NPS standards per site was recorded (Table 5).

1. Anchialine ponds at Waikoloa: All nutrient parameters (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance with NPS standards at least 67% of the time (Table 5A). These parameters had values 1 to 45 times higher than NPS criteria. Several of these parameters (TN, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance 90% of the time or greater. $NO_3^-$ had the highest values above NPS criteria; they were 2 to 45 times higher than NPS standards. Chl *a* and turbidity were out of compliance at least 30% of the time, which is the highest observed value for these parameters at Waikoloa (Section V).

2. Anchialine ponds at Hokuli`a: All nutrient parameters (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance with NPS standards 100% of the time (Table 5B). $NO_3^-$ had the highest values above the NPS criteria; they were 80 to 96 times higher than NPS standards. The other nitrogen parameters were also extremely high. TN values were 24 to 30 times higher and $NH_4^+$ values were 2 to 82 times higher than NPS criteria. Turbidity values were also out of compliance; these values were 1.5 to 4 times higher

than NPS criteria. There were not enough Chl *a* measurements to evaluate compliance for this parameter.

*Discussion:* Anchialine pond water quality at both Waikoloa and Hokuli`a was out of compliance 70% or more of the time for all nutrient parameters (Table 5). At Waikoloa, TN, $NO_3^-$, TP, and $PO_4^{3-}$ were out of compliance 90% of the time or greater (Table 5A). At Hokuli`a, TN, $NH_4^+$, $NO_3^-$, TP, and $PO_4^{3-}$ were out of compliance 100% of the time (Table 5B). Nutrient values measured in these ponds were often higher than those of highly polluted rivers and estuaries (Cole et al. 1993; Rabalais 2002). The average $NO_3^-$ concentration for highly polluted rivers is 63 µM (Cole et al. 1993), whereas the average (arithmetic mean ±S.D.) $NO_3^-$ concentrations in anchialine ponds at Waikoloa and Hokuli`a were 58 (±62) and 422 (±40) µM, respectively. Additionally, $PO_4^{3-}$ concentrations in the anchialine ponds often exceeded values found in highly polluted rivers like the Mississippi (Rabalais 2002). $PO_4^{3-}$concentrations in the Mississippi River range between 1 to 4 µM (Rabalais 2002), whereas average values found in anchialine ponds at Waikoloa and Hokuli`a were 3.8 (±4.0) and 5.5 (±3.2) µM, respectively. These $PO_4^{3-}$ concentrations are particularly high given that Hawaiian streams and groundwater have naturally low $PO_4^{3-}$ concentrations due to the high iron content of the soils (Laws et al. 2004). These results suggest that soils at Waikoloa and Hokuli`a are saturated with phosphorus. Possible sources of phosphorus include irrigation water enriched with treated sewage used to water the development grounds (Waikoloa), dry fertilizers applied to golf courses (Waikoloa), and remnant nutrients in soils from historical agriculture and cattle grazing (Hokuli`a) (Brock et al. 1987; Brock 2000). Additionally, an earlier study from Waikoloa suggests that a greater amount of the phosphorus fertilizers from the golf courses leach into the groundwater at this development because it is underlain by thin layer of sandy soil that appears to not be as effective at binding phosphorus as typical Hawaiian soils (Dollar and Atkinson 1992). These sources of phosphorus to the anchialine ponds are also likely culprits for the high $NO_3^-$ concentrations also observed.

Prior to development of the Waikoloa Resort, nutrient values were significantly lower in the anchialine ponds. Reports from the late 1960's and 1970's measured average $NO_3^-$ concentrations of 32 (±30, n = 7) and 18 (±10, n = 88) µM, respectively (Cox et al. 1969; Bienfang 1977). This comparison suggests that $NO_3^-$ concentrations have more than doubled in these ponds in the last 40 years. During the same time period, $PO_4^{3-}$ values were 1.6 (±0.4) and 1.2 (±0.3) µM, respectively (Cox et al. 1969; Bienfang 1977). Comparison of these historical values to current $PO_4^{3-}$ concentrations at Waikoloa suggests that $PO_4^{3-}$ has also more than doubled in the last 40 years. These early data for Waikoloa more closely represent nutrient concentrations measured in anchialine ponds at Pahoe Bay, HI, an undeveloped region along the west coast of Hawai`i (Parsons unpublished data 2005). Here, average $NO_3^-$ and $PO_4^{3-}$ concentrations are 9.5 (±23) and 0.0 (±0.1) µM, respectively (Parsons unpublished data 2005). The Waikoloa and Hokuli`a data sets combined with nutrient data from ponds in undeveloped areas of West Hawai`i suggest that development has severely impacted water quality in anchialine ponds, creating conditions similar to those in highly polluted rivers and estuaries.

*Biological assessment:* The biological conditions of anchialine ponds along the West Hawai`i coast have been evaluated in several reports (reviewed in Brock and Kam 1997). The biological integrity of anchialine habitat, usually evaluated by the presence and density of hypogeal shrimp, has been compromised by 1) invasive species, primarily alien estuarine fishes, and 2) habitat destruction, primarily due to developments. Brock and Kam (1997) estimated that only 10% of the anchialine resource retained biological integrity. These important habitats have been declining greatly in biological integrity in recent decades, with only a few areas receiving scientific evaluation.

Several development projects have directly eliminated a large proportion of the known anchialine ponds in the state. For example, the development in the Waikoloa area, from Waiulua to Anaehoomalu Bay, eliminated over 130 anchialine ponds, representing more than 20% of the documented state resources (Brock et al. 1988). Numerous anchialine ponds have been destroyed in other areas along the West Hawai`i coast.

The invasion of alien estuarine fishes, primarily poeciliids (guppies, topminnows), continues to be a large problem to biological integrity of anchialine ponds. The presence of invasive species and subsequent change in biological conditions have primarily occurred in anchialine ponds nearest to the shoreline, modified by development, and/or where direct introductions have occurred. Invasive species have even changed the character of anchialine ponds in protected areas, such as Kaloko-Honokohau National Historic Park (KAHO; Brock and Kam 1997). A survey of ponds in KAHO in 1972 documented that 75% of the known 64 anchialine ponds within park boundaries contained the characteristic hypogeal shrimp, opae'ula (*H. rubra*). However, the re-survey conducted in 1997 demonstrated that only 33% of the anchialine ponds had opae'ula, and fewer than 16% had consistent, larger densities of opae'ula. Similarly, Brock and Kam (1997) noted that the anchialine ponds in the Kohanaiki Parcel adjacent to KAHO, surveyed by Maciolek and Brock (1974), were free of invasive fish species in 1972, but subsequent investigations in 1986 and 1997 documented numerous ponds with invasive fish species. Brock and Kam (1997) emphasized that with proper monitoring and management, anchialine ponds could be maintained with good biological integrity.

Unfortunately, adequate monitoring of the biological conditions of anchialine ponds have not been monitored consistently on development sites. The changes in biota and the density of organisms that reside in ponds have not been adequately assessed. Monitoring biological integrity in anchialine ponds consistently should be of highest priority for any monitoring plan.

*Physical/geological assessment:* A summary of the types of data collected on anchialine ponds at the various developments along the Kona and Kau coast examined in this study are presented in Table 6. Only two of the studies carried out systematic measurements of physical parameters taking into account tide state and none considered biweekly tidal inequality (spring and neap tides). Water quality can vary considerably between high and low spring tides and these variations would be completely missed without monitoring during these periods. Only one of the studies carried out day vs. night biological inventories. All other studies were during daylight hours only, yet previous studies (Chai 1993) suggest a noctural preference for pond shrimp. No sediment grain size analyses were carried out in any of the studies, even though the ponds in the Mauna Lani - Makaiwa Bay study were near beach construction which could possibly have resulted in storm overwash and eolian transport of introduced beach sands into ponds. HDOH regulations list specific requirements for grain size that can only be determined by actual grain size analysis. The West Hawai`i Coastal Monitoring Program Guidelines (1992) specifically recommend that "sediment characteristic" be monitored for all anchialine ponds. Sediment character includes particle grain size and particle sorting statistics. No grain size analysis or analysis of sorting statistics were carried out in any of the studies.

Suggested Monitoring Protocol: The chemical parameters recommended in the West Hawai`i Coastal Monitoring Program Guidelines (1992) include nutrient analysis for TN, $NO_3^-$/ $NO_2^-$, $NH_4^+$, dissolved organic nitrogen (DON), TP, and Chl *a*. As a minimum, these analyses must be carried out in order to monitor water quality of anchialine ponds. It is also recommended that biological oxygen demand (BOD) be monitored. Physical parameters of temperature, salinity, and turbidity must also be measured regularly. The monitoring frequency must include time series data collected at both high and low tide during a spring tidal cycle for each data collection period, plus special monitoring following any major rainfall events such as Kona storms. Sampling should also be carried out along both vertical and horizontal transects across ponds in order to determine stratification and/or localized input into ponds. External parameters such as surf conditions should be noted as large surf may produce hydraulic pumping with the potential to modify temperature, salinity, and other parameters. Biological inventories should also follow the monitoring plan for physical parameters and must furthermore include night sampling. Bottom sediment samples must be collected along transects across ponds. Sediment samples should be subjected to grain size analysis with reporting of standard sedimentary statistics to include graphic mean, graphic standard deviation, and skewness.

Overall Recommendations: Given the scarcity of anchialine ponds worldwide and their unusual biota, they are a unique resource that needs to be protected from development. Hawai`i is the only state in the United States with natural anchialine ponds. These anchialine ponds have the highest level of biodiversity as compared to any other Indo-Pacific region (Brock 1985). Currently, anchialine ponds are not protected by the State of Hawai`i for preservation or water quality. If these ponds are to be maintained and preserved, establishment of a management program is essential and water quality standards must be established. Hawai`i County can lead the state by developing an anchialine pond management program that includes water quality. This program can serve as a model for the rest of the state. Key to developing this management program is establishing control sites at undeveloped or minimally impacted locations with low nutrient concentrations. These control sites are critical for evaluating baseline conditions in these ponds and for developing state water quality standards for the ponds.

Resource preservation should be concentrated on those ponds representative of the natural biotope, and a complete island-wide inventory should be made. Ponds need to be protected on both public and private lands and a policy of no net loss of ponds county-wide must be enforced. This policy should mimic the national wetlands no-loss policy, with the exception that no-loss for anchialine ponds means no loss of the 'existing natural' ponds from hereon.

Some restoration may be achieved with elimination of exotic fishes and possible return of native species to the ponds. Acly (2003) reported the return of shrimp to a pond from which the fish had been removed.

Anchialine pond research should be encouraged to answer pressing questions related to the distribution, population sizes, movement, and life histories of anchialine organisms, and the geology, hydrology, and physical parameters of the ponds including temperature and salinity. Considering the rapid pace at which degradation and change are occurring, implementation of preservation should be undertaken **immediately**.

Future developments in locations with anchialine ponds should not be allowed to impact ponds, including ponds in adjacent parcels, and should be required to establish a monitoring program and management plan for the ponds in the area that may be potentially impacted.

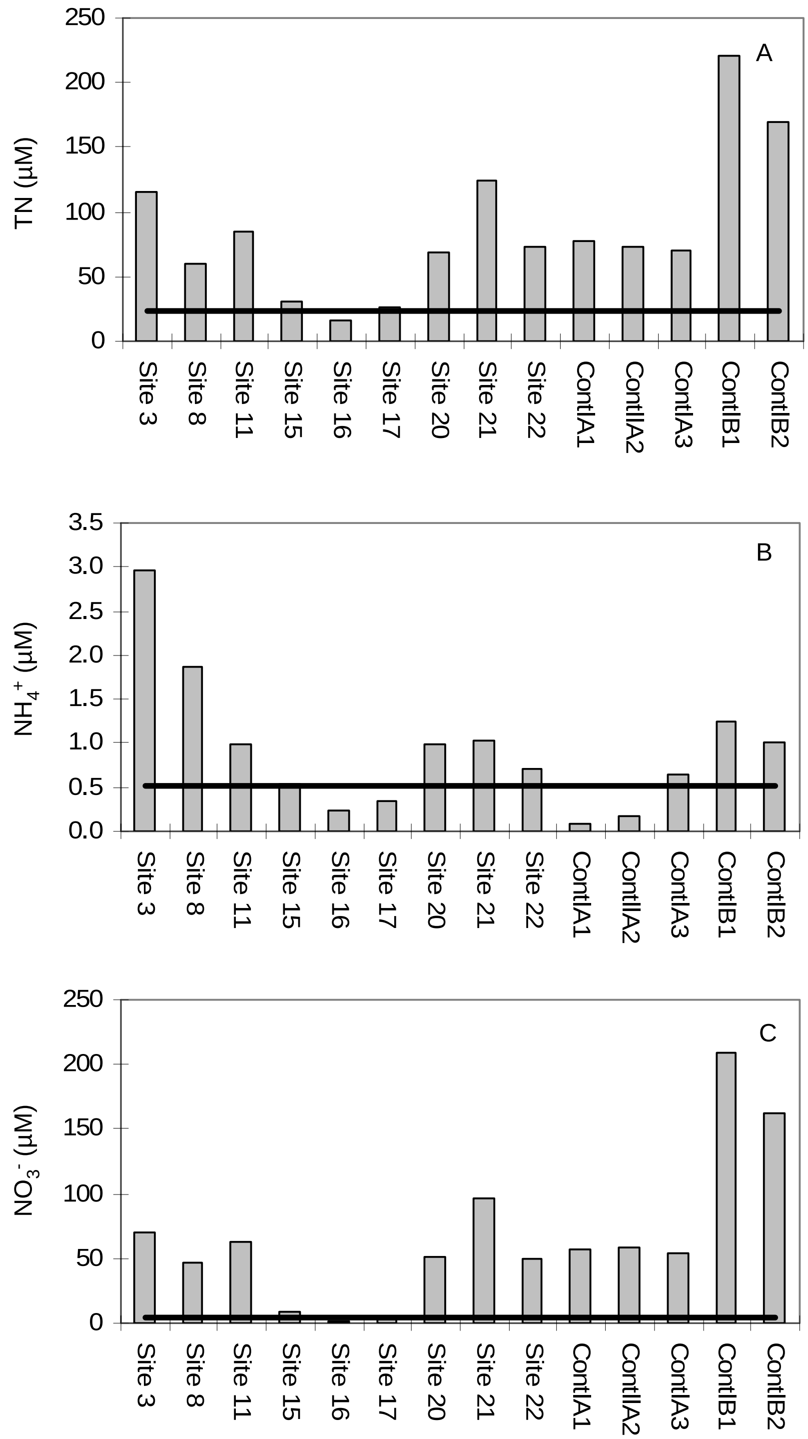



Figure 2A-C. Comparison of water quality data from anchialine ponds at Waikoloa (1991 to 2002) to NPS water quality standards. Waikoloa data are shown as geometric means and represented by gray bars. NPS standards are represented by the solid black lines.

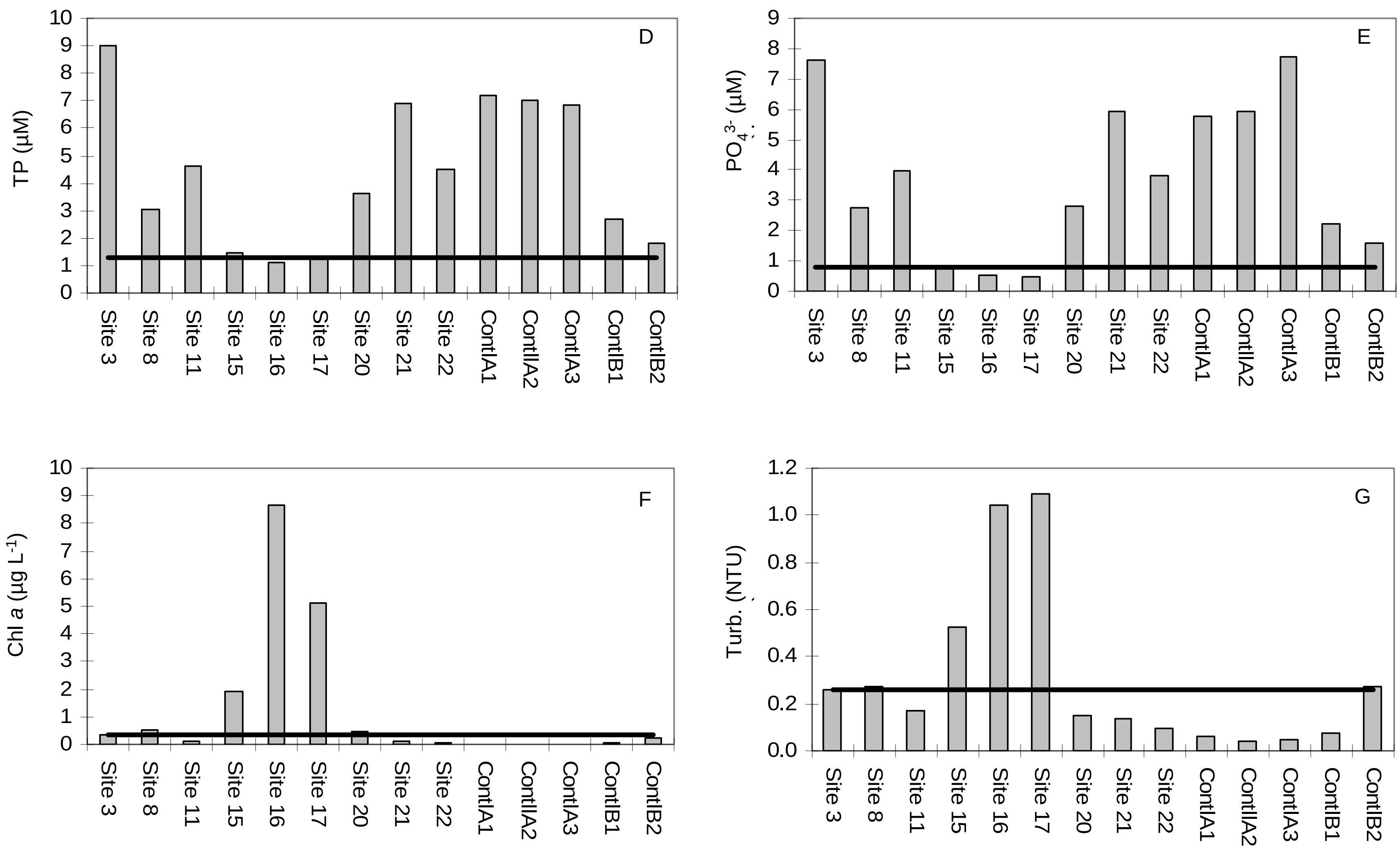



Figure 2D-G. Comparison of water quality data from anchialine ponds at Waikoloa (1991 to 2002) to NPS water quality standards. Waikoloa data are shown as geometric means and represented by gray bars. NPS standards are represented by the solid black lines. Turbidity is abbreviated as Turb.

Table 5. Evaluation of water quality compliance in anchialine ponds for Waikoloa and Hokuli'a. Data in table are presented as number of samples out of compliance with NPS (Table 2) water quality standards (% of samples out of compliance). Control sites for Waikoloa were Awakee-Makalawena (Control A) and Kukio (Control B). The were no control stations at Hokuli'a for anchialine ponds.

| **A. Waikoloa** Site | Sample period | # samples | TN | $NH_4^+$ | $NO_3^-$ | TP | Chl *a* | Turbity | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 1996-2002 | 22 | 22 (100%) | 22 (100%) | 22 (100%) | 22 (100%) | 13 (59%) | 11 (50%) | 22 (100%) |
| 8 | 1991-2002 | 16 | 15 (94%) | 16 (100%) | 16 (100%) | 16 (100%) | 10 (63%) | 6 (38%) | 16 (100%) |
| 11 | 1991-2002 | 40 | 40 (100%) | 34 (85%) | 40 (100%) | 40 (100%) | 1 (3%) | 11 (28%) | 40 (100%) |
| 15 | 1991-2002 | 38 | 28 (74%) | 25 (66%) | 26 (68%) | 21 (55%) | 30 (79%) | 30 (79%) | 18 (47%) |
| 16 | 1991-1994 | 16 | 7 (44%) | 5 (31%) | 7 (44%) | 5 (31%) | 16 (100%) | 15 (94%) | 5 (31%) |
| 17 | 1991-2002 | 37 | 21 (57%) | 18 (49%) | 19 (51%) | 16 (43%) | 15 (41%) | 33 (89%) | 36 (97%) |
| 20 | 1991-2002 | 39 | 37 (95%) | 31 (79%) | 38 (97%) | 37 (95%) | 19 (49%) | 9 (23%) | 37 (95%) |
| 21 | 1992-2002 | 36 | 36 (100%) | 33 (92%) | 36 (100%) | 35 (97%) | 1 (3%) | 2 (6%) | 36 (100%) |
| 22 | 1994-2002 | 28 | 28 (100%) | 22 (79%) | 28 (100%) | 28 (100%) | 0 (0%) | 1 (4%) | 28 (100%) |
| Control A1 | 1994-2002 | 8 | 8 (100%) | 1 (13%) | 8 (100%) | 8 (100%) | 0 (0%) | 0 (0%) | 8 (100%) |
| Control A2 | 1994-2002 | 8 | 8 (100%) | 2 (25%) | 8 (100%) | 8 (100%) | 0 (0%) | 0 (0%) | 8 (100%) |
| Control A3 | 1994-2002 | 8 | 8 (100%) | 3 (38%) | 8 (100%) | 8 (100%) | 0 (0%) | 0 (0%) | 8 (100%) |
| Control B1 | 1994-1999 | 5 | 5 (100%) | 4 (80%) | 5 (100%) | 5 (100%) | 0 (0%) | 0 (0%) | 5 (100%) |
| Control B2 | 1994-1999 | 5 | 5 (100%) | 5 (100%) | 5 (100%) | 4 (80%) | 1 (20%) | 3 (60%) | 5 (100%) |
| **Average (±S.D.)** | | | **90% (±18)** | **67% (±30)** | **90% (±20)** | **86% (±24)** | **30% (±35)** | **34% (±35)** | **91% (±22)** |

| **B. Hokuli'a** Site | Sample period | # samples | TN | $NH_4^+$ | $NO_3^-$ | TP | Chl *a* | Turbidity | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|
| 25-P | 2001 | 1 | 1 (100%) | 1 (100%) | 1 (100%) | 1 (100%) | 0 | 1 (100%) | 1 (100%) |
| 39-P | 2001 | 1 | 1 (100%) | 1 (100%) | 1 (100%) | 1 (100%) | - | 1 (100%) | 1 (100%) |
| 40-P | 2001 | 1 | 1 (100%) | 1 (100%) | 1 (100%) | 1 (100%) | - | 1 (100%) | 1 (100%) |
| **Average (±S.D.)** | | | **100% (±0)** | **100% (±0)** | **100% (±0)** | **100% (±0)** | | **100% (±0)** | **100% (±0)** |

Table 6. Physical and chemical parameters measured at development sites during monitoring studies of anchialine ponds. "X" indicates the type of analysis conducted and "-" indicates the absence of analysis. Temperature and turbidity are abbreviated as Temp. and Turb., respectively.

| Development | Pond studies | Temp. | Salinity | Oxygen | pH | Chl *a* | Turb. | Nutrients | Tide state | Bottom substrate | Sediment analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mahukona | - | - | - | - | - | - | - | - | - | - | - |
| Puako | X | - | X | - | - | - | - | - | X | - | - |
| Mauna Lani (Makaiwa Bay) | X | X | X | X | - | X | X | X | - | - | - |
| Mauna Lani (Pauoa Bay) | - | - | - | - | - | - | - | - | - | - | - |
| Mauna Lani (S. Kohala) | X | - | - | - | - | - | - | - | X | X | - |
| Waikoloa | X | X | X | X | X | X | X | X | - | - | - |
| Kaupulehu | - | - | - | - | - | - | - | - | - | - | - |
| Kukio Beach | X | X | X | X | X | X | X | X | - | - | - |
| NELHA | X | - | X | - | - | - | - | - | - | X | - |
| County DPW | - | - | - | - | - | - | - | - | - | - | - |
| Kohanaiki/Rutter | - | - | - | - | - | - | - | - | - | - | - |
| Hokuli'a | - | - | - | - | - | - | - | - | - | - | - |
| Punalu'u | - | - | - | - | - | - | - | - | - | - | - |

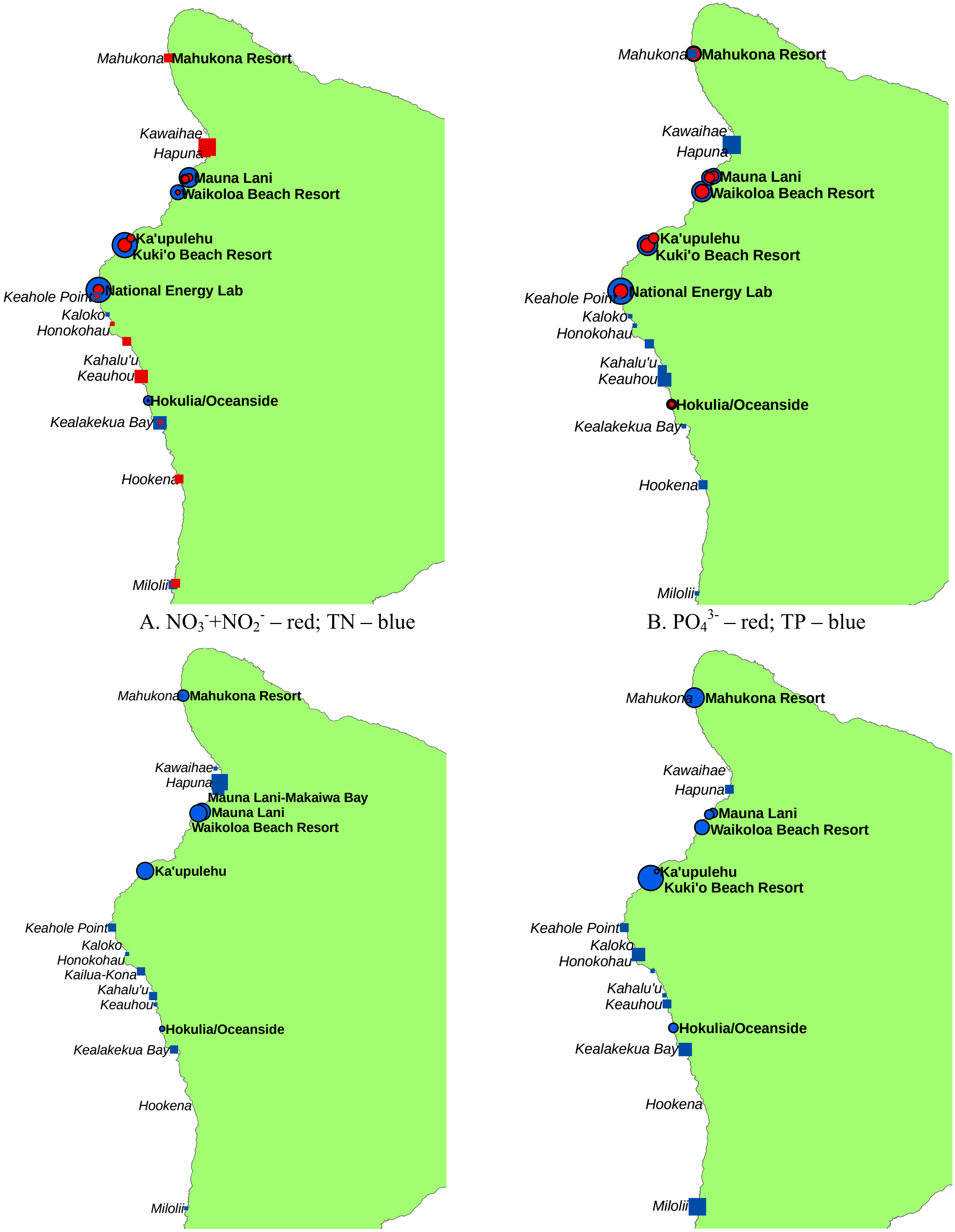
## V. FINDINGS FROM HISTORICAL WATER QUALITY DATA FROM WEST HAWAI`I

### A. Spatial View of Historical Water Quality Data

The earliest values for water quality parameters at developments (1980-1995) were compiled and entered for a spatial view of water quality along the western coast of Hawai`i. These values were compared to data collected by government agencies during the same period. Government data were downloaded from the USEPA Storet System, 1980-1995. Data were parsed into three salinity ranges (25-29.9 ppt, 30-32.9 ppt, 33-36 ppt) for comparison (Table 7).

A few locations showed elevated values compared to other locations along the western coast of Hawai`i (Figure 3). Generally, Mauna Lani, Waikoloa, Kaupulehu, Kukio, and NELHA had higher values than other locations along the coast. One station at NELHA, Station C24 off the coast from the NELHA wastewater trench, had particularly large nutrients values in comparison to other NELHA monitoring sites (Figures 7A-G; Table 11). The government monitoring station with high values between Kawaihae and Hapuna Beach was located at the Mauna Kea outfall. The high values at developments were recorded during early phases of development and do not include higher values recorded in recent years.

The most northern location (Mahukona) and southern location (Miloli`i) had some of the lowest values for nutrients (nitrogen and phosphorus) and turbidity. Interestingly, these locations had high values for Chl *a*, indicating higher photosynthetic activity at these sites than at most sites along the western coast of Hawai`i. These results may be explained by rapid nutrient uptake, where there are short residence times of nutrients in the water (hence the low concentrations observed) due to an active (and efficient) phytoplankton/macroalgal population (hence the high Chl *a* concentrations).




A. $NO_3^-$+$NO_2^-$ – red; TN – blue

B. $PO_4^{3-}$ – red; TP – blue

C. Turbidity

D. Chl *a*

Figure 3. Spatial representation of water quality parameters collected 1980-1995 along western Hawai`i. Development monitoring data for available parameters are represented by circles; government monitoring data are represented by squares (italics).

Table 7. Arithmetic averages of water quality parameters for coastal waters at developments along the Kona Coast, Hawai`i. Data are presented among three salinity levels: Level 1: 25-29.9 ppt, Level 2: 30-32.9 ppt, and Level 3: 33-36 ppt. Sample size (N) for each salinity level for each development is provided. "-" indicates where data were not available.

| Development | N | Salinity level | Salinity | $NO_3^-$ | $NH_4^+$ | TN | $PO_4^{3-}$ | TP | Turbidity | Chl *a* |
|---|---|---|---|---|---|---|---|---|---|---|
| Mahukona | 17 | 3 | 34.73 | 0.40 | 0.19 | 5.69 | 0.82 | 0.33 | 0.09 | 0.30 |
| Mauna Lani | 5 | 1 | 27.73 | 16.08 | 0.30 | 24.10 | 0.40 | 0.58 | 0.18 | 0.42 |
| | 10 | 2 | 31.66 | 6.46 | 0.22 | 14.40 | 0.23 | 0.40 | 0.17 | 0.21 |
| | 77 | 3 | 34.31 | 0.90 | 0.15 | 6.93 | 0.11 | 0.30 | 0.11 | 0.13 |
| Waikoloa | 4 | 1 | 29.48 | 7.35 | 0.37 | 12.95 | 0.50 | 0.72 | 0.32 | 0.26 |
| | 8 | 2 | 31.80 | 5.25 | 0.48 | 10.88 | 0.43 | 0.61 | 0.22 | 0.34 |
| | 51 | 3 | 34.19 | 0.94 | 0.32 | 7.21 | 0.17 | 0.36 | 0.19 | 0.25 |
| Kaupulehu | 1 | 1 | 29.70 | 23.80 | 0.19 | - | 0.29 | - | 0.31 | 0.27 |
| | 2 | 2 | 31.73 | 11.36 | 0.23 | - | 0.20 | - | 0.14 | 0.12 |
| | 25 | 3 | 34.32 | 0.58 | 0.14 | - | 0.17 | - | 0.12 | 0.13 |
| Kukio | 2 | 1 | 26.41 | 19.52 | 2.85 | 50.46 | 0.51 | 0.89 | 0.61 | 0.57 |
| | 2 | 2 | 30.91 | 13.67 | 2.15 | 24.53 | 0.32 | 0.55 | 0.16 | 0.66 |
| | 6 | 3 | 33.77 | 2.65 | 1.20 | 10.72 | 0.08 | 0.28 | 0.08 | 0.22 |
| NELHA | 6 | 1 | 27.70 | 18.77 | 0.31 | 23.07 | 0.68 | 0.93 | - | - |
| | 8 | 2 | 32.24 | 5.93 | 0.26 | 17.25 | 0.28 | 0.96 | - | - |
| | 83 | 3 | 34.32 | 2.44 | 0.19 | 18.63 | 0.22 | 1.08 | - | - |
| Hokuli`a | 23 | 3 | 34.22 | 0.81 | 0.18 | 6.54 | 0.13 | 0.30 | 0.08 | 0.16 |

**B. Analysis of Historical Water Quality Data from Waikoloa and Hokuli`a**

Coastal development can impact water quality of coastal waters by increasing turbidity and inorganic/organic nutrient inputs, and altering local hydrology (Frihy 2001; Harborne et al. 2001). These modifications, in turn, can lead to coral health impacts (Hunter and Evans 1995), including reductions in coral and reef fish diversity (Grigg 1992; Smith et al. 1999). A comparison of historical and recent water quality data can often indicate if enrichment has occurred (e.g., Seitzinger et al. 2002; Parsons et al. 2006). Relatively long records (10 year span) of water quality data were provided for this report for two developments on the west coast of Island of Hawai`i (Waikoloa and Hokuli`a), allowing an historical analysis of water quality. The purpose of this study, therefore, was to determine if water quality changes were evident at either development, potentially in response to land development activities.

Methods: Water quality data were analyzed separately for each development. The data were examined in relation to the salinity range of the data. As nutrients (and often sediment) are primarily introduced to coastal waters from terrestrial sources (run-off and groundwater discharge), nutrient concentrations are expected to be higher in lower salinity waters and lower at higher salinity due to diluting effects of the nutrient-poor surface waters of the ocean (Dollar and Atkinson 1992). Therefore, as nutrient concentrations will naturally vary with salinity, any changes in nutrient concentrations over time should be examined relative to salinity; i.e., across the same salinity range.

Data were selected from the earliest samples analyzed (1991 for both Waikoloa and Hokuli`a) and the latest (2002 and 2001 for Waikoloa and Hokuli`a, respectively). Data were combined over all sites sampled during both time periods, excluding controls. The Waikoloa data were sorted by salinity, and each water chemistry parameter [$NO_3^-$, TP, $NH_4^+$, TN, DON, $PO_4^{3-}$, oxygen saturation (%), pH, turbidity] was plotted against the salinity gradient (which was the same for both periods). The 1991 and 2002 data were then overlaid to determine if the slope of the gradients were different between the two time periods, suggesting that water quality changed over the ten-year period; i.e., a steeper negative slope in 2002 would indicate that incoming groundwater was enriched with nutrients relative to 1991. Potential changes were examined statistically by comparing the slopes of each gradient between the two time periods via analysis of covariance (ANCOVA) using the PROC GLM procedure in the SAS® statistical software (v8.2). If the ANCOVA results indicate that the slope of a parameter is different between the two time periods, then one can surmise that nutrient inputs and/or water quality has changed across the salinity gradient.

The Hokuli`a data could not be analyzed in the same fashion as the Waikoloa data because the Hokuli`a water quality data only overlapped on a very small portion of the salinity gradient (34.5 to 34.8 ppt). Therefore, only the water quality data that fell within that salinity range were used for comparative purposes. The 1991 and 2001 data falling within the 34.5 to 34.8 ppt salinity range were analyzed using analysis of variance (ANOVA) to determine if average parameter values changed between 1991 and 2001.

Results: Most of the Waikoloa sites were sampled four times during 1991 (March, July, November, and December) and 2002 (March, July, October, December). Hokuli`a sites, on the other hand, were sampled only once in 1991 (December), and twice in 2001 (October and November). The Hokuli`a data, therefore, were less complete and bound to be less representative of regional conditions.

ANCOVA results indicate that two of the Waikoloa parameters had a significant change in slope (concentration versus salinity) between 1991 and 2002; TN and DON (Table 8; Figure 4). None of the other parameters ($NH_4^+$, $NO_3^-$, $PO_4^{3-}$, TP, turbidity, or pH) exhibited statistically significant differences. The slope of the DON dilution gradient increased 107%, whereas, TN increased 49%, indicating that in addition to being statistically significant, these differences are numerically substantial as well.

Every parameter of the Hokuli`a data set showed potential evidence of altered water chemistry at high salinity (Table 9), with the exception of % oxygen saturation, which showed no apparent difference between 1991 and 2001. Nitrate concentrations exhibited the biggest change, a 410% increase between 1991 and 2001.

Discussion: There is evidence of nutrient enrichment at Waikoloa, particularly with respect to DON. The elevated concentrations of DON appeared to be responsible for the increase in TN as well (Table 8). The enrichment appeared to be greatest at low salinities (Figure 4), suggesting the nutrient source has a freshwater origin, possibly urea-based fertilizer, irrigation water, or waste water (all potential sources of DON; Seitzinger et al. 2002). At higher salinities, the enrichment effect attenuated and appeared to be absent at full-salinity ocean water (~35 ppt), a characteristic often noted in Hawaiian coastal waters (Dollar and Atkinson 1992). The significance of DON enrichment is that it may lead to community shifts in primary producers (i.e., more/different macroalgal and phytoplankton species) and may increase the preponderance of harmful algal species (Glibert et al. 2001), such as those that cause ciguatera fish poisoning (Bagnis et al. 1994). Further analyses are needed to truly determine the nature of the DON enrichment (e.g., stable isotope testing) and potential resultant impacts.

The water quality parameters of Hokuli`a exhibited broad differences, which in many cases were large (e.g., a 410% increase in $NO_3^-$ concentrations, Table 9). One possible explanation would be altered water chemistry (and nutrient enrichment) between 1991 and 2001. Although the results were statistically significant, the paucity of data prevented a strong statement of this conclusion; i.e., the differences could reflect inadequate sampling, resulting in unrepresentative results. If, however, the results were an accurate representation of water quality conditions at Hokuli`a, then there has been a dramatic shift in water quality, which may lead to coastal ecological impacts as mentioned above.

Recommendations: Altered water chemistry and nutrient enrichment are possible consequences of coastal development. If programs are to be set up to monitor for such change, it is recommended that a rigorous sampling regime is established (i.e., more frequent sampling, across a larger salinity gradient), something that the Hokuli`a study failed to do.  The Waikoloa water chemistry data were much more thorough, although not clearly organized respective to salinity (parameters will vary widely with different salinity; Figure 4).  DON appeared to be the major parameter displaying characteristics of enrichment, indicating that it may be a good indicator for future studies.

It is also recommended that the County adopt Before-After/Control-Impact (BACI) sampling protocols which are designed to test for impacts by sampling the to-be-impacted site and a non-impacted control site for a period of time before the impact and following the impact.  Statistical analyses can then be used to determine the nature and magnitude of the impacts.

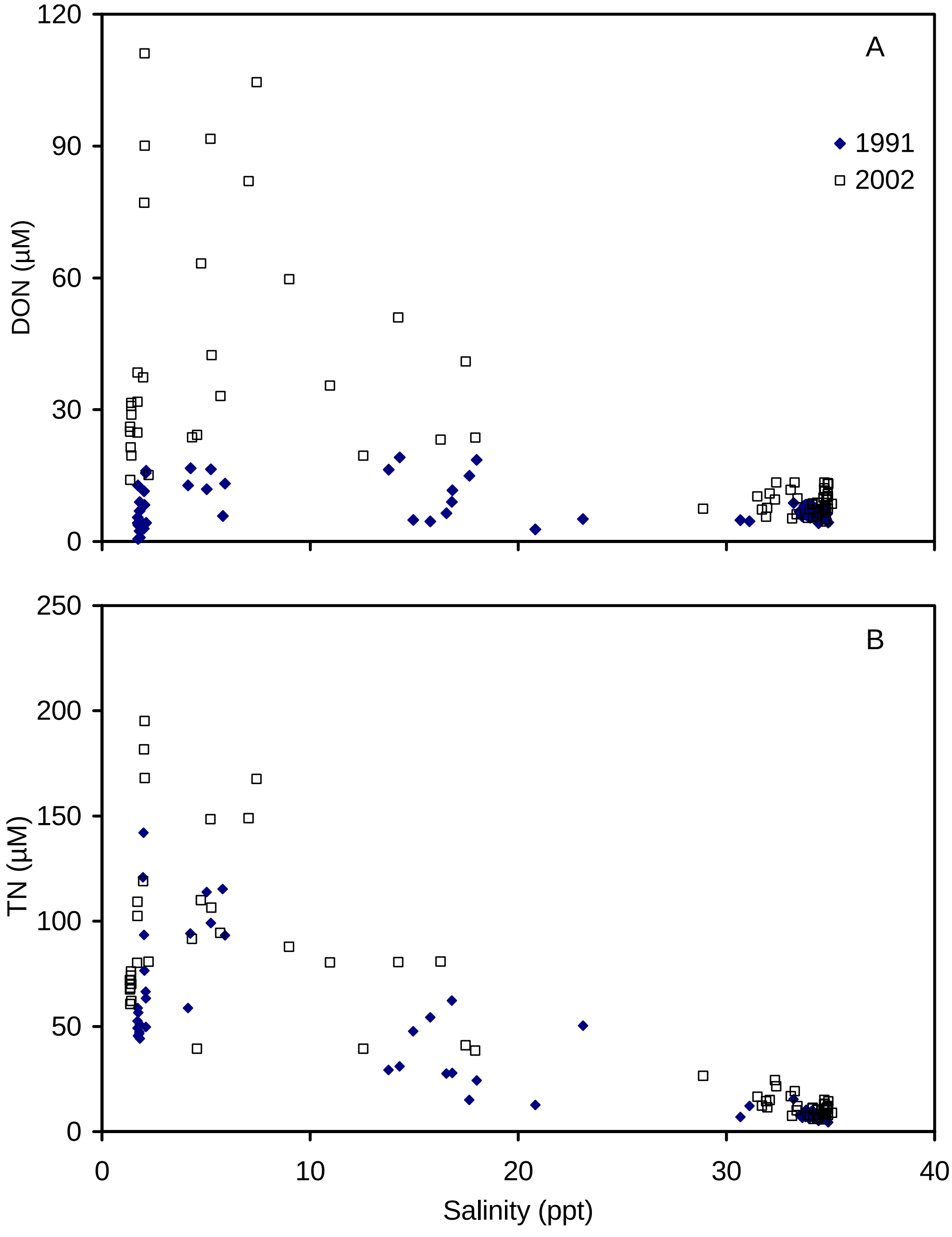



Figure 4. A comparison of A) DON and B) TN concentrations over a salinity gradient (1 to 35 ppt) between 1991 and 2002 across all sampling sites of the Waikoloa development monitoring project.

Table 8. The slopes (± 95% confidence intervals) of the three nitrogen-based parameters ($NH_4^+$, DON, TN) over a salinity gradient of 2 to 35 ppt. The % difference in the slopes, p-values of the differences (according to ANCOVA results), and significance are noted.

| Parameter | 1991 slope | 2002 slope | % difference | p-value | Significant change? |
|---|---|---|---|---|---|
| DON (µM) | -1.5 (± 1.4) | -3.1 (± 0.9) | 107% | 0.003 | Yes |
| TN (µM) | -3.9 (± 1.2) | -5.9 (± 2.0) | 49% | 0.002 | Yes |

Table 9. Arithmetic averages of water chemistry parameters (± S.D.) by year (1991 and 2001) from the Hokuli`a sampling sites (all samples within the salinity range of 34.5 and 34.8 ppt). Percent difference refers to the change in parameter values between 1991 and 2001. The p-value refers to the statistical significance of these differences according to ANOVA results.

| Parameter | 1991 average | 2001 average | % difference | p-value | Significant change? |
|---|---|---|---|---|---|
| TN (µM) | 5.33 (± 1.2) | 9.13 (± 4.3) | + 71% | 0.016 | Yes |
| DON (µM) | 4.51 (± 1.2) | 12.12 (± 5.6) | + 169% | 0.001 | Yes |
| $NO_3^-$ (µM) | 0.093 (± 0.08) | 0.474 (± 0.21) | + 410% | <0.001 | Yes |
| $NH_4^+$ (µM) | 0.121 (± 0.06) | 0.336 (± 0.21) | + 178% | 0.006 | Yes |
| TP (µM) | 0.267 (± 0.02) | 0.419 (± 0.06) | + 57% | <0.001 | Yes |
| $PO_4^{3-}$ (µM) | 0.079 (± 0.02) | 0.175 (± 0.03) | + 122% | <0.001 | Yes |
| pH | 8.16 (± 0.1) | 8.07 (± 0.01) | - 1% | 0.019 | Yes |
| Turbidity (NTU) | 0.073 (± 0.01) | 0.094 (± 0.02) | + 29% | 0.022 | Yes |

## C. Water Quality Compliance for Waikoloa, NELHA, and Hokuli`a

In Hawai`i, there is a tremendous economic reliance on the quality and health of coastlines. The west coast of the Island of Hawai`i is a major tourist destination. It is world renowned for its great weather, beautiful waters, and coral reefs. During the past 25 years, the population of Kailua-Kona, the main city on west side of the Island of Hawai`i, has more than doubled. Resort development also peaked in this region during this time. Currently, there are no continuous measurements of water quality for this region from state, federal, or private agencies or organizations. Hence, it is imperative that the fate and potential impacts of terrestrial inputs to coastal waters are quantified and managed.

Oahu and Maui, more developed islands in the State of Hawai`i, have already experienced water quality issues related to development that have resulted in loss of millions of dollars to their county's economy, with the west coast of Maui being the most recent example. Over the last 10 years, the Kīhei coast of Maui has experienced nuisance algal blooms related to nutrient-rich groundwaters discharging at the coast (USEPA 1998). Fertilizers from agricultural fields, resort grounds, and golf courses are thought to be the sources of these nutrients (USEPA 1998). It is estimated that Maui County loses $20 million dollars annually in potential revenue primarily from depressed property values ($9.4 million) and incomes from hotel and rental properties ($10.8 million) (Davidson et al. 2003). Maui County and the area's condominium owners now pay $200,000 each year to remove the nuisance algae from the beaches.

Water quality measurements for three developments [Waikoloa, NELHA (selected coastal water sites), Hokuli`a] along the west coast of the Island of Hawai`i have been reviewed and evaluated on the basis of HDOH water quality standards. The analysis provides insights into current water quality issues in West Hawai`i and indicates that management efforts are critically needed on the Island of Hawai`i to prevent nuisance algal blooms from occurring in the coastal waters.

Methods: Data on water quality parameters that HDOH regulates (Table 1) were compiled from reports for Waikoloa from 1991 to 2002 and Hokuli`a from1991 to 2001 for estuaries and open coastal waters. For NELHA, five open coastal water sites, sampled from 1992 to 1997, were selected for water quality assessment. Geometric means for the parameters were calculated and evaluated with HDOH standards (Figures 5-8). Additionally, frequency of non-compliance with HDOH standards was recorded for individual sites at Waikoloa, NELHA, and Hokuli`a (Tables 10-12). Open coastal waters sampled at Waikoloa, NELHA, and Hokuli`a were evaluated using Kona Coast standards because these three developments fall within the geographic and physiochemical range identified for these criteria (Table 1).

Results:

1. *Waikoloa*

   a) Estuarine: All nutrient parameters (TN, $NH_4^+$, $NO_3^-$, TP) were out of compliance with HDOH standards at least 50% of the time (Table 10A). Of these parameters, $NO_3^-$ values were 2.5 to 56 times higher than state criteria 95% of the time. All estuarine sites at Waikoloa were out of compliance for $NO_3^-$. Consistently, Site 4 was out of compliance with HDOH standards for all nutrient parameters (Table 10A). Site 4 is located along the shoreline on the seaward side of the channel connecting the Hilton lagoon with the ocean. This site fronts the Waikoloa Hilton Resort. Chl *a* and turbidity were the only parameters that had values below HDOH criteria.

b) Open coastal waters: All nutrient parameters (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance with HDOH standards at least 64% of the time (Table 10B). Of these parameters, $NO_3^-$ had the highest values above state criteria. $NO_3^-$ concentrations were 1.4 to 16 times higher than HDOH standards. $NH_4^+$ and $PO_4^{3-}$ also had values that were higher than HDOH standards; their values were 1 to 5 times higher than state standards. For TN, $NH_4^+$, $NO_3^-$, $PO_4^{3-}$, and turbidity, control sites B3 and B4 consistently had the highest values for all the open coastal water sites sampled at Waikoloa. Chl *a* was the only parameter where all sites sampled had geometric means below the HDOH criteria.

2. *NELHA*

a) Open coastal waters: All nutrient parameters (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance with HDOH standards at least 40% of the time (Table 11). $NH_4^+$and $NO_3^-$ concentrations were out of compliance at least 83% of the time (Table 11). $NH_4^+$ concentrations were 1.5 to 3 times higher than HDOH standards, while $NO_3^-$ concentrations were 10 to 100 times higher. Chl *a* and turbidity were out of compliance 9% and 46% of the time, respectively (Table 11). Site C24 generally had the highest nutrients and turbidity values of all the open coastal water sites sampled at NELHA (Figures 7A-G). This site is located where the Host Park disposal trench discharges into the coastal waters.

3. *Hokuli`a*

a) Open coastal waters: All nutrient parameters (TN, $NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance with HDOH standards at least 23% of the time (Table 12). Of these parameters, TN had concentrations 1 to 4 times higher than HDOH 73% of the time. Other nutrient parameters ($NH_4^+$, $NO_3^-$, TP, $PO_4^{3-}$) were out of compliance 23 to 46% of the time. Site control 30S had the highest values compared to all sites for all nutrient parameters. Chl *a* and turbidity were out of compliance at least 20% of the time.

Discussion:

*Open coastal waters:* Phosphorus and nitrogen concentrations often exceed HDOH standards in open coastal waters at Waikoloa, NELHA, and Hokuli`a (Tables 10-12). $PO_4^{3-}$ was out of compliance 68% (±22), 64% (±33), and 23% (±29) of the time at Waikoloa, NELHA, and Hokuli`a, respectively. These results are surprising because most Hawaiian streams and groundwaters have low $PO_4^{3-}$ concentrations (Laws et al. 2004). Low $PO_4^{3-}$concentrations result from the high iron content of Hawaiian soils (Garrels and Mackenzie 1971); iron effectively binds phosphorus, particularly in the form of $PO_4^{3-}$ (Brady and Weil 1999). Measurable $PO_4^{3-}$ concentrations at Waikoloa and Hokuli`a suggest that soils at these locations are potentially saturated with phosphorus. Possible sources of phosphorus include irrigation water enriched with treated sewage used to water the development grounds (Waikoloa), dry fertilizers applied to golf courses (Waikoloa), and remnant nutrients in soils from historical agriculture and cattle grazing (Hokuli`a) (Brock et al. 1987; Brock 2000). Additionally, an earlier study from Waikoloa suggests that a greater amount of the phosphorus fertilizers from the golf courses leach into the groundwater at this location because it is underlain by thin layer of sandy soil that appears to be less effective at binding phosphorus than typical Hawaiian soils (Dollar and Atkinson 1992). In contrast, high $PO_4^{3-}$ concentrations at NELHA most likely result from the nutrient-rich effluent from aquaculture and other activities discharged into the open coastal waters.

Like $PO_4^{3-}$, $NO_3^-$ was out of compliance 73% (±24), 86% (±14), and 39% (±39%) of the time at Waikoloa, NELHA, and Hokuli`a, respectively. These results are not surprising since many coastal areas in the state of Hawai`i often have $NO_3^-$ concentrations higher than HDOH standards (Laws et al. 2004). Little action has been taken to bring these waters into compliance because it has been argued that high $NO_3^-$ concentrations fall within the natural range observed for Hawaiian coastal waters (Brock et al. 1987; Laws et al. 2004). The primary source of $NO_3^-$ in Hawaiian coastal waters is from groundwater discharging at the shoreline. It is thought that groundwater $NO_3^-$ contributes to high coastal water $NO_3^-$ concentrations and variability (Brock et al. 1987; Laws et al. 2004). Careful examination of the historical data reveals that $NO_3^-$ concentrations in groundwater vary considerably, but high concentrations are generally observed in areas down gradient from agricultural or resort/residential developments (Soicher and Peterson 1997). Sites above developments on Maui and Oahu have $NO_3^-$ concentrations between 20 (Maui) to 50 μM (Oahu) (Soicher and Peterson 1997; USGS 2001, 2003). $NO_3^-$ values should be lower on the island of Hawai`i because Hawai`i is geologically younger than Maui and Oahu and basalt contains no nitrogen (Walker and Syers 1976). The only naturally occurring nitrogen in groundwater should be from rain or native nitrogen-fixing organisms in young lava flows (Vitousek 2004).

Additionally, it has also been argued that $NO_3^-$ in Hawaiian coastal waters is not a serious environmental problem unless there is biologically available phosphorus present (i.e. $PO_4^{3-}$). It is predicted that only when both nitrogen and phosphorus are available at high concentrations algal blooms will occur. Algal blooms have been observed in Kaneohe Bay (Oahu) and off of the west coast of Maui (Smith et al. 1981; Laws et al. 2004); in the case of Maui, some of the blooms were comprised of nuisance, exotic algal species (West Maui Watershed Management Advisory Committee 1997). A survey to waterfront condominium and hotels in West Maui found that approximately 80% of their beaches have an algal problem (West Maui Watershed Management Advisory Committee 1997). Algal blooms in Oahu and Maui have been linked to high nutrient concentrations in coastal waters from sewage effluent, agriculture, landscaping activities, and golf courses (Smith et al. 1981; USEPA 1998). At Waikoloa, NELHA, and Hokuli`a, $NO_3^-$ and $PO_4^{3-}$ are higher than HDOH standards (Tables 10-12). A tool often used to evaluate nutrient limitation of algae is the Redfield Ratio (Redfield 1958), which is the natural occurring ratio of nitrogen to phosphorus in a typical algal cell (16 nitrogen atoms to 1 phosphorus atom). Ratios greater than 16 indicate that phosphorus should limit algal growth, while ratios below 16 indicate that nitrogen should limit. Average ratios of $NO_3^-$ to $PO_4^{3-}$ in coastal ocean waters at Waikoloa, NELHA, and Hokuli`a are 3:1, 13:1, and 2:1, respectively. Accordingly, Waikoloa, NELHA, and Hokuli`a should be nitrogen limited, not phosphorus limited. Thus, additional nitrogen inputs to these areas could stimulate a near-shore algal bloom. Near-shore algal blooms may already be occurring at Waikoloa and Hokuli`a as suggested by their high Chl *a* concentrations that are above state standards (Tables 10 and 12).

To date, the only data set that exists for Hawai`i demonstrating how management can improve water quality comes from Kaneohe Bay (Smith et al. 1981). Prior to 1977, waste from residential cess pools and two sewage treatment plants discharged directly into Kaneohe Bay. Following diversion of sewage in 1977 to a deep ocean outfall, nutrient and Chl *a* concentrations in Kaneohe Bay were reduced by 80% and depth of light penetration in the water increased by 50% in areas most heavily affected by sewage. Changes in water quality in Kaneohe Bay greatly affected zooplankton as biomass was reduced by 50% in the most sewage impacted areas. Studies from Waikoloa, NELHA, and Hokuli`a do not include measurements beyond the primary producers (algae measured as Chl *a* concentrations), so it is difficult to assess whether increased nutrients at these sites have impacted their food web structure and dynamics. Regardless, the Kaneohe Bay study demonstrates that with proper management of coastal waters in Hawai`i (i.e., management of nutrient inputs), water quality can be dramatically improved.

Currently in Maui, the county and other public groups have taken steps to improve West Maui's coastal water quality. Nutrient loads to the coast have been reduced by >50% as the result of upgrades in the level of treatment at the Lahaina Wastewater Reclamation Facility and the use of reclaimed water for irrigation of golf courses and landscaping at the Kaanapali development (West Maui Watershed Management Advisory Committee 1997). Construction of sediment retention basins and use of best management practices by pineapple plantations are some of the actions that have been taken to reduce sediment loads to coastal waters (West Maui Watershed Management Advisory Committee 1997). In addition, several groups are educating the public about the relationship between nutrients and algal blooms and a 'Watershed Manual' has been developed (West Maui Watershed Management Advisory Committee 1997). West Maui Watershed Project has held several workshops on fertilizer practices for homeowners and managers of hotels, condominiums, and apartments about pollution prevention practices and environmentally-friendly fertilizing techniques (USEPA 1998). Cooperative Extension Services and the Landscape Industry Council of Hawai`i have also offered training course on landscape fertilization and management (USEPA 1998). Activities like those taken in Maui would most likely improve coastal water quality in West Hawai`i.

*Issues with control sites:* At both Waikoloa and Hokuli`a, controls for open coastal waters had the highest nutrient values of all sites sampled. This raises serious concerns. Controls are supposed to evaluate baseline conditions in unaffected areas, and they should have relatively low nutrient concentrations. At both Waikoloa and Hokuli`a, the controls are not measuring baseline conditions, but instead appear to be more affected by human activities than the regular sampling sites at the developments. For adequate assessment, it is critical to select appropriate controls for water quality analysis. Controls should be located in undeveloped, or minimally developed, coastal areas that have low nutrient concentrations. It is essential that these conditions are met so that a data base of existing conditions in these areas can be established and natural variability with regards to water quality parameters and long-term trends can be ascertained (West Hawai`i Coastal Monitoring Task Force 1992). Establishing baseline conditions for coastal waters in West Hawai`i is critical for 1) taking appropriate resource management actions to preserve, protect, or enhance water quality conditions, 2) quantifying and qualifying potential impacts of proposed coastal projects, and 3) providing policy makers information to make educated decisions regarding potential positive and negative aspects of a proposed coastal project relative to other uses for the sites (West Hawai`i Coastal Monitoring Task Force 1992).

*Issues with NELHA:* Site C24 located off of the NELHA facility has suspiciously high nutrient and fecal indicator bacterial cell concentrations. Levels for both of these parameters are higher than the HDOH standards. According to NELHA's 'Final Supplemental Environmental Impact Statement (EIS), 1987', NELHA has four septic tanks for domestic waste. At the time of the EIS in 1987, it was proposed that domestic waste from HOST Park be disposed of through a trench system. We suspect that Site C24 is that trench given its location and the water quality conditions at that site. With over 200 employees and poor water coastal water quality conditions at NELHA, sewage treatment may now be warranted for this development.

Recommendations:

1) A county-wide water quality monitoring program needs to be established using HDOH water quality standards. This would be a long-term program that would monitor water quality at existing and future developments in West Hawai`i. This program would be directed by the county and funded off of fees charged to the resorts. All resorts would have to pay into the monitoring program system and be monitored.

a) Sites need to be visited at least semi-monthly to provide sufficient data for analysis of conditions different seasonal, tidal, and weather conditions.
b) Appropriate controls sites need to be identified for open coastal waters. These should be located in areas of minimal development and naturally low nutrient concentrations.
c) This program will allow the county to target nutrient sources in these waters and suggest best management practices to reduce them.

2) HDOH needs to establish a time period and number of samples that need to be collected to evaluate whether a water body is in or out compliance with state water quality standards. We suggest that at least 30 samples be collected at a particular water body over the course of a year to evaluate compliance with HDOH standards.

3) Hawai`i County needs to develop an aggressive education campaign to educate the public and developments about pollution prevention practices and environmentally friendly fertilizing techniques. Best management practices for the fertilization practices at resorts and golf courses must be adopted and enforced.

4) HDOH water quality data for other sites in West Hawai`i should be analyzed in a similar fashion to the data used in this report to develop a more comprehensive analysis of water quality for the region.

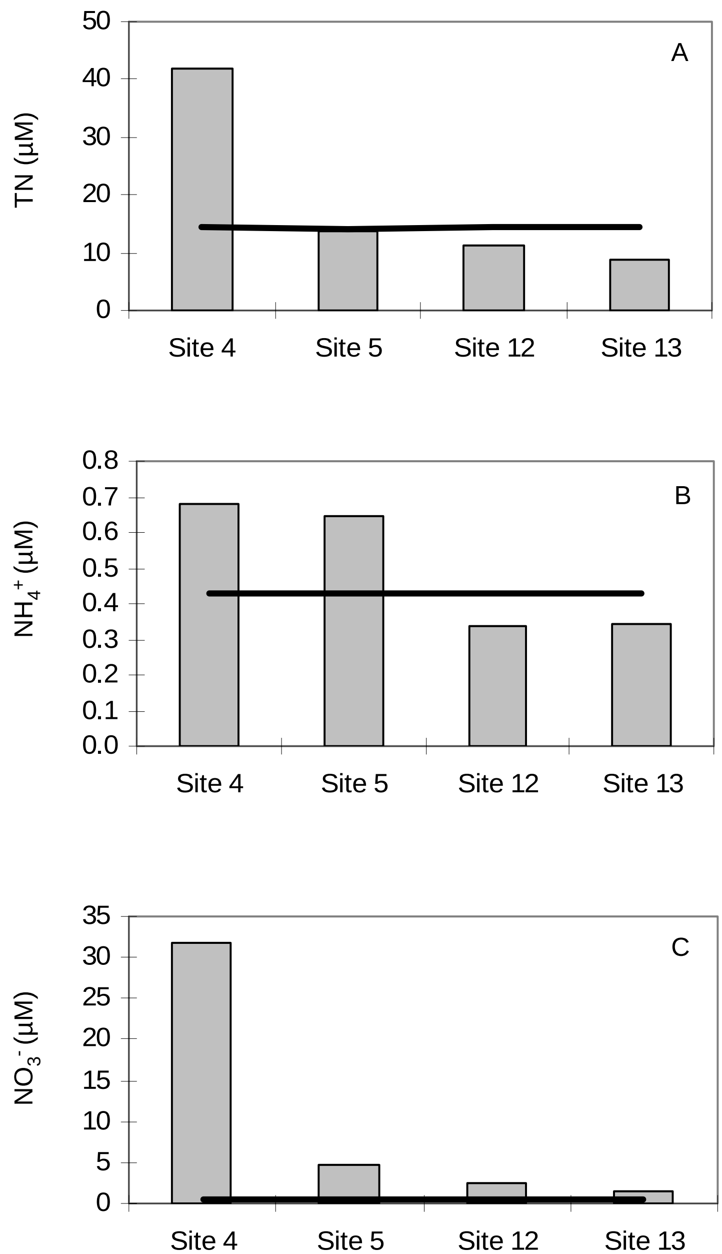



Figure 5A-C. Comparison of water quality measurements for estuarine waters at Waikoloa (1991 to 2002) to HDOH water quality standards. Waikoloa data are presented as geometric means and represented by gray bars. HDOH standards are represented by the solid black lines.

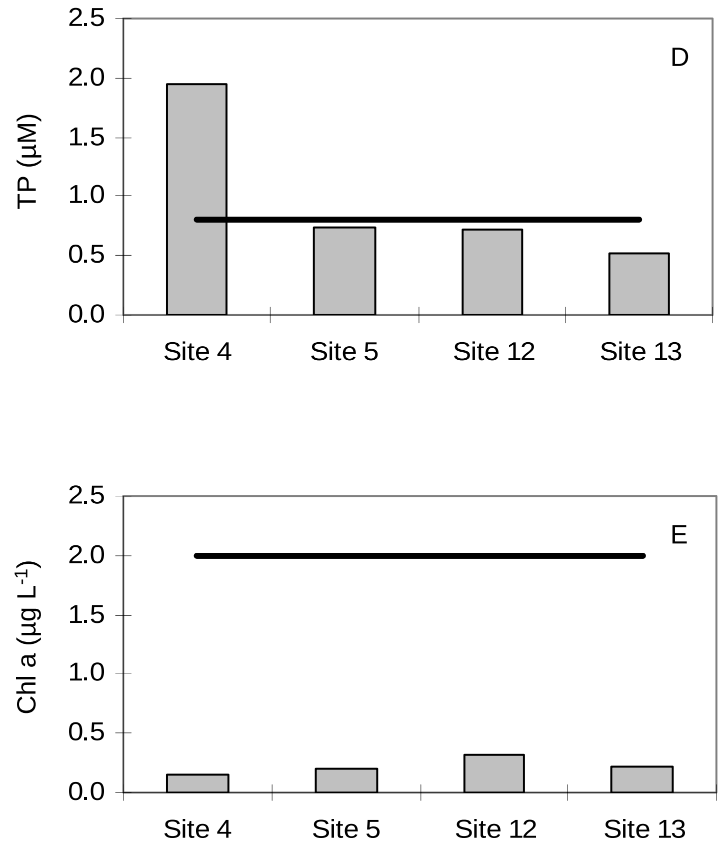



Figure 5D-E. Comparison of water quality measurements for estuarine waters at Waikoloa (1991 to 2002) to HDOH water quality standards. Waikoloa data are presented as geometric means and represented by gray bars. HDOH standards are represented by the solid black lines.

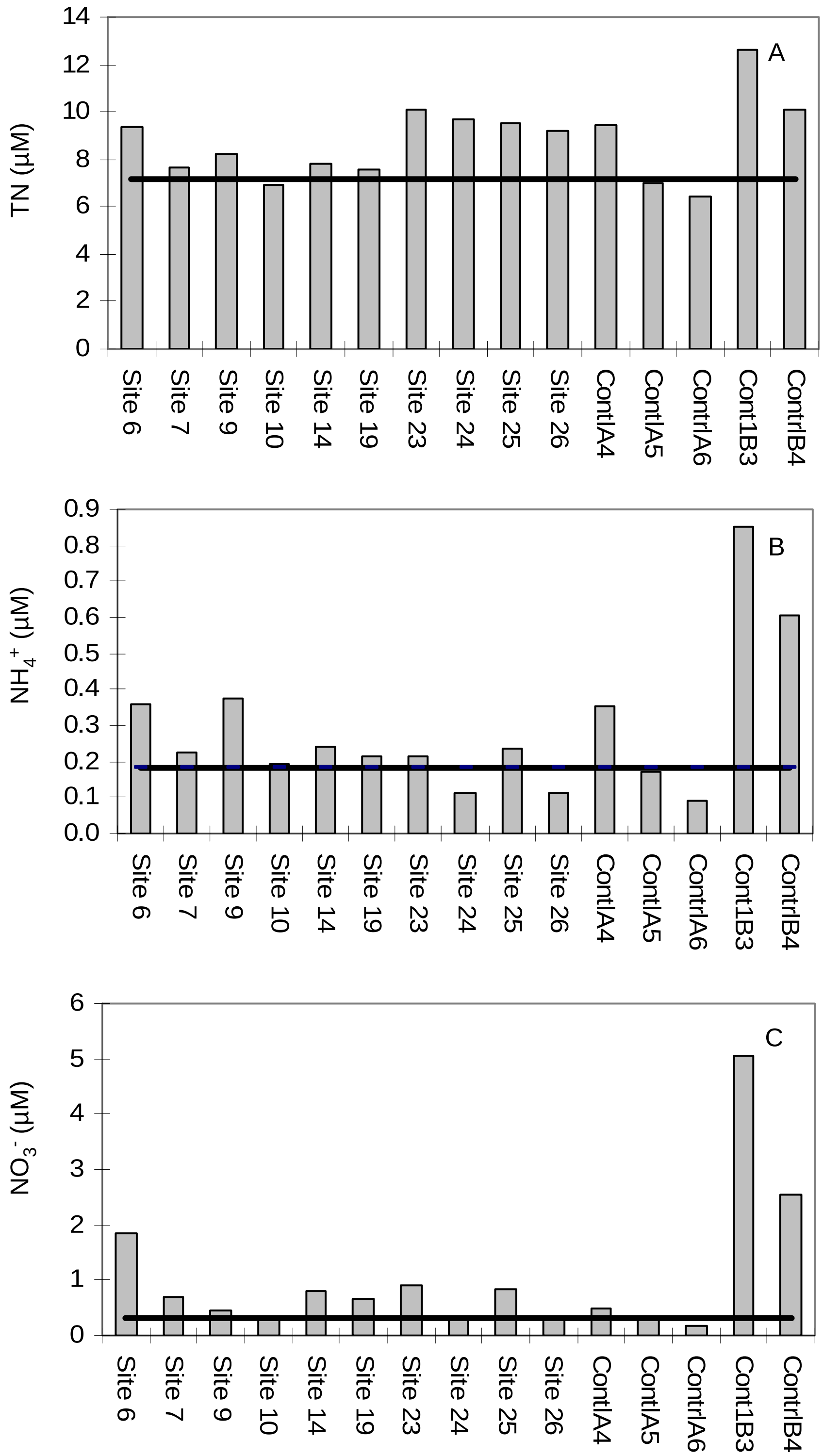



Figure 6A-C. Comparison of water quality data for open coastal waters at Waikoloa (1991 to 2002) to HDOH water quality standards. Waikoloa data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines.

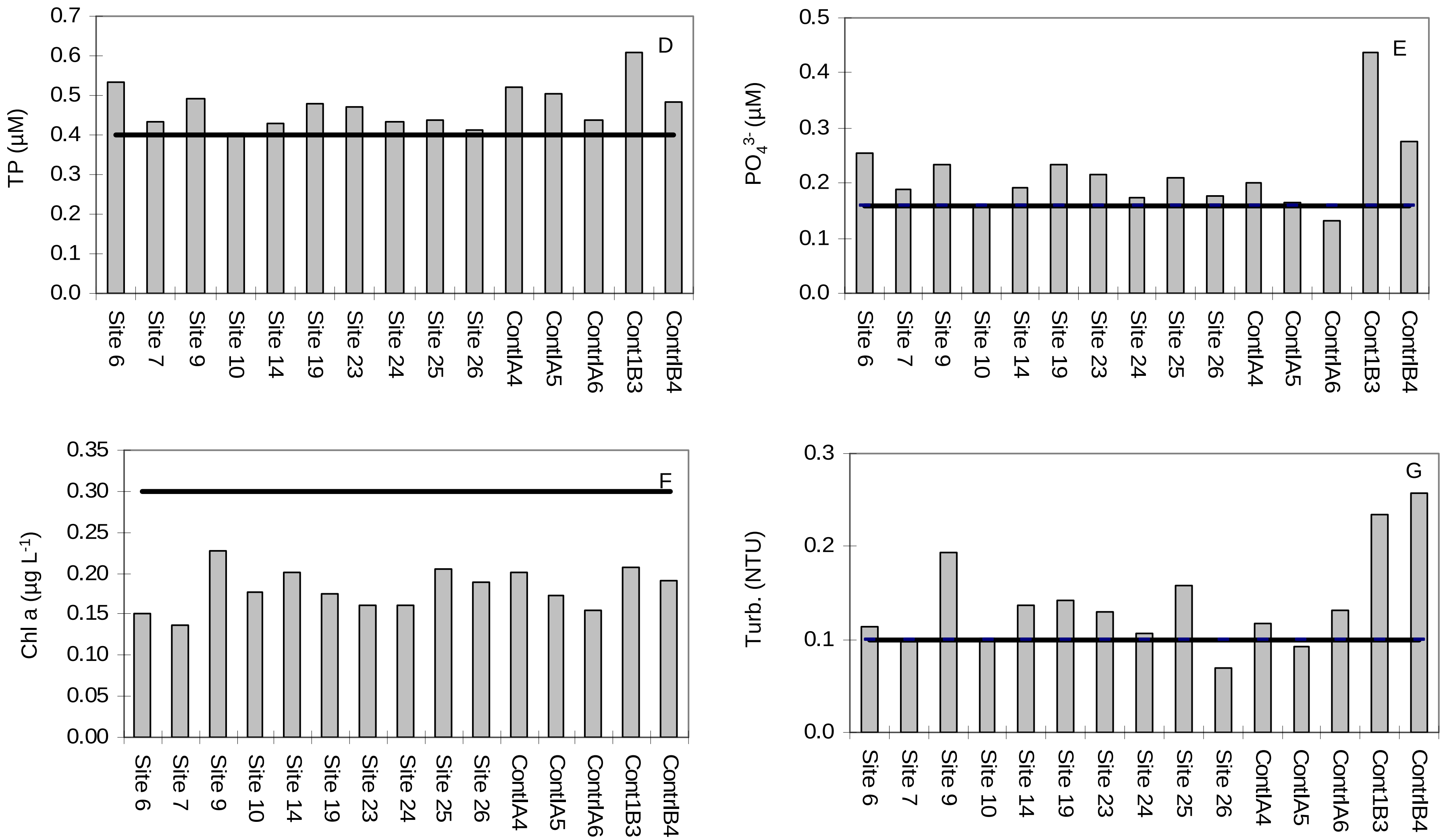



Figure 6D-G. Comparison of water quality data for open coastal waters at Waikoloa (1991 to 2002) to HDOH water quality standards. Waikoloa data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines. Tubidity is abbreviated as Turb.

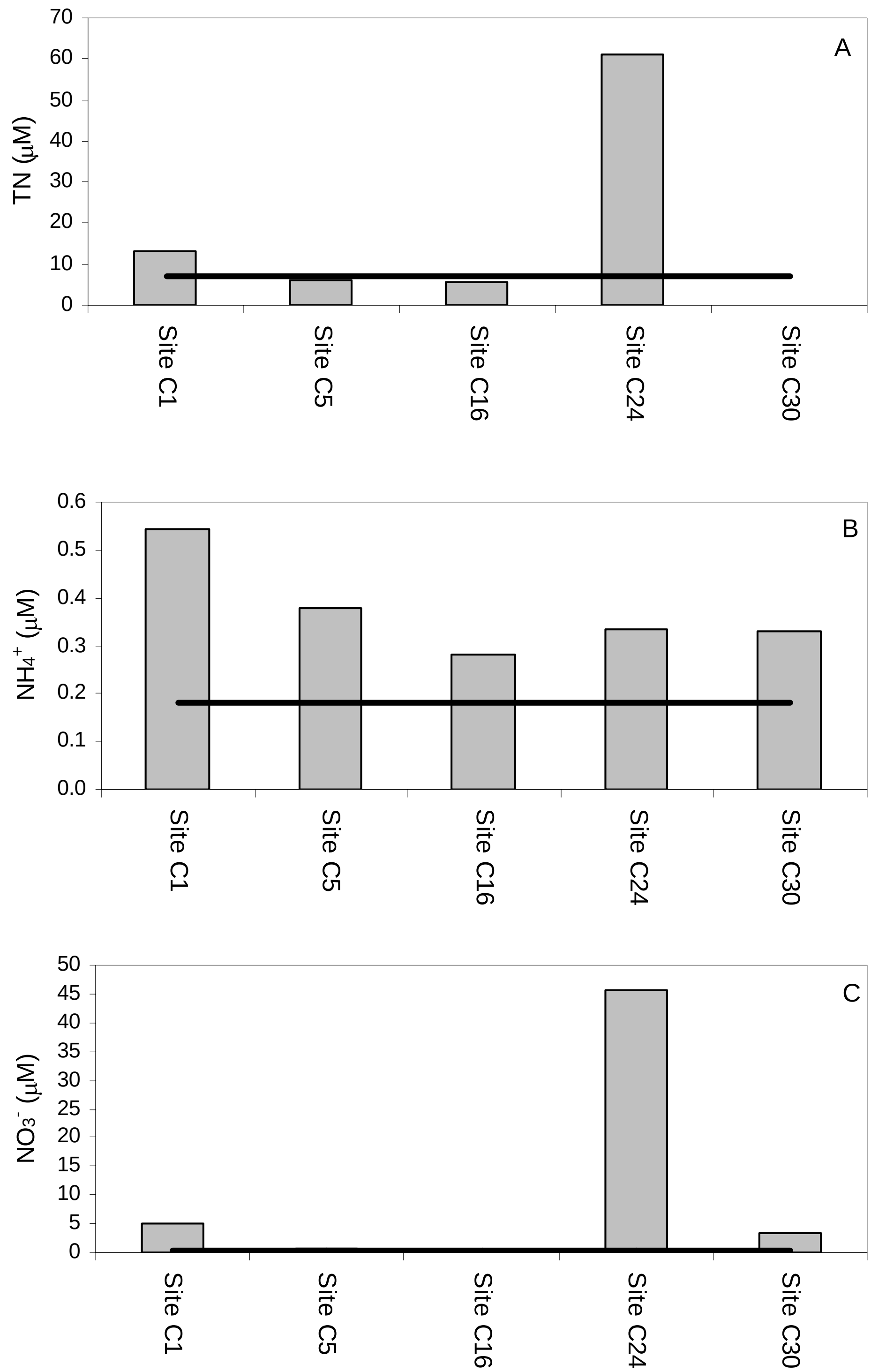



Figure 7A-C. Comparison of water quality standards for open coastal waters at NELHA (1992 to 1997) to HDOH water quality standards. NELHA data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines.

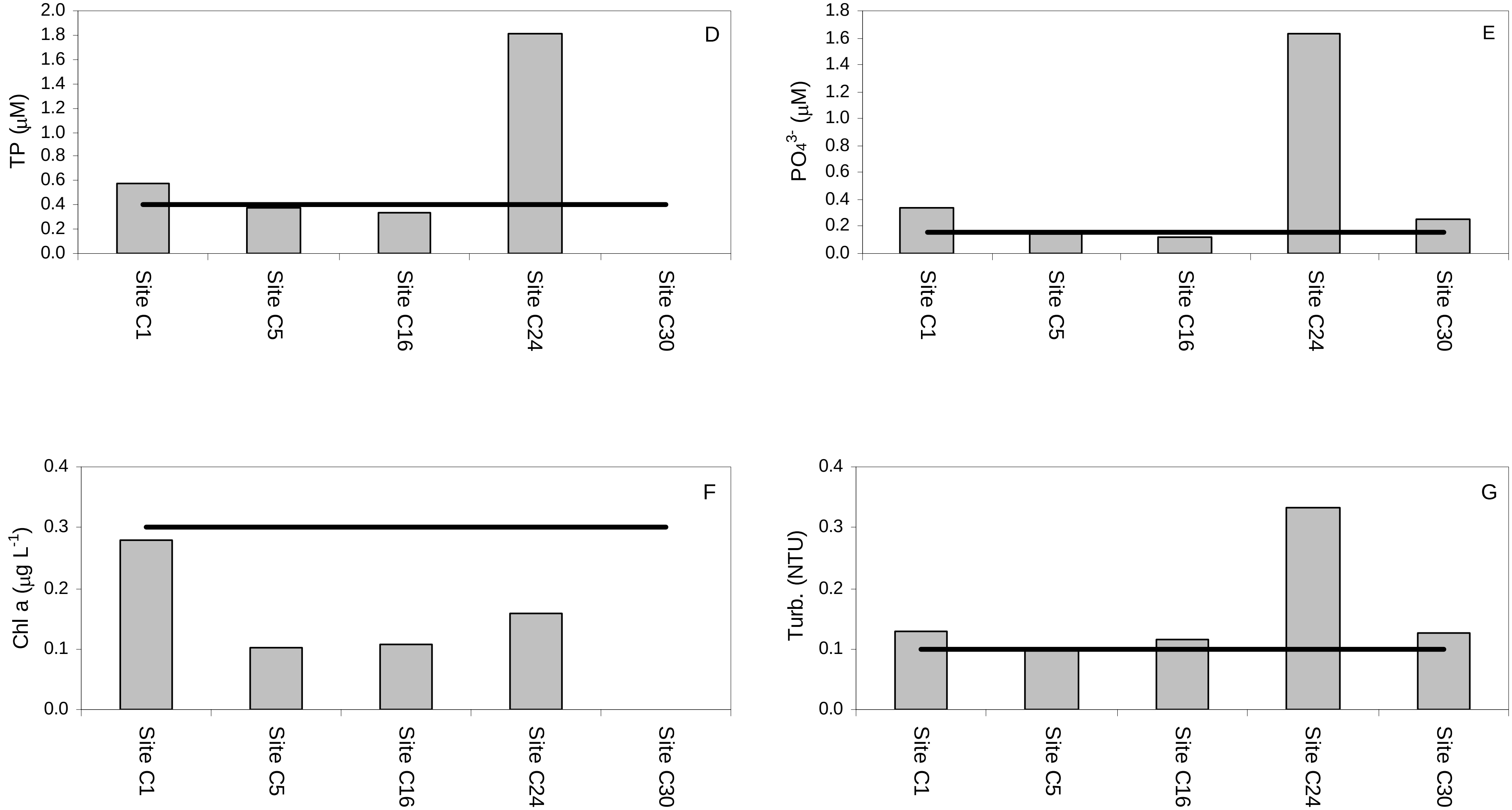



Figure 7D-G. Comparison of water quality standards for open coastal waters at NELHA (1992 to 1997) to HDOH water quality standards. NELHA data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines. Turbidity is abbreviated as Turb.

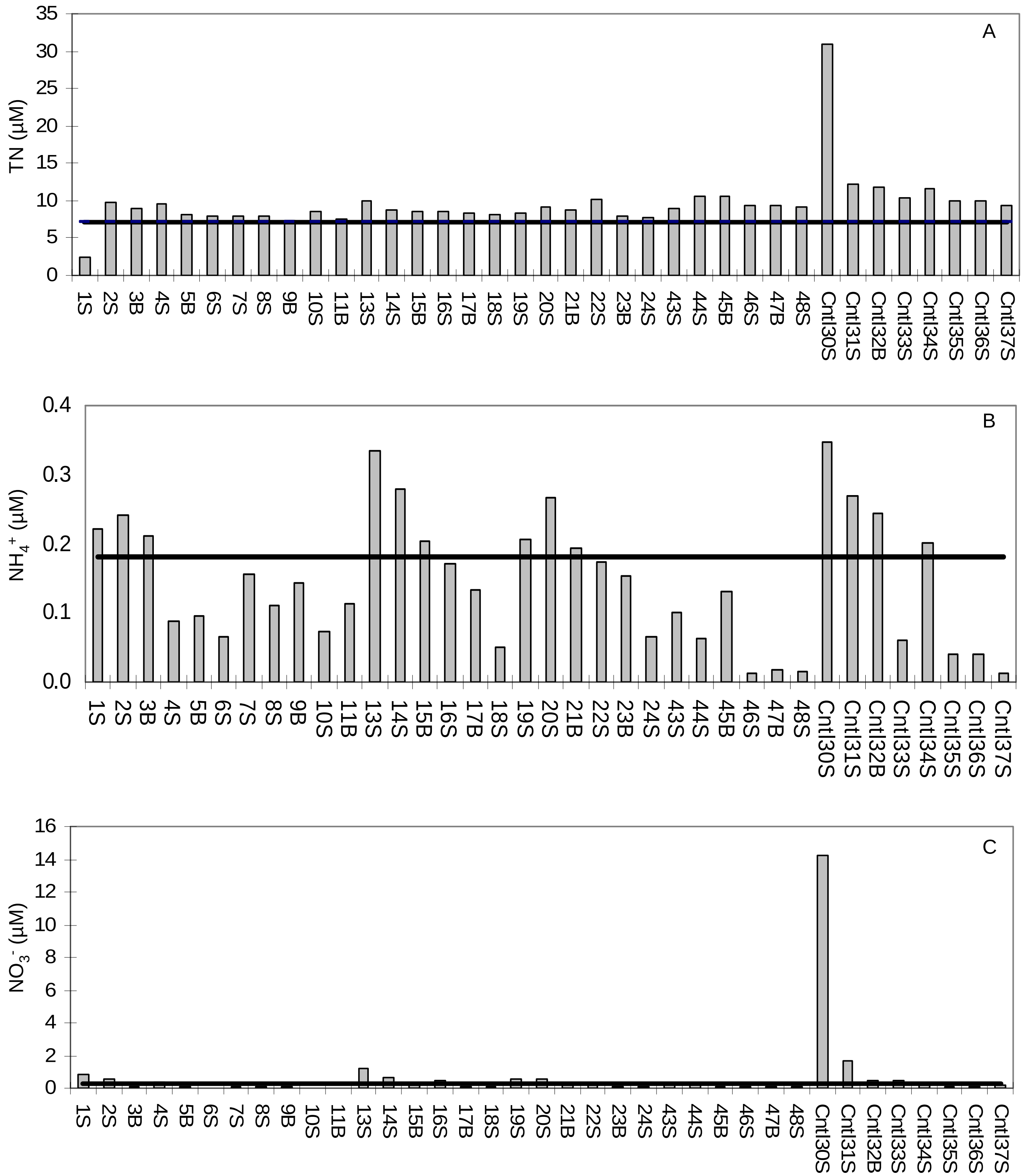
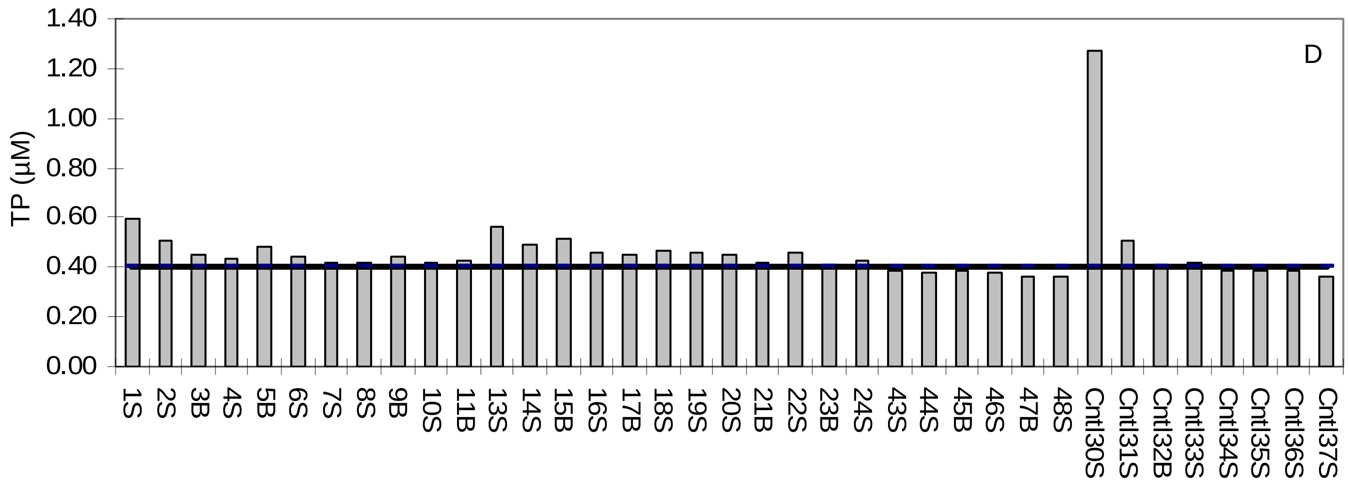



Figure 8A-C. Comparison of water quality standards for open coastal waters at Hokuli'a (1991 to 2001) to HDOH water quality standards. Hokuli'a data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines.



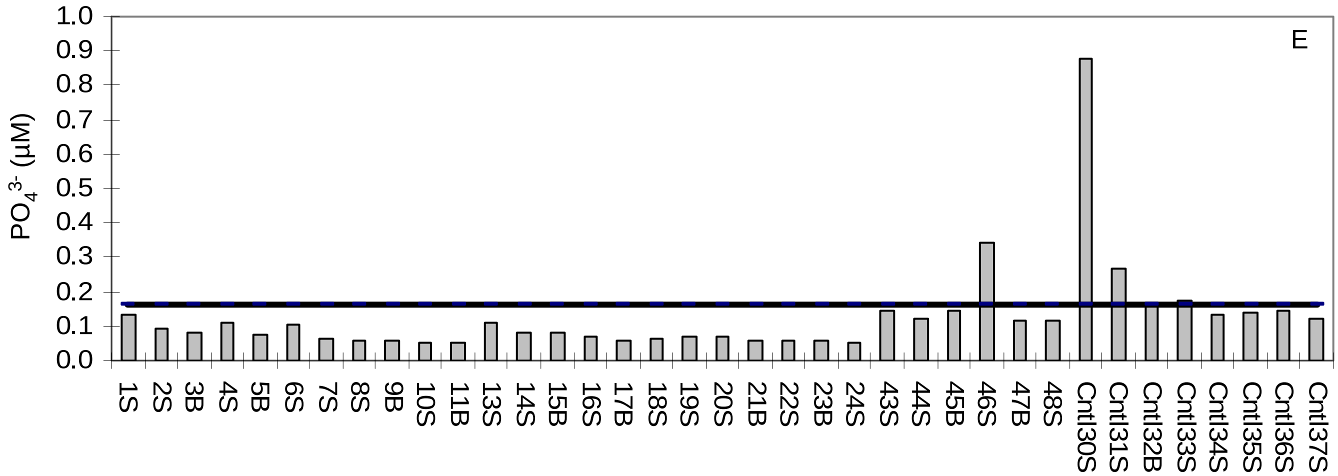




Figure 8D-E. Comparison of water quality standards for open coastal waters at Hokuli'a (1991 to 2001) to HDOH water quality standards. Hokuli'a data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines.

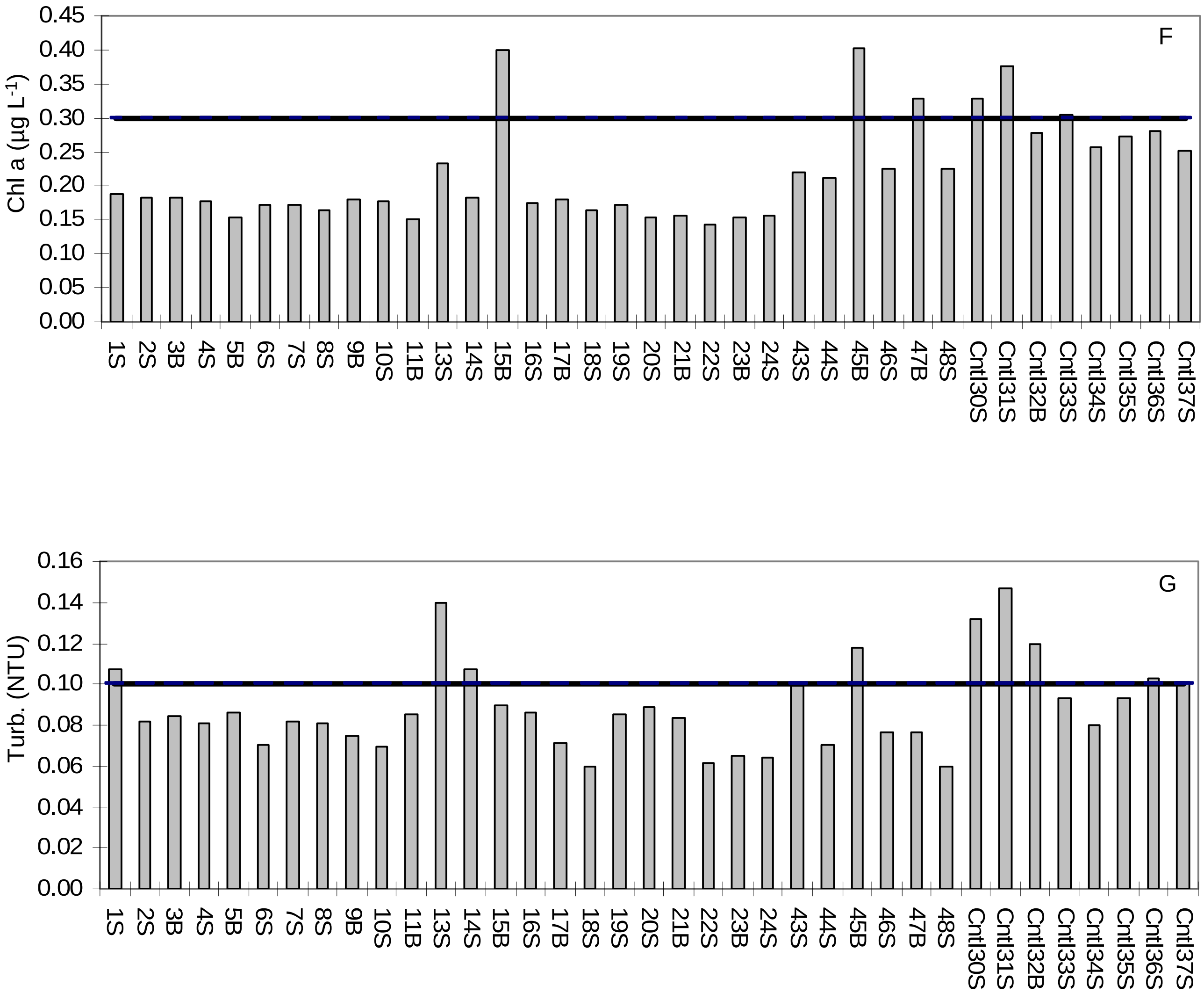



Figure 8F-G. Comparison of water quality standards for open coastal waters at Hokuli'a (1991 to 2001) to HDOH water quality standards. Hokuli'a data are shown as geometric means and represented by the gray bars. HDOH standards are represented by the solid black lines. Turbidity is abbreviated as Turb.

Table 10. Evaluation of water quality compliance for Waikoloa monitoring sites. Data in tables are presented as number of samples out of compliance with HDOH water quality standards (% of samples out of compliance). Control sites for Waikoloa were Awakee-Makalawena (Control A) and Kukio (Control B).

| **A. Estuaries** Site | Sample period | # samples | TN | $NH_4^+$ | $NO_3^-$ | TP | Chl *a* | Turbity |
|---|---|---|---|---|---|---|---|---|
| 4 | 1991-2002 | 38 | 38 (100%) | 30 (79%) | 38 (100%) | 38 (100%) | 0 (0%) | 0 (0%) |
| 5 | 1991-2002 | 38 | 19 (50%) | 32 (84%) | 37 (97%) | 14 (37%) | 0 (0%) | 0 (0%) |
| 12 | 1991-2002 | 38 | 11 (29%) | 14 (37%) | 34 (89%) | 16 (42%) | 1 (3%) | 0 (0%) |
| 13 | 1991-2002 | 38 | 37 (97%) | 10 (26%) | 36 (95%) | 5 (13%) | 0 (0%) | 0 (0%) |
| **Average (±S.D.)** | | | **45% (±41)** | **54% (±28)** | **95% (±4)** | **48% (±37)** | **1% (±1)** | **0% (±0)** |

| **B. Open coastal waters** Site | Sample period | # samples | TN | $NH_4^+$ | $NO_3^-$ | TP | Chl *a* | Turbidity | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 1991-2002 | 38 | 33 (87%) | 34 (89%) | 36 (95%) | 29 (76%) | 1 (3%) | 23 (61%) | 35 (92%) |
| 7 | 1991-2002 | 37 | 25 (68%) | 30 (81%) | 33 (89%) | 21 (57%) | 2 (5%) | 20 (54%) | 25 (68%) |
| 9 | 1991-2002 | 39 | 27 (69%) | 36 (92%) | 28 (72%) | 24 (62%) | 14 (36%) | 30 (77%) | 26 (67%) |
| 10 | 1991-2002 | 39 | 16 (41%) | 23 (59%) | 20 (51%) | 14 (36%) | 5 (13%) | 20 (51%) | 17 (44%) |
| 14 | 1991-2002 | 38 | 25 (66%) | 31 (82%) | 36 (95%) | 22 (58%) | 8 (21%) | 27 (71%) | 26 (68%) |
| 19 | 1991-2002 | 36 | 20 (56%) | 27 (75%) | 31 (86%) | 17 (47%) | 5 (14%) | 25 (69%) | 23 (64%) |
| 23 | 2001-2002 | 9 | 9 (100%) | 6 (67%) | 8 (89%) | 6 (67%) | 1 (11%) | 7 (78%) | 8 (89%) |
| 24 | 2001-2002 | 9 | 8 (89%) | 2 (22%) | 5 (56%) | 7 (78%) | 3 (33%) | 5 (56%) | 6 (67%) |
| 25 | 2001-2002 | 9 | 9 (100%) | 5 (56%) | 8 (89%) | 5 (56%) | 3 (33%) | 9 (100%) | 9 (100%) |
| 26 | 2001-2002 | 9 | 7 (78%) | 2 (22%) | 5 (56%) | 5 (56%) | 3 (33%) | 2 (22%) | 5 (56%) |
| Control A4 | 1994-2002 | 8 | 4 (50%) | 5 (63%) | 4 (50%) | 7 (88%) | 2 (25%) | 4 (50%) | 5 (63%) |
| Control A5 | 1994-2002 | 8 | 4 (50%) | 4 (50%) | 4 (50%) | 6 (75%) | 1 (13%) | 3 (38%) | 3 (38%) |
| Control A6 | 1994-2002 | 4 | 2 (50%) | 0 (0%) | 1 (25%) | 2 (50%) | 0 (0%) | 3 (75%) | 1 (25%) |
| Control B3 | 1994-1999 | 5 | 4 (80%) | 5 (100%) | 5 (100%) | 5 (100%) | 1 (20%) | 5 (100%) | 5 (100%) |
| Control B4 | 1994-1999 | 5 | 5 (100%) | 5 (100%) | 5 (100%) | 4 (80%) | 1 (20%) | 5 (100%) | 4 (80%) |
| **Average (±S.D.)** | | | **72% (±20)** | **64% (±30)** | **73 (±24)** | **66% (17)** | **19% (±12)** | **67% (±23)** | **68%(±22)** |

Table 11. Evaluation of water quality compliance for NELHA monitoring sites. Data in tables are presented as number of samples out of compliance with HDOH water quality standards (% of samples out of compliance). Turbidity is abbreviated as Turb.

| **A. Open coastal waters** Site | Sample period | # samples | TN | $NH_4^+$ | $NO_3^-$ | TP | Chl *a* | Turb. | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|
| C1 | 1992-1997 | 24 | 19 (79%) | 23 (96%) | 21 (88%) | 15 (63%) | 8 (33%) | 13 (54%) | 21 (88%) |
| C5 | 1992-1997 | 22 | 3 (14%) | 18 (82%) | 16 (73%) | 5 (23%) | 0 (0%) | 5 (23%) | 8 (36%) |
| C16 | 1992-1997 | 23 | 2 (9%) | 16 (70%) | 16 (70%) | 1 (4%) | 1 (4%) | 11 (48%) | 5 (22%) |
| C24 | 1992-1997 | 23 | 23 (100%) | 19 (83%) | 23 (100%) | 22 (96%) | 2 (9%) | 14 (62%) | 22 (96%) |
| C30 | 1992-1997 | 23 | 0 (0%) | 20 (87%) | 23 (100%) | 0 (0%) | 0 (0%) | 10 (43%) | 18 (78%) |
| **Average (± S.D.)** | | | **40% (±46)** | **83% (±10)** | **86% (±14)** | **37% (±41)** | **9% (±14)** | **46% (±14)** | **64% (±33)** |

Table 12. Evaluation of water quality compliance for Hokuli'a monitoring sites. Data in tables are presented as number of samples out of compliance with HDOH water quality standards (% of samples out of compliance). Control sites for Hokuli'a were located within Kaawaloa cove inside Kealakekua Bay along an onshore-offshore transect. Turbidity is abbreviated as Turb.

| **A. Open coastal waters** Site | Sample period | # samples | TN | $NH_4^+$ | $NO_3^-$ | TP | Chl *a* | Turb. | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1S | 1991-2001 | 7 | 5 (71%) | 3 (±43%) | 6 (86%) | 5 (71%) | 1 (14%) | 3 (43%) | 5 (71%) |
| 2S | 1991-2001 | 7 | 6 (86%) | 3 (43%) | 6 (86%) | 4 (57%) | 1 (14%) | 2 (29%) | 4 (57%) |
| 3B | 1991-2001 | 7 | 5 (71%) | 4 (57%) | 3 (43%) | 3 (43%) | 1 (14%) | 1 (14%) | 2 (29%) |
| 4S | 1991-2001 | 7 | 6 (86%) | 2 (29%) | 3 (43%) | 4 (57%) | 0 (0%) | 1 (14%) | 2 (29%) |
| 5B | 1991-2001 | 7 | 5 (71%) | 3 (43%) | 1 (14%) | 4 (57%) | 1 (14%) | 1 (14%) | 2 (29%) |
| 6S | 1991-2001 | 7 | 4 (57%) | 3 (43%) | 1 (14%) | 2 (29%) | 1 (14%) | 1 (14%) | 1 (14%) |
| 7S | 1991-2001 | 7 | 5 (71%) | 2 (29%) | 4 (57%) | 2 (29%) | 1 (14%) | 2 (29%) | 1 (14%) |
| 8S | 1991-2001 | 7 | 5 (71%) | 5 (71%) | 1 (14%) | 2 (29%) | 1 (14%) | 1 (14%) | 0 (0%) |
| 9B | 1991-2001 | 7 | 4 (57%) | 2 (29%) | 1 (14%) | 3 (43%) | 1 (14%) | 1 (14%) | 1 (14%) |
| 10S | 1991-2001 | 7 | 5 (71%) | 2 (29%) | 0 (0%) | 2 (29%) | 1 (14%) | 0 (0%) | 0 (0%) |
| 11B | 1991-2001 | 7 | 4 (57%) | 4 (57%) | 0 (0%) | 2 (29%) | 1 (14%) | 1 (14%) | 0 (0%) |
| 13S | 1991-2001 | 7 | 6 (86%) | 5 (71%) | 6 (86%) | 7 (100%) | 2 (29%) | 5 (71%) | 5 (71%) |
| 14S | 1991-2001 | 7 | 5 (71%) | 6 (86%) | 6 (86%) | 5 (71%) | 1 (14%) | 4 (57%) | 5 (71%) |
| 15B | 1991-2001 | 7 | 5 (71%) | 4 (57%) | 1 (14%) | 5 (71%) | 2 (29%) | 2 (29%) | 0 (0%) |
| 16S | 1991-2001 | 7 | 5 (71%) | 4 (57%) | 4 (57%) | 4 (57%) | 1 (14%) | 1 (14%) | 1 (14%) |
| 17B | 1991-2001 | 7 | 4 (57%) | 2 (29%) | 0 (0%) | 3 (43%) | 1 (14%) | 1 (14%) | 0 (0%) |
| 18S | 1991-2001 | 7 | 4 (57%) | 3 (43%) | 2 (29%) | 3 (43%) | 1 (14%) | 0 (0%) | 0 (0%) |
| 19S | 1991-2001 | 7 | 5 (71%) | 4 (57%) | 4 (57%) | 4 (57%) | 0 (0%) | 2 (29%) | 2 (29%) |
| 20S | 1991-2001 | 7 | 5 (71%) | 4 (57%) | 5 (71%) | 4 (57%) | 1 (14%) | 1 (14%) | 2 (29%) |
| 21B | 1991-2001 | 7 | 5 (71%) | 3 (43%) | 1 (14%) | 3 (43%) | 0 (0%) | 1 (14%) | 0 (0%) |
| 22S | 1991-2001 | 7 | 6 (86%) | 2 (29%) | 2 (29%) | 4 (57%) | 0 (0%) | 0 (0%) | 2 (29%) |
| 23B | 1991-2001 | 7 | 4 (57%) | 4 (57%) | 0 (0%) | 1 (14%) | 0 (0%) | 0 (0%) | 0 (0%) |
| 24S | 1991-2001 | 7 | 3 (43%) | 2 (29%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (14%) | 0 (0%) |
| 43S | 2001 | 3 | 3 (100%) | 1 (33%) | 2 (67%) | 1 (33%) | 1 (33%) | 2 (67%) | 0 (0%) |
| 44S | 2001 | 3 | 3 (100%) | 0 (0%) | 3 (100%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| 45B | 2001 | 3 | 2 (67%) | 0 (0%) | 1 (33%) | 1 (33%) | 2 (67%) | 1 (33%) | 0 (0%) |
| 46S | 2001 | 3 | 2 (67%) | 0 (0%) | 0 (0%) | 1 (33%) | 0 (0%) | 0 (0%) | 1 (33%) |
| 47B | 2001 | 3 | 2 (67%) | 1 (33%) | 0 (0%) | 0 (0%) | 2 (67%) | 1 (33%) | 0 (0%) |
| 48S | 2001 | 3 | 2 (67%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Control 30S | 2001 | 3 | 3 (100%) | 3 (100%) | 3 (100%) | 3 (100%) | 2 (67%) | 2 (67%) | 3 (100%) |
| Control 31S | 2001 | 3 | 0 (0%) | 2 (67%) | 3 (100%) | 2 (67%) | 1 (33%) | 2 (67%) | 3 (100%) |
| Control 32B | 2001 | 3 | 3 (100%) | 1 (33%) | 2 (67%) | 3 (100%) | 1 (33%) | 1 (33%) | 1 (33%) |
| Control 33S | 2001 | 3 | 3 (100%) | 0 (0%) | 3 (100%) | 2 (67%) | 1 (33%) | 1 (33%) | 1 (33%) |
| Control 34B | 2001 | 3 | 3 (100%) | 1 (33%) | 0 (0%) | 1 (33%) | 1 (33%) | 1 (33%) | 0 (0%) |
| Control 35S | 2001 | 3 | 2 (67%) | 0 (0%) | 1 (33%) | 2 (67%) | 1 (33%) | 1 (33%) | 1 (33%) |
| Control 36S | 2001 | 3 | 3 (100%) | 0 (0%) | 1 (33%) | 2 (67%) | 1 (33%) | 1 (33%) | 1 (33%) |
| Control 37S | 2001 | 3 | 3 (100%) | 1 (33%) | 0 (0%) | 1 (33%) | 0 (0%) | 1 (33%) | 0 (0%) |
| **Average (±S.D.)** | | | **73% (±20)** | **38% (±25)** | **39% (±36)** | **46% (±26)** | **19% (±19)** | **25% (±20)** | **23% (±29)** |

## VI. RECOMMENDATIONS

**A. Highest Priority Recommendations:** These recommendations are provided as a result of a review of the development projects' reports. The recommendations will provide adequate assessment and evaluation of environmental conditions and impacts on coastal resources and water quality in West Hawai`i.

**1)** Develop standardized permit application and environmental report guidelines. These new guidelines should be specific to requirements of sampling/monitoring for new developments.

**2)** Develop a Hawai`i County coastal monitoring program to monitor long-term changes in water quality to include (but not limited to) monitoring of the following parameters: water quality, benthic substrate, biological parameters, microbiological parameters, oceanographic parameters, sediments, and anchialine ponds.

- This program would serve as an alternative to independent monitoring projects implemented for each development (and completed resorts).
- This program would provide more consistent and useful data for environmental assessment, trend analysis, development impact determination, and evaluation of management strategies.
- We recommend that all development projects should be required to pay into a fund that will support an integrated county coastal monitoring program.

**3)** Develop an anchialine pond protection/management program in Hawai`i County.

- Establish water quality standards for anchialine ponds
- Inventory anchialine ponds island-wide
- Develop and enforcement policy of no net loss of ponds on both public and private lands
    - No development project should be approved that eliminates or impacts anchialine ponds
    - Development projects must map anchialine ponds and monitor their physical, chemical, and biological status
    - Management of anchialine ponds on development project land should include assessment and removal of invasive species

### Other Recommendations

**4)** As a requirement of all permits submitted for developments in the coastal zone, complete characterization of conditions should be required in adjacent and potentially impacted areas.

- This should include creation of a fine-scale habitat map, based on the NOAA Benthic Maps available from NOAA (http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd/index.htm), and thorough characterization of coastal conditions seaward of the development to the 30 m isobath and extending adjacent to development boundaries at least 500 m.

**5)** Hawai`i County needs to develop a manual of concise guidelines for the environmental report to provide to each developer prior to permit application.

**6)** Hawai`i County needs to develop a check sheet of requirements for monitoring for developers to ensure that all of the specified parameters are measured during monitoring projects.

**7)** Any development permit issued in coastal zone should have requirements that include coastal sampling/monitoring.

- Monitoring of all parameters must be initiated prior to permit application submission, during the environmental assessment period, and continuing for at least 5 years following completion of the project.
- Monitoring of areas for development should minimally include all parameters outlined in the 'Monitoring Protocol Guidelines', provided by the West Hawai`i Coastal Monitoring Task Force in 1992. The monitoring protocol guidelines should be revised and enhanced with mechanisms in place for compliance and enforcement of the standards.
- Hawai`i County should require developers to adopt Before-After/Control-Impact (BACI) sampling protocols designed to test impacts by sampling the to-be-impacted site and a non-impacted control site for a specified time before the impact and following the impact.

**8)** All data collected at stations should have associated GPS coordinates (latitude/longitude) with metadata recorded (including DATUM type used, e.g., WGS 84).

**9)** Data generated from development monitoring projects should be submitted annually to the County in an electronic format (e.g., database or spreadsheet).

## B. Categorical Recommendations

### 1) <u>Summary of Water Quality Recommendations</u>

- Establish a time period and number of samples that need to be collected to evaluate whether a water body is in or out compliance with HDOH water quality standards
- Develop an aggressive campaign to educate the public and developments about pollution prevention practices and environmentally friendly fertilizing techniques
- Enforce best management practices for the fertilization practices at resorts and golf courses
- Establish salinity gradient parameters for water quality monitoring

**2) <u>Summary of Microbiological Water Quality Recommendations</u>**

- Establish a time period and number of samples that need to be collected to evaluate whether a water body is within compliance of HDOH microbiological water quality standards
- Follow standard methods for all sample analysis
- Analysis of data must be consistent with HDOH microbiological analyses for geometric means of *E. coli* and enterococci

**3) <u>Summary of Biological Monitoring Recommendations</u>**

- Biological sampling, especially of benthic components (e.g., corals, algae), is extremely important, however, data would be much more valuable if collected in a coordinated program with an island-wide scientific design. A more effective allocation of biological sampling effort and an improved monitoring design would entail fewer sites per bay, more sites along the entire coast, and an increase in sampling effort of other important parameters, particularly, microbiological parameters.
- Biological sampling should have details of sampling provided to include GPS coordinates (latitude/longitude with datum metadata recorded) for each station sampled, direction sampled from the station point, quadrat size and number of quadrats sampled per transect, and length and width of transect.
- All stations should be identified on a GIS-produced map. Samples should be taken in each zone and habitat type. Coastal marine community maps should be developed based on the NOAA Benthic Maps to a depth of 30 m. (http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd/index.htm)

**4) <u>Summary of Recommendations for Marine Sediment Monitoring</u>**

- Sample sediment substrates of coral reef, reef flat, marine pools, protected coves, and anchialine ponds
- Perform grain size analysis of sediments and determine percentage carbonate
- Carry out statistical treatment of grain size analysis to include graphic mean, graphic standard deviation, and skewness
- Conduct chemical analysis for pre-selected toxic pollutants as warranted

**5) <u>Summary of Recommendations for Physical Monitoring of Nearshore Waters</u>**

- Redefine *brackish waters* as having salinities between 0.5 and 30 ppt, thereby bringing monitoring definitions and HDOH standards in line with accepted values for brackish waters
- Define wet and dry seasons consistently among water body types
- Note tide state relative to the local datum noting and any local deviations from predicted tide
- Measure wind direction and speed, and note any recent prior major weather events
- Note surf conditions to include local significant wave height. In addition, buoy data on wave period and height, and swell direction and source should be included
- Measure circulation using moored current meters and/or drogues

**6) <u>Summary of Recommendations for Anchialine Ponds</u>**

- Measure temperature, salinity, and turbidity at both high and low tide during the maximum biweekly tidal cycle, plus special monitoring following any major rainfall events such as Kona storms
- Measure physical parameters along both vertical and horizontal transects across ponds in order to determine stratification and/or localized input into ponds
- Note external parameters such as surf conditions
- Sample bottom sediments, determine grain size, and calculate sedimentary statistics
- Development projects that will eliminate or impact anchialine ponds should not be approved
- Development projects should be required to map anchialine ponds and monitor their physical, chemical, and biological status at least two times annually
- Management of anchialine ponds on development project land should include assessment and removal of invasive species at least two times annually
- Establish control sites for anchialine ponds at undeveloped or minimally impacted locations with low nutrient concentrations

## VII. SUGGESTED FUTURE RESEARCH PROJECTS

### A. Coastal Water Projects

1. Review HDOH coastal water quality data for spatial and temporal trends, as well as compliance with HDOH water quality standards. This project, in combination, with results from this report will provide a more complete analysis of water quality for West Hawai`i.
2. Map out groundwater seeps in West Hawai`i, measure nutrient concentrations in groundwater, and identify nutrient sources.

### B. Anchialine Pond Projects

1. Conduct an inventory of anchialine ponds island-wide.
   a. This would be accomplished through an aerial survey, followed by ground-truthing visits. Ponds can be categorized as: 1) pristine and must be protected, 2) capable of rehabilitation, and 3) lost forever.
   b. For ponds that fall into category 1 and 2 from above, the following should be measured at those ponds:
      1) Water quality parameters (Section IV)
      2) Biological parameters (Section IV)
      3) Physical/geological parameters (Section IV)
2. Develop education module for anchialine ponds and signage for sites in West Hawai`i to educate the public about ponds and their ‘protected’ status.

### C. Benthic Community Projects

1. Conduct a comprehensive survey of benthic community conditions along the coast of West Hawai`i in coordination with DAR. The methods used for this research should be reviewed by professionals conducting similar programs throughout the state. The data base generated through this survey would provide a baseline and comparison for future studies and monitoring programs.

### D. Development Impact Project

1. Conduct an assessment of post-development impacts at developments in West Hawai`i. The original sites established during development projects would be re-sampled using methods described in reports. Control sites would be required and final experimental design reviewed by professionals. A thorough analysis of data collected before and after developments and with established control sites would be required.

### E. Development of a Model Environmental Report

1. Development of a model environmental report for future development projects. This report would be created during a future study on a selected bay in West Hawai`i that would include all the recommendations made in this report and the 1992 West Hawai`i Coastal Monitoring Task Force report. This model environmental report would be made available to developers and required for review prior to development permit application.

## VIII. CONCLUSIONS

A strong consensus of the authors is that a comprehensive and integrated coastal monitoring program is critically needed in order to assess water quality trends and evaluate management needs on the Island of Hawai`i. Data collected during the various development monitoring projects are difficult to analyze due to the differences in data quality, parameters sampled, methods utilized, and reporting. Few monitoring projects had adequate controls and were of sufficient duration to analyze for trends and evaluate impacts.

The people of the Island of Hawai`i, particularly in West Hawai`i, are very interested in their natural resources as evident from the public interest in projects, attendance at public meetings, and participation in activist groups. As the Island of Hawai`i continues to grow and be developed, environmental and water quality will be of increasing importance. In order to avoid the adverse impacts due to improperly managed development, resulting in problems such as cultural eutrophication observed on Oahu and Maui, yielding nuisance algal growth and decreased water quality, adequate water quality assessment is essential. Adequate control in very sensitive environments, such as anchialine ponds, is critically needed to avoid continuing loss. The most effective way to provide scientific evaluation of water quality and development impacts is to have quality data provided from a comprehensive monitoring program.

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**XI. APPENDIX I:** ‘West Hawai`i Coastal Monitoring Program – Monitoring Protocol Guidelines’, April 1992.