National Park Service
U.S. Department of the Interior

Water Resources Division
Natural Resource Program Center

Technical Report NPS/NRWRD/NRTR-2005/344

ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS IN KALOKO-HONOKOHAU NATIONAL HISTORICAL PARK, HAWAI‘I

Dr. Daniel Hoover and Colette Gold

Cover photos provided by Kristen Keteles.

The National Park Service Water Resources Division is responsible for providing water resources management policy and guidelines, planning, technical assistance, training, and operational support to units of the National Park System. Program areas include water rights, water resources planning, regulatory guidance and review, hydrology, water quality, watershed management, watershed studies, and aquatic ecology.

Technical Reports

The National Park Service disseminates the results of biological, physical, and social research through the Natural Resources Technical Report Series. Natural resources inventories and monitoring activities, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences are also disseminated through this series.

Copies of this report are available from the following:

National Park Service (970) 225-3500
Water Resources Division
1201 Oak Ridge Drive, Suite 250
Fort Collins, CO 80525

National Park Service (303) 969-2130
Technical Information Center
Denver Service Center
P.O. Box 25287
Denver, CO 80225-0287

Assessment of Coastal Water Resources and Watershed Conditions in Kaloko-Honokohau National Historical Park, Hawai‘i

Dr. Daniel Hoover, Colette Gold

Technical Report NPS/NRWRD/NRTR- 2005/344

Department of Oceanography
University of Hawai‘i at Manoa
Honolulu, HI 96822

December 2005

This report was prepared under Task Order J2380040120 of the Hawai‘i-Pacific Islands Cooperative Ecosystems Studies Unit (agreement H8080040012).

WATER RESOURCES DIVISION

National Park Service - Department of the Interior
Fort Collins - Denver - Washington

List of Figures

List of Tables

ACKNOWLEDGEMENTS

Many people contributed to this project. Cliff McCreedy and Kristen Keteles played key roles in setting up and managing the project, along with Mark Flora, Jim Tilmant, Fritz Klasner, Darcy Hu, Tekla Seidl Vines, and David Keola. Park personnel and cooperators were major resources for data, documents, and insight into the park and into related NPS activities: Sallie Beavers, Kimber DeVerse, Lisa Marrack, Rebecca Most, Sonia Stephens, Raychelle Daniel, Gordon Dicus, Leslie HaySmith and Noelani Puniwai all are gratefully acknowledged for their input. Sandy Margriter, Lisa Wedding and Matt Barbee provided GIS data and expertise, and Mariska Weijerman and Paul Bienfang generously shared preliminary data from ongoing projects in the park. Larry Basch provided a wealth of information, insight, and photographs, as well as a detailed review of the draft report. Mark Flora, Rebecca Beavers, Paula Cutillo, Cliff McCreedy, Jim Tilmant, Fritz Klasner, Kimber DeVerse, and Kristen Keteles also provided invaluable feedback on report drafts, while Reuben Wolff provided expert assistance with the USGS PACN water quality database. Kathy Kozuma provided her usual expert assistance and positive attitude, Fred Mackenzie provided office space and computer resources, and Rebecca Scheinberg is gratefully acknowledged for support, patience, and good cheer.

LIST OF ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practices
CESU	Cooperative Ecosystems Study Unit
chl-*a*	Chlorophyll-*a*
cm	Centimeter
CO_2	Carbon dioxide
CRAMP	Coral Reef Assessment and Monitoring Program
d	Day
DAR	Division of Aquatic Resources
DLNR	Division of Land and Natural Resources
DO	Dissolved Oxygen
DOH	Department of Health
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
EH	Redox potential, usually measured in volts or millivolts
EPA	Environmental Protection Agency
FLIR	Forward Looking Infra-Red
FRA	Fish Replenishment Area
GW	Groundwater
ha	Hectare
HAVO	Hawaiʻi Volcanoes National Park
HI	Hawaiʻi
HUC	Hydrologic Unit Code
in	Inch
JTU	Jackson Turbidity Units
KAHO	Kaloko-Honokohau National Historical Park
l	Liter
mg/l	Milligrams per liter
m	Meter
Mgal	Million gallons
NEC	North Equatorial Current
NH4	Ammonium
NO2	Nitrite
NO3	Nitrate
NO3+	Nitrate plus nitrite
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NTU	Nephelometric Turbidity Units
PACN	Pacific Island Vital Signs Network
pH	Unitless measurement of acidity/alkalinity, calculated as the negative logarithm of the hydrogen ion concentration in a solution
PICRP	Pacific Islands Coral Reef Program
PO4	Phosphate
PPB	Parts per billion
PPT	Parts per thousand

PSU	Practical Salinity Units
PUHE	Puukohola Heiau National Historic Site
PUHO	Puuhonua o Honaunau National Historical Park
S	Salinity
SCUBA	Self-Contained Underwater Breathing Apparatus
SiO2	Silicate
SRP	Soluble Reactive Phosphorus
STORET	STorage and RETrieval database (EPA water quality database)
T	Temperature
TDN	Total Dissolved Nitrogen
TDP	Total Dissolved Phosphorus
Temp	Temperature
Turb	Turbidity
UH	University of Hawaiʻi
USGS	U.S. Geological Survey
VOGNET	Volcanic Fog Monitoring Network
WHAP	West Hawaiʻi Aquarium Project
WQAOI	Water Quality Area Of Interest
WWTP	Waste Water Treatment Plant
y	Year
% sat	Percent of saturation value
°C	Degrees Celsius
µg/kg	Micrograms per kilogram
µg/l	Micrograms per liter
µM	Micromoles per liter

EXECUTIVE SUMMARY

Kaloko-Honokohau National Historical Park (KAHO) is a small park (469 ha/1160 acres) located on the Kona or west coast of the island of Hawaiʻi. The park was established primarily to preserve and protect native Hawaiʻian culture and cultural sites, but the park also contains a diverse and unique array of water resources. The climate is arid, and there are no freshwater resources in or near the park, but brackish groundwater flows seaward through the park and is exposed in a large number of subaerial anchialine pools and in a large (12 ha/30 acres) coastal pond/wetland system (Aimakapa). Brackish groundwater discharges also affect two other major ponds (Kaloko and Aiopio) that were modified by ancient Hawaiʻians for fish trapping and aquaculture, and groundwater discharging along the park shoreline and from offshore springs affects intertidal and coastal water quality. Brackish and marine waters in the park support a wide range of flora and fauna, including several rare and endangered species. The cultural and ecological value of these remarkably diverse water resources are significant, but park waters are threatened by development, particularly in upslope and surrounding areas where light industrial and residential development could affect both groundwater supply and quality. No point source pollutant discharges are present in KAHO, but treated sewage is pumped into an infiltration pit just south and upslope of the park, and a development (The Shores at Kohanaiki) is being built along the northern boundary of the park that may result in additional discharges. A number of non-point sources in and around the park have the potential to affect coastal water resources, particularly the industrial park immediately inland of the park, Honokohau small boat harbor, which abuts KAHO's coastal waters at the harbor mouth, and the Kohanaiki development along the park's northern boundary.

Despite the value of water resources in the park, there are few data available for quantitative assessment of water quality and associated biological resources. The National Park Service (NPS) Horizon report and a recent USGS park water quality database (Wolff unpubl.) include a number of coastal sites with relatively long-term datasets, but while these sites fall within the Water Quality Area of Interest (WQAOI) established for the park, all of the sites are too distant from park waters to support a meaningful assessment of coastal water quality. Of the remaining sites, a significant number are small anchialine pools that were sampled only once, and only for temperature and salinity, and few of the sites within the park that were monitored for a wider range of parameters were monitored for extended periods of time. Biological assessments of park water resources have been sporadic, usually limited in scope, and often have not used quantitative methods, making it difficult to compare results across studies. Nonetheless, combining available data from water quality databases with additional water quality and biological data from published reports does provide insight into water quality and biological resource conditions in the park's groundwater, anchialine pools, fishponds, intertidal areas, and coastal waters.

Overall, the available water quality data and the apparently good condition of associated aquatic ecosystems suggest that park waters probably are in relatively good condition. Data for pesticides, solvents, and heavy metals are very sparse, but the few water, sediment, and tissue samples that have been analyzed contained detectable concentrations of only a few analytes, most of which occurred at very low levels that were interpreted as natural or trace concentrations. The most significant contaminant identified to date in park waters is nitrogen, which has increased in groundwater in two monitoring wells in the park. This increase is of concern because groundwater plays a major role in determining the quality of water in the park's coastal resources, and because where nutrients limit primary production in marine ecosystems, nitrogen often is the most limiting nutrient. Water quality data and a groundwater modeling study also suggest that groundwater flows in the park have decreased significantly over the last 30 years. Both the increase in nitrogen and the decrease in flow likely are related to upslope development, which almost certainly will increase as population continues to increase in the area. Thus, groundwater flows and groundwater quality are fundamental issues for all of the park's coastal water resources.

Biological resources in park waters mostly are poorly characterized. Available data indicate that while water quality and other impacts on biological resources mostly appear to be minor at this time, there are a number of existing and potential issues that warrant action or further study, and additional study is needed in virtually all areas to establish baseline data adequate for assessing current status and future trends. These issues and key biological features of each of the major coastal water resources are summarized briefly below.

Anchialine pools

Anchialine pools are rare, and associated ecosystems are poorly understood. Historical data suggest that many of the anchialine pool ecosystems in the park probably are impacted significantly by alien fish, but pool ecosystems also may be impacted by long-term reductions in groundwater flow and in some areas by light pollution. While anchialine ecosystems appear to be relatively tolerant of variations in salinity, temperature, and nutrients, tolerance probably varies from pool to pool, and they may be vulnerable to toxic contaminants. Although anchialine pools appear to be tolerant of nutrient variation, there is the potential for impacts if the trend of increasing nutrient levels continues. Anchialine pools also provide habitat for some rare and candidate endangered species, such as the orange-black damselfly (*Megalagrion xanthophelas*).

Fishponds

None of the major ponds in the park (Kaloko, Aimakapa, and Aiopio) have been studied in enough detail to characterize ecosystem status, or to link their current status to water quality or other forcing factors. All receive significant inputs of groundwater, but their large size and differences in hydraulic connectivity between individual ponds and adjacent coastal waters result in significant differences in groundwater residence times. These differences should result in associated differences in ecosystem response to contaminant inputs. For instance, the residence time of groundwater in Kaloko pond appears to have increased significantly due to restoration of the fishpond wall, which in turn should increase the impacts of groundwater contaminants on the pond ecosystem. Increased nitrogen inputs in particular would be expected to enhance photosynthetic production in the pond, and while no direct production data are available, dissolved oxygen has increased in recent measurements, suggesting that production also may have increased. The impacts of this response on other portions of the ecosystem are not known, but are a significant concern as one of the major objectives of the restoration effort is to utilize the pond for traditional aquaculture. Invasive species also are a concern in Kaloko pond, as the pond is the site of a major infestation of the alien alga *Acanthophora spicifera*, which is disrupting the pond ecosystem and threatens adjacent park coastal waters, an issue currently being addressed under PMIS project 91680. Aimakapa fishpond is the most isolated of the major ponds with respect to exchange with coastal waters, and contains the highest proportion of groundwater, making it the most vulnerable to changes in groundwater quality. Because Aimakapa pond and its associated wetlands provide critical habitat for endangered waterbirds including the Hawaiʻian stilt (*Himantopus mexicanus knudseni*) and the Hawaiʻian coot (*Fulica americana alai*), characterizing pond vulnerability to water quality changes and other stressors should be a priority. Aiopio pond is the smallest of the three major ponds and probably has the most efficient exchange with offshore waters, making it the least vulnerable to contaminant inputs. However, the pond appears to receive significant inputs of groundwater that may be contaminated by upslope sewage disposal, and there are essentially no data on water quality in the pond or on the pond ecosystem, so a cursory survey at least is needed to obtain baseline data. In addition, the pond is used heavily by park visitors, so bacterial data are needed to assess the potential for human health risks.

Wetlands

KAHO's wetlands primarily are associated with Kaloko and especially Aimakapa fishponds, with smaller areas associated with some of the anchialine pools in the park. Wetlands are rare in west Hawaiʻi, so KAHO's wetlands provide critical habitat for resident and transient birds. There is no indication of water quality impacts on wetland biota, but invasive species are a significant issue, including mangroves (*Rhizophora mangle*) and pickleweed (*Batis maritima*), both of which are subjects of ongoing eradication and control efforts.

Intertidal

Biological resources in KAHO's intertidal have received only very cursory study. There is no indication that they are impacted significantly by water quality changes or by invasive species, although no rigorous studies have been done. Recreational harvesting of intertidal organisms may be a significant issue, but also would require further study. Intertidal zones do provide significant habitat for endangered waterbirds and green sea turtles (*Chelonia mydas*), potential habitat for threatened hawksbill turtles (*Eretmochelys imbricata*) and for endangered Hawaiʻian monk seals (*Monachus schauislandi*), and are foci of visitor activity.

Coastal waters

Coastal waters include both pelagic and benthic habitats, from subtidal sands to extensive coral communities, that support a diverse community of resident and transient fish, reptiles, mammals, invertebrates, and other organisms, including turtles, monk seals, spinner dolphins, sharks, manta rays, and threatened humpback whales (*Megaptera novaeangliae*) offshore of the park. The few studies that have addressed pelagic and benthic biological resources generally have concluded that they are in good condition, although several alien fish are established in park waters, and stressors such as sound and light pollution and behavioral impacts due to visitor activities (e.g. wading, swimming, snorkeling, SCUBA diving, boating) have not been addressed. Although park coastal waters and associated biota probably are relatively tolerant of contaminant inputs due to the strong natural dilution characterizing Hawaiʻi's coastal waters, contaminant inputs from Honokohau Harbor are a possible concern, particularly in the area immediately adjacent to the harbor mouth. Sediment contamination is a problem in many harbors, and contaminants from this source might be an issue for park biota that ingest sediments or organisms that live in or ingest sediments. Other stressors that warrant additional study and monitoring include the potential for increased coral bleaching and disease with increasing ocean temperatures, and the continuing potential for alien species introductions, including pathogens that may result in disease in corals and other organisms.

Table i summarizes the above discussion in terms of the major stressors affecting park coastal water resources and our assessment of existing and potential impairments due to these stressors. Many of the stressors are associated with development around the park and visitor impacts on the park, and thus present options for management that may include actions to reduce or eliminate the stressor. Others, such as sea level rise and increased temperature, are driven primarily by global processes and cannot be managed directly. Existing impairments in the park are well known only for invasive species in anchialine pools, Kaloko pond, and in wetlands around Kaloko and Aimakapa ponds, but invasive species also may be impacting other resources, and potential impairments exist in many other areas.

Recommendations for studies, monitoring, and actions to address existing and potential impairments are summarized in Table ii. Although a number of recent, ongoing, and planned studies will significantly improve knowledge of the status of selected resources, significant gaps still exist in the characterization of most resources and in understanding the potential for impacts due to the stressors identified above. The recommended studies will provide the baseline data needed to document the current status of water quality and biological resources in the park, and will allow for initial assessment of vulnerability to the stressors listed in Table i.

Table i. Existing and potential impairments in KAHO's coastal water resources.

Stressor	Ground-water	Anchialine Pools	Kaloko Pond	Aimakapa Pond	Aiopio Pond	Wetlands	Intertidal	Coastal Waters
Water Quality								
Nutrients	OK	PP	PP	PP	PP	OK	OK	OK
Fecal bacteria	OK	OK	OK	OK	PP	OK	OK	OK
Dissolved oxygen	OK	OK	OK	PP	OK	OK	OK	OK
Metals	OK	OK	OK	OK	OK	OK	OK	PP
Toxic compounds	PP	PP	PP	PP	OK	PP	OK	OK
Increased temperature	OK	OK	OK	OK	OK	OK	OK	PP
Water Quantity								
Reduced GW flux	OK	PP	PP	PP	OK	PP	OK	OK
Population Effects								
Fish/shellfish harvest	na	PP	OK	OK	OK	OK	PP	OK
Invasive species	PP	EP	EP	PP	PP	EP	PP	PP
Physical impacts	na	OK	OK	OK	PP	OK	OK	OK
Behavioral impacts	na	OK	OK	OK	PP	PP	PP	PP
Habitat Disruption								
Sea level rise	OK	PP	OK	OK	PP	OK	PP	OK
Sound pollution	na	OK	OK	PP	OK	PP	PP	PP
Light pollution	na	PP	OK	OK	PP	OK	OK	PP

EP - existing problem, PP - potential problem, OK - not currently or expected to be a problem, shaded - limited data, na - not applicable.

Table ii. Recommendations for additional studies, monitoring, and actions to address existing and potential impairments.

Studies

1. Characterize groundwater flow dynamics in and around the park, and its response to existing and planned development (withdrawals and wastewater inputs)
2. Document the current biological status of anchialine pool communities, particularly with respect to alien fish
3. Characterize circulation and mixing in Kaloko pond
4. Characterize ecosystem structure and function in Kaloko pond
5. Characterize circulation and mixing in Aimakapa pond
6. Characterize ecosystem structure and function in Aimakapa pond
7. Perform a preliminary characterization of water quality and flushing dynamics in Aiopio pond
8. Characterize the locations and intensity of groundwater inputs to coastal waters
9. Conduct a quantitative survey of biological resources in rocky intertidal zones in the park
10. Characterize water quality and circulation and dilution processes in coastal waters adjacent to Honokohau Harbor
11. Characterize sediment contamination in Honokohau Harbor and potential for transfer to park waters via sediment export and faunal consumption and transport
12. Characterize recreational fishing catch and effort in park waters
13. Characterize recreational SCUBA activity in the park
14. Perform a preliminary assessment of light pollution in the park and the potential for impacts to park resources
15. Perform a preliminary assessment of underwater noise pollution in the park and the potential for impacts to park resources

Monitoring

1. Monitor groundwater heads and groundwater quality in the park
2. Monitor groundwater quality at selected upgradient sites to provide ‘early warning’ of contaminant inputs
3. Monitor water quality and ecosystem status, including rare and endangered species, in selected anchialine pools
4. Monitor water quality and ecosystem status in Kaloko pond
5. Monitor water quality and ecosystem status in Aimakapa pond, including continued monitoring of endangered birds
6. If warranted based on preliminary data, monitor water quality in Aiopio pond
7. Monitor water quality in coastal waters adjacent to the mouth of Honokohau Harbor.
8. Continue benthic ecosystem monitoring initiated under the WHAP project, including coral health and alien species
9. Continue fish community monitoring initiated under the WHAP project, including alien species
10. Continue sea turtle monitoring in the park

Table ii. (cont.)

Actions

1. Continue *A. spicifera*, *R. mangle*, and *B. maritima* eradication and control efforts in and around Kaloko pond
2. Work with the Kohanaiki developer to maximize the utility of their anchialine pool and coastal water monitoring program to water quality and biological resource concerns in the park
3. Work with the State of Hawaiʻi to mitigate potential contaminant sources in Honokohau Harbor, and potential impacts of the planned harbor expansion
4. Consider prohibiting harvesting of endemic Hawaiʻian limpets (opihi) in the park
5. Increase enforcement of existing fishing regulations in the park
6. Collaborate with researchers working in the park to maximize the relevance of ongoing and planned studies to park needs for basic, robust data on water quality and biological resources in the park.

A. INTRODUCTION

This project was conducted to assess coastal water resources in Kaloko Honokohau National Historical Park, on the west coast of the island of Hawaiʻi (Figure 1). The goal of the project was to identify both the state of knowledge regarding individual resources and the degree to which they are affected by natural and anthropogenic factors. As a result, this report summarizes the condition and state of knowledge for individual resources, identifies information gaps where data are insufficient to assess resource condition, and makes recommendations for future studies to fill information gaps and to facilitate resource management. While the focus of this effort was on coastal resources, watershed conditions and surface and groundwater in adjacent watersheds also were considered as they might affect coastal water quality and resources. A wide range of

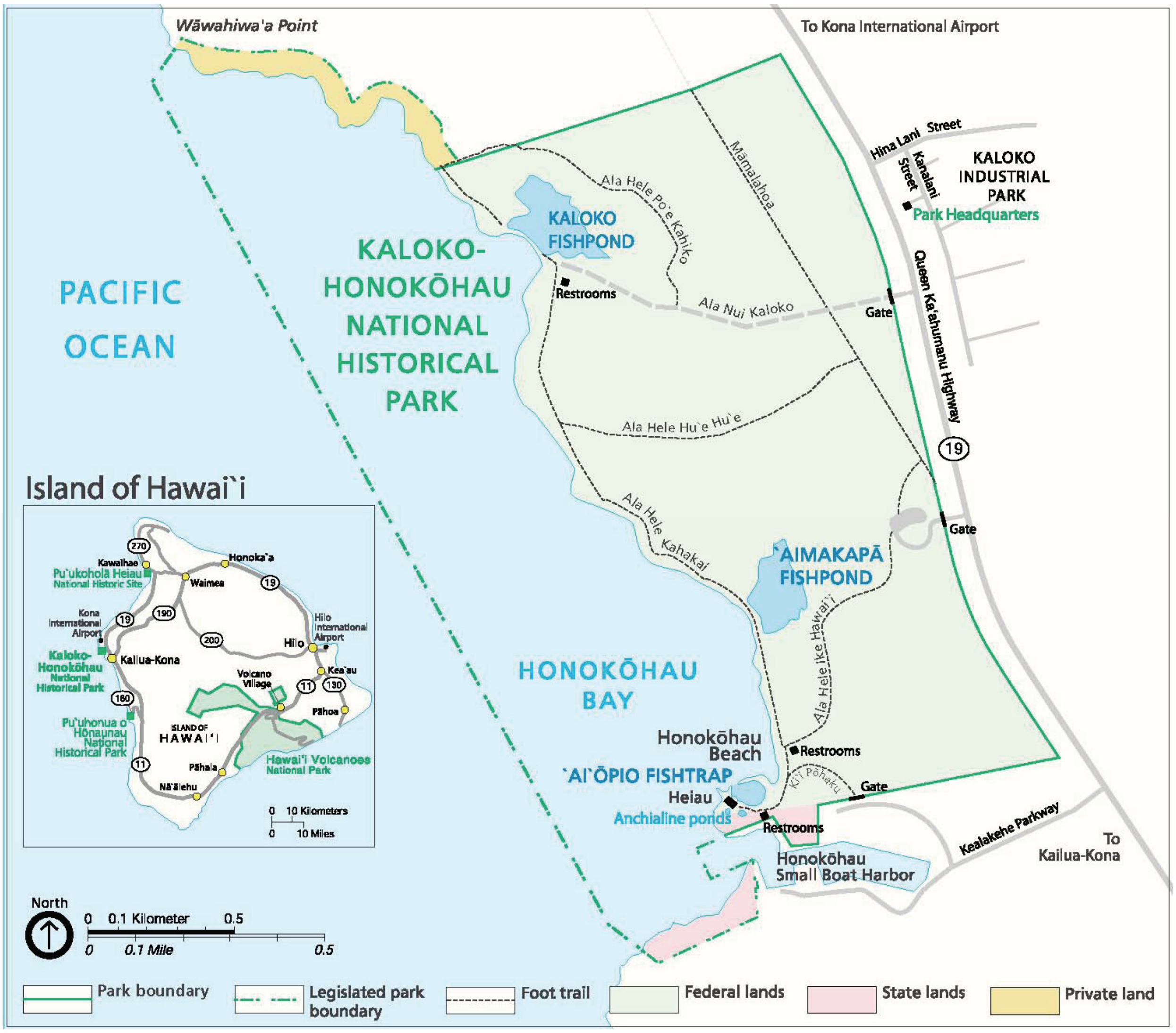


Figure 1. Kaloko-Honokohau National Historical Park (http://www.nps.gov/kaho/pphtml/maps.html)

sources were reviewed to obtain information on coastal water resources in the park. Sources cited in the text are listed in the bibliography; other useful sources are included in Appendix A.

B. PARK DESCRIPTION

B.1. Background

B.1.a. Size, boundaries, holdings, and location

Kaloko-Honokohau National Historical Park (KAHO) is located on the western (leeward) shoreline of the island of Hawai‘i, 3.6 miles north of the town of Kailua-Kona (Figure 1). The total area of the park is 469 ha (1,160 acres), of which 241 ha (596 acres) is marine subtidal area. The park extends from the coast inland to the Queen Ka‘ahumanu Highway. The northern boundary follows a mostly straight line running inland along the historical boundary between the traditional Hawai‘ian Kaloko and Kohanaiki land or watershed divisions (ahupua‘a). The southern boundary is discontinuous, with the main portion of the park lying north of Honokohau Harbor, and a small portion located along the coast south of the harbor. A thin strip of coastal land between the northern boundary of the park and Wawahiwa‘a point (Figure 1) is within the park's legislated boundary, but is privately held and instead is slated for development. The coastal waters and reefs of KAHO have been designated as a Marine Area Reserve (Hapke et al. 2005); coastal waters and submerged lands within the legislated park boundary technically are under the jurisdiction of the State of Hawai‘i but are managed unofficially by the park. A management agreement formalizing this relationship currently is being drafted by NPS (Sallie Beavers pers. comm. 2005).

KAHO was established in 1978 to preserve and protect traditional Native Hawai‘ian culture and cultural sites. KAHO is considered a sacred place by native Hawai‘ians, with many culturally significant resources, including ancient burials, salt pans, a heiau (Hawai‘ian temple), petroglyphs, and sacred rocks, or pohaku. Culturally significant water resources include numerous anchialine pools and three major ponds that were modified for fish production and trapping. The ponds were a significant asset for ancient Hawai‘ians, as they provided a dependable source of food, and their size and location probably encouraged settlement and development in the area (Greene 1993). Park waters still are a central element in many native Hawai‘ian practices and rituals that rely heavily on the quality of the water (Stan Bond pers. comm. 2005, Larry Basch pers. comm. 2005).

While KAHO was established primarily as a cultural park, park waters also include many significant biological resources. Anchialine pools and their associated biota are unusually abundant in the park relative to their numbers statewide, and are a significant resource due to their rarity, endemic species, and their rapidly dwindling numbers in Hawai‘i. Important vegetation resources are found in wetlands, coastal strands, and anchialine pools and fishponds. Critical animal species of concern within the park include the Hawai‘ian stilt (*Himantopus mexicanus knudseni*), Hawai‘ian coot (*Fulica americana alai*), green sea turtles (*Chelonia mydas*), and hawksbill turtles (*Eretmochelys imbricata*). Threatened humpback whales (*Megaptera novaeangliae*) are seasonally present in waters offshore of the park, and beaches in the park provide potential habitat for the endangered Hawai‘ian monk seal (*Monachus* *schauislandi*). Intertidal habitats are geologically and ecologically diverse and contain rich biota. Subtidal environments also are diverse; coral colonized basalt substrates and coral reefs are widespread and contain abundant and diverse biota. Processes affecting coastal water resources are varied, complex, and not well understood (Basch et al., in prep.).

B.1.b. Land use

Although a significant portion of park lands are zoned for urban use, virtually all of the land in KAHO is managed as conservation land, with only a small area developed for a visitor center. Most of the lands around KAHO were undeveloped when the park was established, but extensive areas now are developed or zoned for urban use, with only scattered areas of agricultural and conservation land (Figure 2). Immediately inland of the eastern boundary are a rock quarry, equipment storage areas, a gasoline station, and a light industrial park that is under expansion. Honokohau Harbor and its associated fuel and maintenance facilities border the park to the south, and construction of a resort/residential development adjacent to the northern boundary of the park started in 2005, with a park planned for the coastal portion of the property. Residential development also is present inland and upslope of the industrial park inland of KAHO.

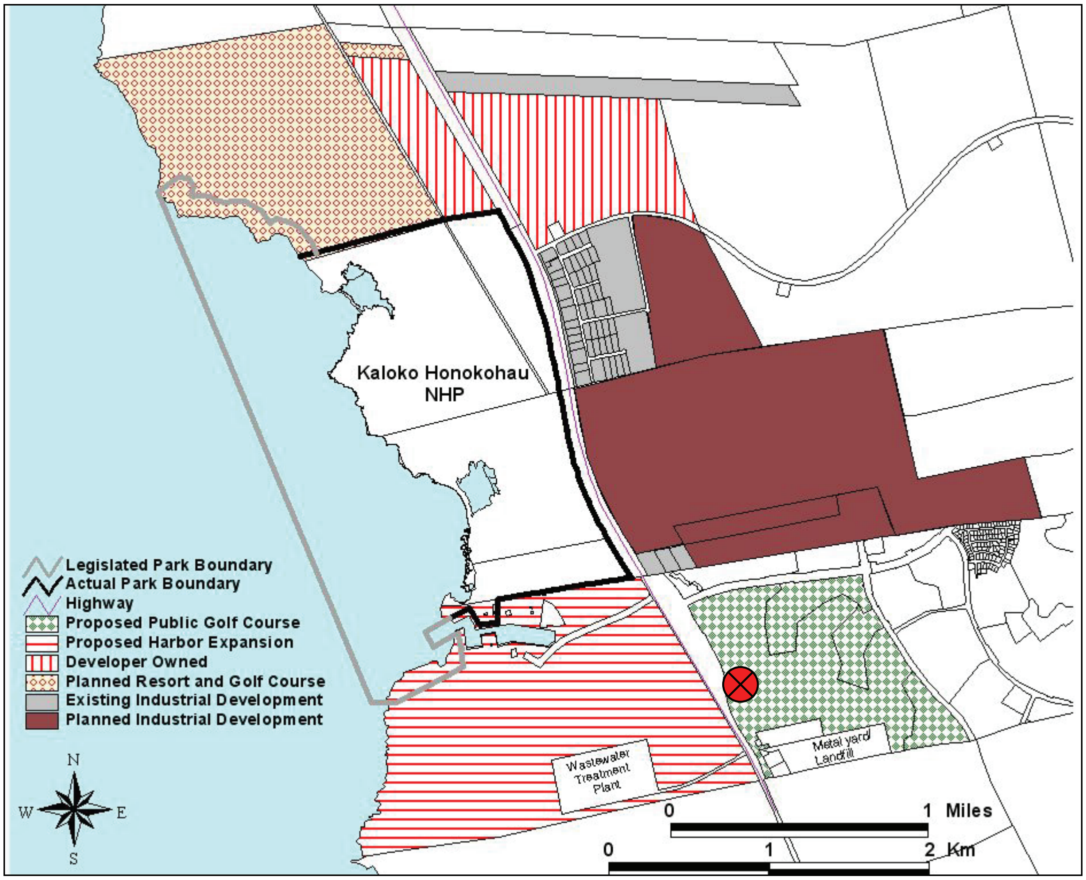


Figure 2. Land use around KAHO circa 2003 (NPS unpubl.; Sallie Beavers pers. comm. 2005). Red circle shows approximate location of Wastewater Treatment Plant disposal pit.

B.1.c. Human utilization: historic and current

Human utilization of resources in and around KAHO probably extends back as much as 1000 years, with initial human presence possibly as early as 900-1000 AD (Cordy et al. 1991; Greene 1993). The relatively sheltered nature of Kaloko Bay, and the presence of a large natural inlet (now Kaloko pond) and a brackish pond (Aimakapa) made the site attractive for settlement and for the application of aquaculture in the ponds. The large heiau and other religious structures in the park probably were built soon after settlement, while the fishponds are believed to have been developed for aquaculture by about 1500 – 1600 AD (Kikuchi and Belshe 1971). Early Hawai‘ian settlements utilized both coastal and inland resources, including extensive agricultural activity in inland areas (Kelly 1983). Early utilization thus probably included significant development of lands inland of, as well as within, park boundaries.

By the time of Captain Cook's initial contact with Hawai‘ians in 1778, the Hawai‘ian population is believed to have grown to a significant size. Estimates of the actual number vary, but it has been argued that the extensive agricultural developments characterizing that time, and particularly the cultivation of many areas of marginal agricultural value, reflect a population approaching or exceeding the carrying capacity of the available resources (Cuddihy and Stone 1990). However, the population of native Hawai‘ians declined rapidly after Cook's arrival, due primarily to disease introduced by western visitors. In the early 1800s, Kaloko still was an identifiable community, with approximately six households living near the fishpond, but by the 1830s – 1840s, abolition of the ancient religious system and the associated use of the heiau and other religious shrines in the area, and the movement of the high chiefs to Honolulu, resulted in abandonment of the coastal settlement. Subsequently, agricultural opportunities in upland areas attracted new settlers to the area, and by the early 1900s, large ranches owned or leased lands that were once owned by Hawai‘ian chiefs. Land use in and around the park during this period probably was minimal due to the extremely low rainfall in the area, although Kaloko fishpond was used for fish production until the 1950s (Bond and Gmirkin 2003).

In the latter half of the 20th century, coastal development along the Kona coast increased dramatically as it became an increasingly popular tourist destination. Inland development followed as the need for urban and residential developments paralleled resort development. In 1971, Kaloko pond was dredged as part of a planned development, but concern over the associated loss of cultural and archaeological resources led to a 1972 federal court memorandum declaring that the Kaloko-Honokohau area was to remain in its rural state, and that its inhabitants were to remain relying on the ocean and the land for their subsistence. In 1978, Kaloko-Honokohau National Historical Park was authorized by the U.S. Congress "… to provide a center for the preservation, interpretation, and perpetuation of traditional native Hawai‘ian activities and culture, …, and to provide a needed resource for the education, enjoyment, and appreciation of such traditional native Hawai‘ian activities by local residents and visitors" (Anonymous 1978). Despite its designation as a National Park, human utilization of park resources during the second half of the 1900s probably was very low, with the most concentrated use in a coastal residential area near the southern border, and with recreation, fishing and diving occurring from the shore or from small boats. However, development around the park during the same period was significant, with construction of the Honokohau small boat harbor adjacent to the southern boundary of the park in 1970, expansion of the harbor in 1979, development and subsequent expansion of a light industrial park along the park's inland boundary, and residential development upslope of the industrial park.

Today, human utilization within the park still is relatively limited, with a significant portion of park visitation by local residents using park beaches and waters for recreation and fishing, particularly in the southern portion adjacent to Honokohau Harbor. Limited access reduces visitation to the central and especially the northern portions of the park, although the parking area and associated facilities by Kaloko pond have improved access to the central portion. Visitation to the park is fairly steady throughout the year, although the park receives a few more visitors during the winter than in the summer. Visitor numbers have increased in recent years, from about 66,000 in fiscal year 2002 to 94,000 in fiscal year 2004 (http://www.nps.gov/kaho/pphtml/facts.html). Visitation should continue to increase as the park's infrastructure improves and as tourism and population increase statewide, and in the Kona district in particular. Human utilization around the park also is expected to increase with the many urban and residential developments being added and expanded on, both adjacent to and inland of the park. Visitation to the northern portion of the park in particular is likely to increase dramatically if the Shores at Kohanaiki development is completed, with its associated shoreline park immediately north of KAHO.

B.2. Hydrologic information

B.2.a. Oceanographic setting

Oceanographic features of park waters are not yet well characterized, although considerable work by NPS, UH and USGS is in progress. Some general features can be inferred from the location of the island relative to large-scale oceanographic features, from the position of the park on the island's west coast, and from limited nearshore oceanographic data and local topography. However, nearshore oceanography likely is complex due to the varied topography in nearshore park waters, and the effects of alongshore and subtidal brackish groundwater discharges on circulation and stratification.

The island of Hawai'i is situated between 19 and 20 degrees north latitude, near the southern margin of the North Pacific gyre. Relatively high surface water temperatures, strong stratification, and low biological productivity are typical of coastal and offshore waters in this region (Bidigare et al. 2003). Coastal biological communities are adapted to the prevailing oligotrophic (low nutrient) conditions, especially in areas not subject to significant inputs of terrestrial nutrients or to upwelling of deep, higher-nutrient, waters. Hawai'i Island is the southernmost island in the Hawai'ian archipelago, and is located to the north of the main axis of the westward-flowing North Equatorial Current (NEC), but the northern edge of the NEC impinges on the island, resulting in the deflection of a portion to the northwest. The interaction between the island and the NEC, and surface wind variations associated with the prevailing tradewinds and the positions and topography of Hawai'i and Maui islands, result in the formation of large eddies to the west of the island (Chavanne et al. 2002). These eddies may play a role in enhancing biological productivity in the waters west of the island, and in the transport of planktonic larvae in the area, but their importance to KAHO park resources is not well known (Bidigare et al. 2003). Coastal currents offshore of the park generally flow in a southerly direction along the coast at velocities on the order of 0.4 knots (Juvik and Juvik 1998), although offshore eddies can result in northerly flow for extended periods (Seki et al. 2002). Tides along the west Hawai‘i Island coast are mixed diurnal, with a tidal range normally less than 1 m (Juvik and Juvik 1998). Sea level rise and island subsidence have resulted in significant inundation of coastal areas around the island on geologic time scales (Apple and MacDonald 1966); present-day rates probably vary, but appear to be on the order of 0.34 cm (0.13 inch) per year (Hapke et al. 2005).

The location of the park on the west coast of the island of Hawai‘i has a significant effect on the degree to which park waters are exposed to open-ocean swell and to locally-generated wind swell. The west coast of the island is sheltered from waves generated by the prevailing northeasterly tradewinds, and wave energy associated with northerly and southerly swells that arrive during winter and summer, respectively is attenuated compared to sites with more northerly or southerly exposures. Northerly swells can be particularly large, but some protection from these swells also is provided by ‘shadowing’ by the other islands in the Hawai‘ian archipelago and by Wawahiwa‘a Point and Keahole point to the north of the park (Figure 3) (Storlazzi and Presto 2005).

Details of KAHO’s nearshore oceanography are not well known, but a recent study monitored currents, tides, waves, and water quality (temperature, salinity and turbidity) at two sites for a 6 month period from April – October 2004 (Storlazzi and Presto 2005). Instruments deployed on the bottom in ~14 m of water off Kaloko and Aimakapa ponds showed that currents primarily were tidally driven, with flow typically alongshore at the southern site and on-off shore at the northern site. Net flows at the sites were to the SE and offshore respectively, with near-surface velocities typically on the order of 0.2 m/sec or less, and lower velocities near the seafloor. Temperatures near the sea floor mostly ranged from about 26.0 to 28.5°C, with salinities ranging from about 34.0 to 34.8 psu. Temperatures showed a strong seasonal trend and varied with tides, but both temperature and salinity also showed evidence of intermittent freshwater inputs likely due to groundwater intrusion, and of high frequency perturbations associated with the passage of internal waves. Near-bottom turbidities increased during periods of high wave activity, suggesting sediment resuspension and/or transport. The instruments used in the study still are deployed in the park and data collection by NPS and by the University of Hawai‘i, Manoa is ongoing (Larry Basch pers. comm. 2005).

Studies of currents and circulation within Honokohau Harbor provide some insight into the factors controlling water exchange between the harbor and adjacent KAHO coastal waters. Studies were performed for five years following construction in 1970, with one additional study in 1982 after the harbor was expanded in 1979. Historical data show that the area excavated for the harbor is a site of enhanced groundwater discharge to coastal waters (Fischer 1966), and Gallagher (1980) showed that groundwater discharge into the harbor facilitated flushing, with a net seaward discharge of brackish water from the harbor mouth at the surface, and landward flow of seawater into the harbor at depth. Flushing of the harbor as a whole degraded significantly after harbor expansion in 1979 (Bienfang 1980; Bienfang and Johnson 1980; Bienfang 1983), although the change affected primarily the newly excavated mauka, or inland, extension. Sluggish circulation increased residence time significantly in the new extension, but circulation

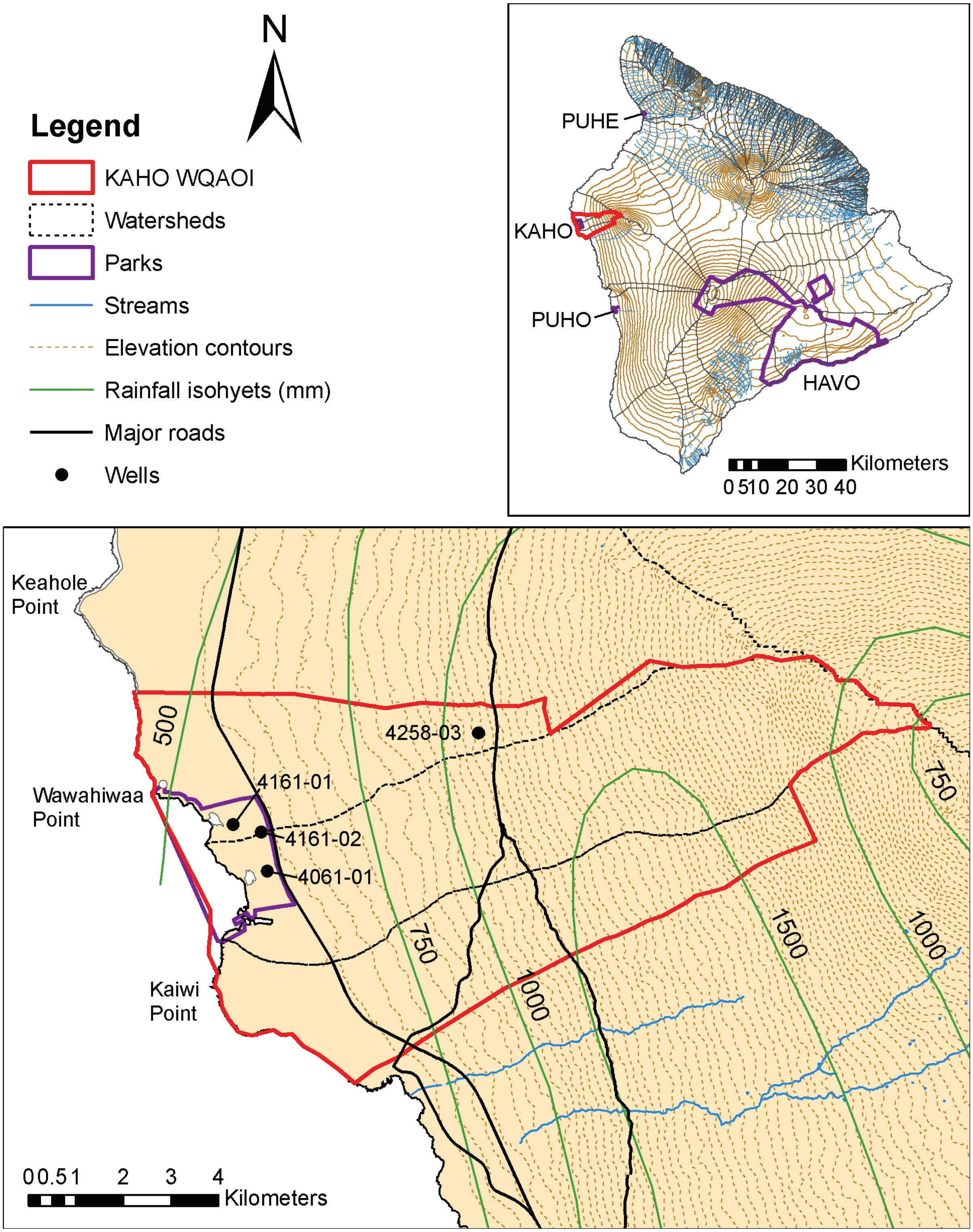


Figure 3. KAHO topography and hydrologic features. Elevation contours are at 100’ intervals in detail map, 500’ in island map. KAHO and its associated Water Quality Area of Interest (WQAOI) lie within USGS HUC 20010000, which covers the entire island of Hawaii. Wells used for water quality monitoring in and upslope of the park also are shown with their associated identification numbers.

in the original areas of the marina, and presumably exchange between the marina and offshore waters, appear not to have been affected dramatically by the modifications.

B.2.b. Hydrology affecting the park

Climate in KAHO is warm and dry, with a median annual rainfall of about 600 mm (Figure 3) and a mean annual temperature of 24 ºC (75 ˚F) (Wilson Okamoto & Associates 2000). Rainfall is highest during the winter months along the coast (National Park Service 2000), but high temperatures and dry conditions probably cause the majority of local precipitation to evaporate. Some precipitation does infiltrate the highly permeable rock and soils in the area to recharge groundwater, but there are no perennial streams in or adjacent to the park, or in the upslope watershed (Parrish et al. 1990) (Figure 3). Rainfall increases upslope of the park to 2000 mm/yr at elevations of 1,000 to 2,000 feet (Figure 3), with more rainfall in summer months (Pratt and Abbott 1996; Juvik and Juvik 1998), then declines to 750 - 1000 mm/yr at the highest elevations (6,500') (Oki et al. 1999). Recharge in the higher rainfall areas maintains subsurface groundwater that flows downslope toward the park. Fresh groundwater that reaches sea level floats on and mixes with underlying salt water. Because mixing begins well inland of the park, groundwater flowing through the park is brackish, with salinity increasing as it approaches the coast (Oki et al. 1999).

B.2.c. Water bodies and other water resources

KAHO has a diverse and unique array of water resources. Groundwater is a significant park resource, as groundwater is a major contributor to all of the park's surface water resources, and groundwater discharges affect nearshore coastal water quality. Surface water resources all are brackish and include anchialine pools, Kaloko and Aimakapa fishponds, Aiopio fishtrap, and wetlands associated with the various ponds and pools. Coastal water resources include rocky and sandy intertidal areas, and coastal waters. Honokohau Harbor is not technically within the park, but the harbor entrance abuts park coastal waters, so processes affecting water quality in the harbor also affect park coastal waters.

B.2.c.i. Groundwater

Groundwater in the park consists of a relatively thin brackish layer floating on underlying seawater. Maximum groundwater heads in the park probably are less than 2 feet, with seaward flow maintained primarily by recharge upslope of the park. Groundwater intersects the land surface in the park's many anchialine pools, and groundwater flow through the park results in a significant number of groundwater intrusions or springs within Kaloko and Aimakapa fishponds, Aiopio fishtrap, and along the park coastline and offshore to depths of at least 30 m (Fischer 1966; Adams 1969; Oki et al. 1999; Larry Basch pers. comm. 2005). Although groundwater head gradients in the park are low (about 0.7 foot per mile), flows still are significant due to the highly permeable nature of the lavas making up the park (Oki et al. 1999). Groundwater discharges alter the salinity and temperature of receiving waters, and add nutrients and other dissolved constituents derived from upland portions of the watershed. Groundwater flow through the park may be impacted significantly by upslope land use, which can affect rainfall and recharge, and by withdrawals and artificial recharge associated with irrigation and wastewater disposal. Upslope land use also may affect groundwater quality via the direct introduction of wastewater, or contamination of runoff by non-point sources.

B.2.c.ii. Anchialine pools

KAHO is one of only three legally protected sites in the state of Hawai‘i with anchialine pools. Anchialine pools contain water that is a mixture of seaward-flowing brackish groundwater and more saline seawater (Brock et al. 1987; Brock and Kam 1997). Brock and Kam (1997) identified 70 anchialine pools and pool complexes in KAHO, with an additional 18 in the coastal strip north of the park in the park’s originally legislated boundary, but in recent years park personnel have inventoried over 120 ponds within KAHO alone (Sallie Beavers pers. comm. 2005). Anchialine pools in the park mostly are located near the coast in natural depressions in rough lava. Of the 82 pools assessed by Brock and Kam (1997), 68% had surface areas less than 10 m^2, 27% were between 10 and 100 m^2, and 5% were greater than 100 m^2. Depths were less variable, with 93% less than 0.5 m, and the remaining 7% between 0.5 and 1.5 m. Because anchialine pools are surface expressions of the local groundwater table, and groundwater quality varies both with the degree of mixing between freshwater and seawater, and with local factors affecting water quality, water in anchialine pools naturally displays a wide range of physical and chemical conditions (Brock and Kam 1997).

B.2.c.iii. Ponds

There are three major ponds in KAHO, all of which were modified for fish production by ancient Hawai‘ians. Kaloko fishpond is a 4.5 ha (11-acre) ‘loko kuapa’ formed by the construction of a massive 230 m (750 foot) long dry set rock wall across the entrance to a natural embayment (Figure 4). Kikuchi and Belshe (1971) noted that over fifty percent of the pond had depths of 3’ (0.9 m) or less to bedrock, with a maximum depth of 12’ (3.7 m). Sediments on the pond floor sometimes exceeded 5’ (1.5 m) in thickness, and consisted of an accumulation of organic rich sediment made up of roughly equal parts of decomposing algal material and silt transported by wind and water, with a small amount of coral rubble and sand (Kikuchi and Belshe 1971). The pond exchanges water with the offshore ocean through interstices in the main rock wall, and through two sluice gates, or makahas, in the wall. Restoration of the main wall and the two makahas was well underway in November 2004 (Figure 4, D. Hoover, pers. obs.), but the integrity of the main wall and the makahas has varied considerably since aquaculture was abandoned in the pond in the 1950s (Bond and Gmirkin 2003). Because water quality and the biological community in the pond likely vary with the degree of isolation of the pond from offshore waters, water quality and biological conditions in the pond probably have varied significantly over the past 50 years.

Aimakapa fishpond is a 6 ha (15-acre) ‘loko puone’, or inland waterbody separated from the open sea by a narrow sand beach barrier (Figure 1). A makaha through the north end of the barrier beach currently is filled with sand, but its presence and the possibility of one or more additional makahas buried under the beach berm (Kikuchi and Belshe 1971; Duarte and Kauahikaua 1999) suggest that the pond probably had greater exchange with the offshore ocean when it was in use. In its present position, the visible makaha abuts marsh area on the inland

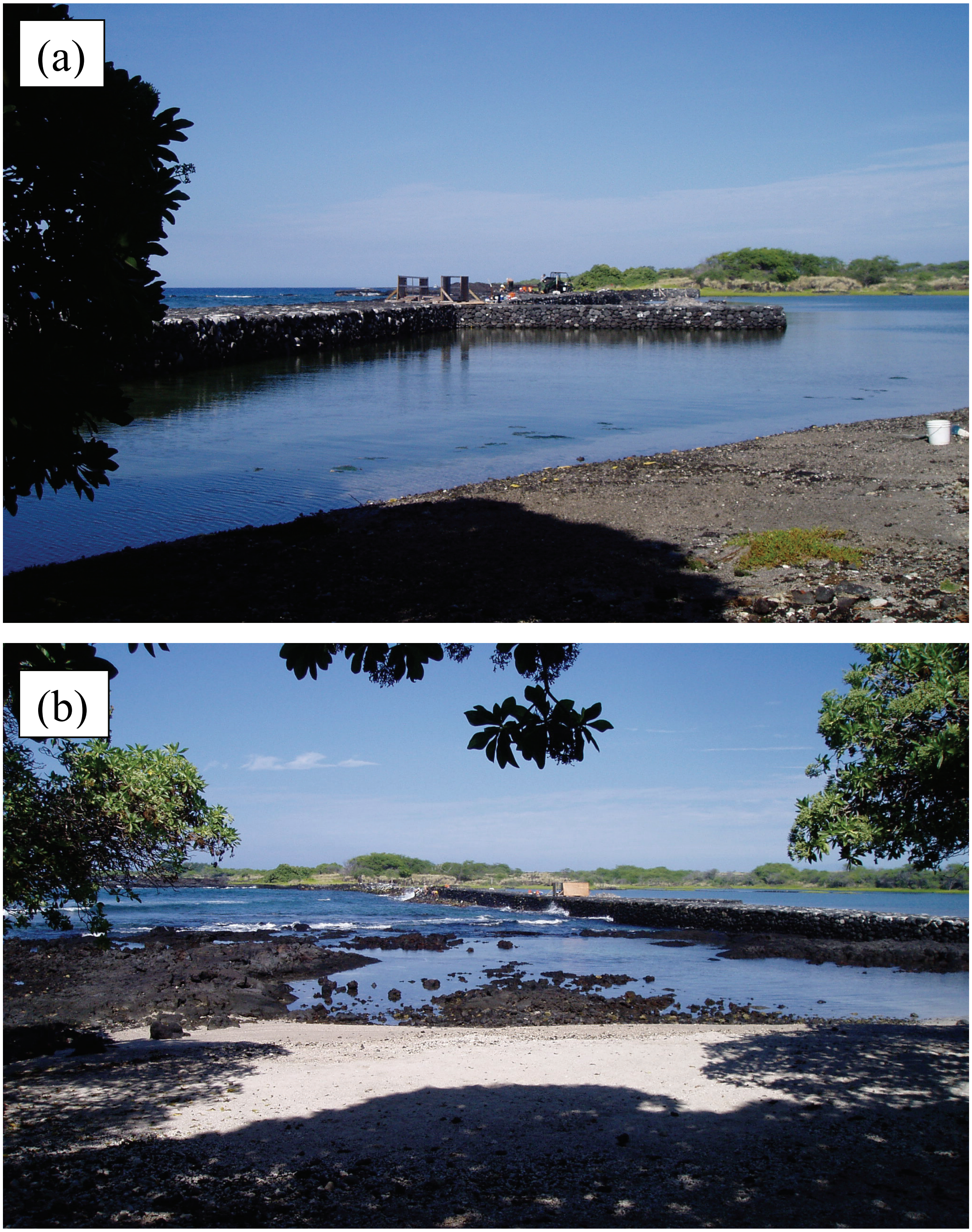


Figure 4. Kaloko fishpond wall during restoration on 11/29/04. (a) View north from pond edge just inland of wall. Structure extending into pond from wall is makaha, or sluice gate. (b) View north from seaward side of wall. Restoration of the southern portion of the wall is complete; masons are visible working on the central portion. Photos by D. Hoover.

side, suggesting that that area, and possibly other marsh areas, were open water when the pond was maintained. Reductions in pond area in recent times probably have resulted primarily from infilling by locally-generated sediments and overgrowth by alien vegetation. In 2000, pond depths ranged from 2 to 6 feet (0.6 - 1.8 m), and sediments generally were a foot or more in thickness (Marine Research Consultants 2000). Kikuchi and Belshe (1971) described Aimakapa sediments as consisting of "silt and organic-rich muck". Sediment cores recently were collected from Aimakapa but have not been analyzed. The cores currently are stored frozen at UH Hilo in Dr. Mike Parsons' laboratory (Sallie Beavers pers. comm. 2005)

Aiopio fishtrap is a 0.69-ha (1.7 acres) coastal enclosure near the southern end of the park (Figure 1). The seaward portion of the enclosure is a man-made wall, but there is a narrow channel in the wall that provides for flow between the pond and the offshore ocean, and as of 1971, the central portion of the wall was awash at high tide, allowing some additional exchange (Kikuchi and Belshe 1971). Exchange probably was less when the trap was in use, as tidal records show that sea level rose at an average rate of 0.34 cm/y (0.13 in/y) between 1946 and 2002, or a total of 19 cm (7.5 in) over that period (Hapke et al. 2005). Sea level rise on the Kona coast is the result of both natural subsidence of the island and sea level rise due to global climate change (Apple and Macdonald 1966). Both processes are continuing, but the effects of global climate change are restricted mostly to recent times (~the last 100 years), while island subsidence has been ongoing since the fishtrap was constructed. Depths in the pond range from about 1 to 4 feet (0.3 - 1.2 m), and in 1971, pond floor sediments were 'sandy with little or no plant growth' (Kikuchi and Belshe 1971).

B.2.c.iv. Wetlands

KAHO's wetlands cover about 3% of the park's land area and are among the most abundant and diverse in west Hawai'i (Canfield 1990). Significant areas of wetlands are found primarily to the north and northwest of Kaloko and Aimakapa fishponds, with a smaller area inland of Aiopio fishtrap (Kikuchi and Belshe 1971; Canfield 1990; Pratt 1998). Small wetland habitats also are associated with some of the anchialine pools in the park.

The large area of wetlands north and northwest of Kaloko pond was invaded by red mangroves (*Rhizophora mangle*) sometime after 1971 (Pratt 1998), and was almost entirely covered by 1987 (Canfield 1990). Mangroves were removed in 1991-1992, but the area subsequently was invaded by alien pickleweed (*Batis maritima*) (Pratt 1998).

Wetlands around Aimakapa pond are very extensive, covering an area roughly equal to the existing area of open water in the pond (~15 acres/6 ha). A map in Kikuchi and Belshe (1971) shows most of the wetlands in a contiguous area on the north side of the pond, with a small area near the coast on the southern side. Wetland vegetation around Aimakapa pond is discussed in Pratt (1998):

> "A recent map of the pond and wetland vegetation of Aimakapa shows Kiawe forest to the north and south and a broken band of milo forest almost encircling the pond... Marsh vegetation is particularly pronounced on the northwest and southwest margins of the pond. Canfield (1990) recognized more than ten distinct associations of marsh plants on the margin of Aimakapa pond. More than half of the recognized associations include the alien knotgrass either in pure stands,

> mixed with the alien pickleweed, or mixed with native sedges, aeae, or milo; knotgrass-dominated marsh and meadow was noted on all sides of Aimakapa... An open vegetation of milo shrubs in knotgrass meadow was described for the edge of the wetter marshes both north and south of the pond".

Exposed mudflats and other areas of the wetland surrounding Aimakapa are important feeding areas for the endangered Hawai'ian black-necked stilt and for other waterbirds (Pratt 1998). A portion of the wetland area north of the pond was cleared of invasive mangroves in 1992 (Pratt 1998), and mangrove control efforts are ongoing around the pond.

B.2.c.v. Rocky and sandy intertidal

Most of KAHO's coastal margin consists of a low-lying basalt platform made up of intact pahoehoe lava, which terminates as a rather steep cliff, or step, descending to the ocean floor (Parrish et al. 1990; Cochran-Marquez 2004). The rocky intertidal zone is an area of active water exchange and contains tide pools and associated flora and fauna, as well as other intertidal flora and fauna associated with rocky substrates that are subject to cyclic submergence and emergence by tide and wave action, or which receive intermittent moisture in the form of splash and spray. Tidepools are most abundant in the northern strip of coastline between the current park boundary and Wawahiwa'a point (Parrish et al. 1990).

In many areas the park's basalt shoreline is overlain by intertidal and supratidal perched carbonate and basalt sand and gravel beaches (Parrish et al. 1990; Pratt and Abbott 1996; Hapke et al. 2005). The distribution of sand deposits along the shoreline varies from year to year (Hapke et al. 2005), but significant intertidal deposits normally are found mostly in the berm separating Aimakapa Fishpond from the ocean and along the coast immediately north and south of the berm (Figure 5). Hapke et al. (2005) showed that beaches in KAHO experienced net landward erosion over the period 1950 – 2002, with an average loss of 0.3 m/y, "…likely [due to] the rise in annual mean high water and the subsidence of the island due to loading from the active volcano". Erosional rates were variable along the park coastline, with most areas experiencing horizontal losses of 0.2 – 0.4 m/y, but with high rates (~0.7 m/y) in the perched beach on Kaloko Point south of Kaloko fishpond, no net change in the intertidal beach fronting Aimakapa fishpond, and with a few small areas experiencing net increases of up to 0.24 – 0.70 m/y. Sand losses are affecting cultural resources in the southern portion of the park, where beach erosion has resulted in the loss of at least one palm tree (Hapke et al. 2005), and sand losses expose the walls of Aiopio fishtrap to potentially greater damage from waves and currents.

B.2.c.vi. Coastal waters

KAHO's coastal waters cover a total of 241 ha (596 acres), extending offshore for about 800 m (0.5 mile) (Figure 1). Maximum depths are about 45 m (150 feet) (Parrish et al. 1990).

KAHO's benthic topography is complex (Parrish et al. 1990) and is controlled primarily by the extent and characteristics of the constituent lava flows, with 'flat to gently rolling pahoehoe flows, shear ledges, pinnacles and ridges, and steep flow fronts' (Gibbs et al. 2004). The majority of benthic substrate in park waters is lava from recent [1,500 –10,000 years old (Hapke et al. 2005)] flows, with limited areas of (predominantly carbonate) sand. Consolidated coral reefs do not form significant substrate in KAHO, although corals are a significant component of the benthic biota in some areas and corals have colonized much of the basalt substrate to varying degrees. Parrish et al. (1990) identified seven major subtidal benthic habitats based on substrate type and morphology: submerged sand, pinnacles and canyons, deep coral slope, shore cliff and shallow cliff, deep cliff, shallow pavement, and boulder and deep pavement (Figure 6). These

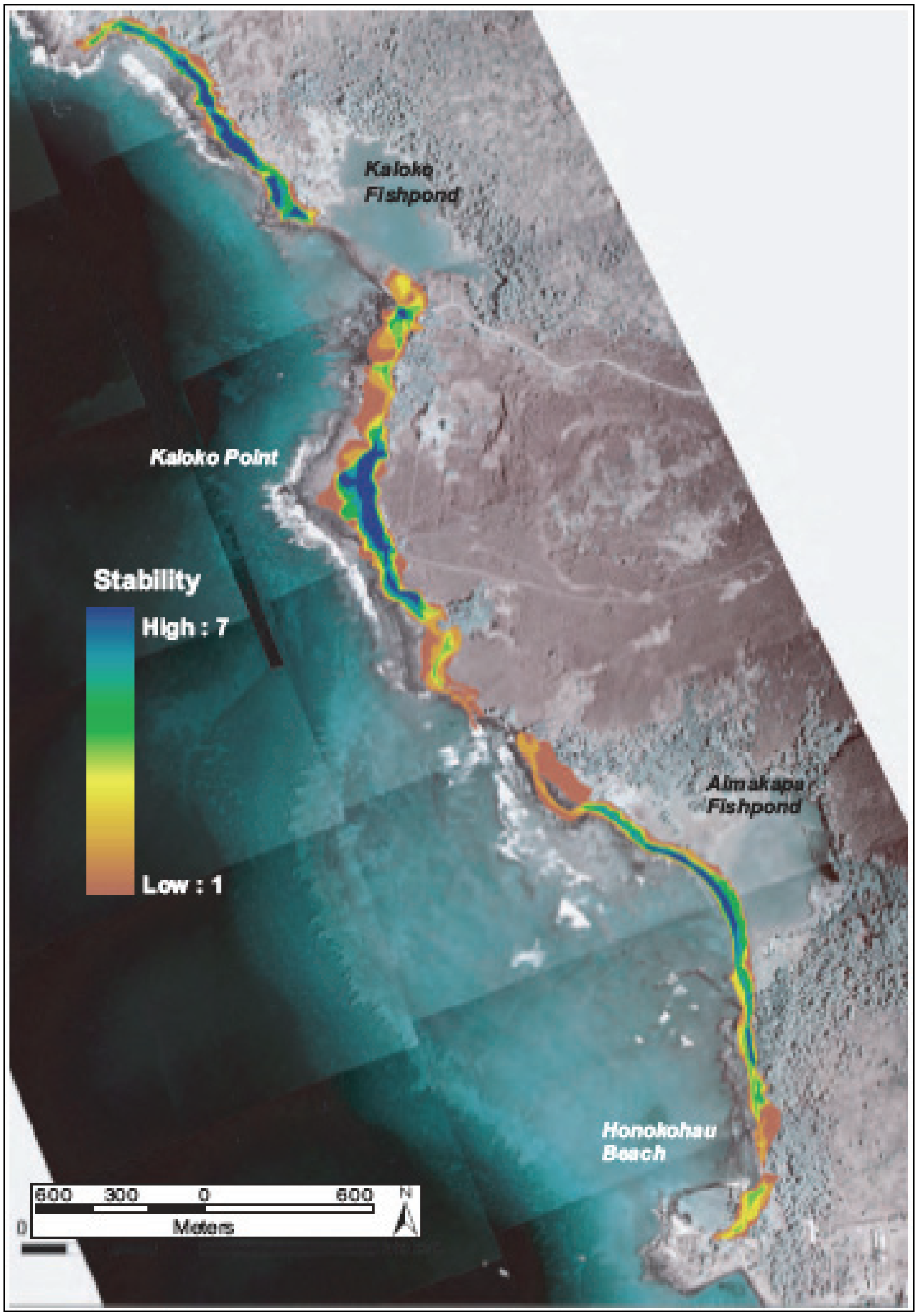


Figure 5. Beaches in KAHO. Stability scale indicates persistence of beach as determined from analysis of aerial photographs taken in 1950, 1954, 1965, 1970, 1988, 1992, and 2002. Most of the beach areas shown are supratidal; significant intertidal beaches are limited to the areas around Aiopio fishtrap and Aimakapa fishpond, and a small area north of Kaloko fishpond. Figure from Hapke et al. (2005).

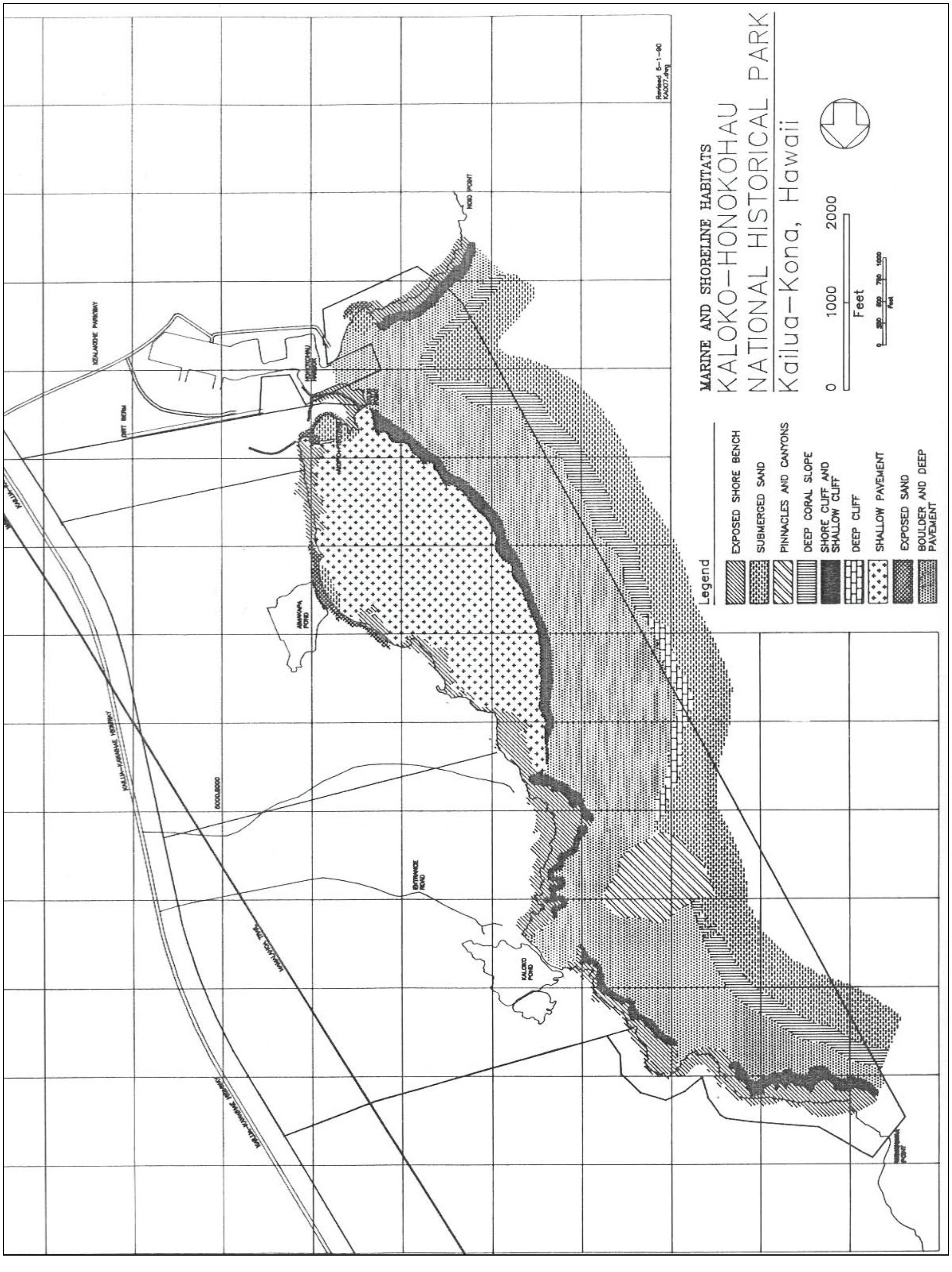


Figure 6. Marine habitats in KAHO coastal waters. Figure from Parrish et al. (1990).

habitat types were selected because of the controlling influence substrate type, depth, and relief have on benthic and associated pelagic communities. Marine Research Consultants (2000) surveyed KAHO’s coastal waters off of Kaloko and Aimakapa ponds and observed that the morphology along onshore-offshore transects was similar to that found in many areas of West Hawai‘i, with a shallow nearshore bench, a deeper (~25-50’ depth) platform, and a deep slope (>50’ depth, with a slope of 20 – 30°). More recently, NOAA classified benthic habitats from aerial photographs and Ikonos satellite imagery (Figure 7). Significant changes in the overall morphology of KAHO’s benthic substrate are unlikely due to the robust nature of the lava substrate, but occasional changes occur in the deep coral slope due to slumping, which may be

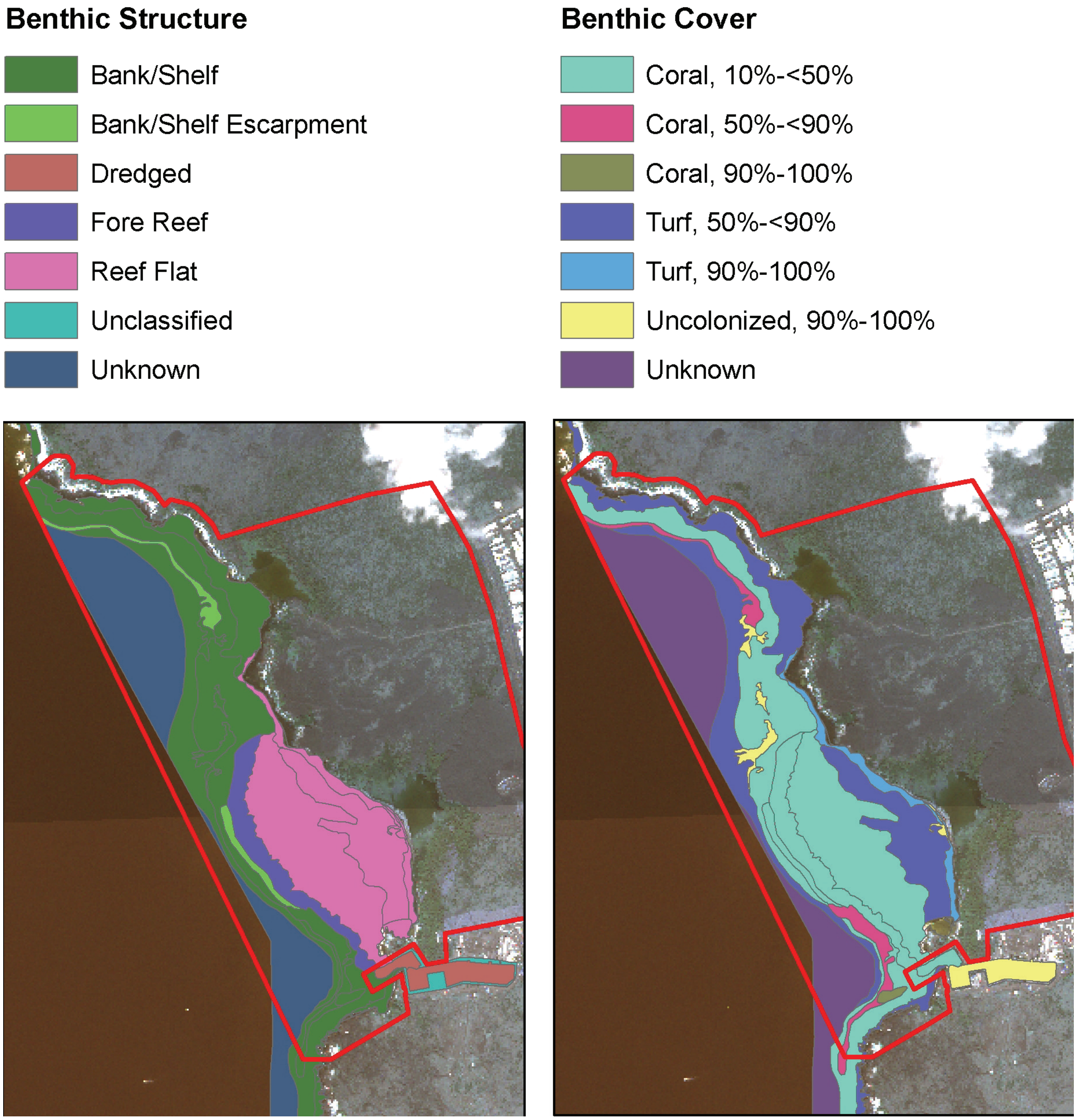


Figure 7. Benthic substrates in KAHO coastal waters classified by structural and biological attributes. Data courtesy of T. Battista, NOAA Center for Coastal Monitoring and Assessment.

triggered by severe storms (Parrish et al. 1990; Larry Basch pers. comm. 2005) and possibly by boat anchors, and changes may occur in the presence and extent of subtidal sand deposits.

B.2.c.vii. Honokohau Harbor

Honokohau small boat harbor is located adjacent to the main southern boundary of the park, with the harbor entrance abutting park coastal waters (Figure 1). The harbor was constructed in 1970 and enlarged in 1979 by blasting and excavating shoreline lavas. The present harbor includes 8 ha (20 acres) of water area with depths ranging from about 3 – 5 m (10 - 16 feet). Prior to harbor construction, strong groundwater discharges had been observed at the coast near the harbor site (Fischer 1966). After construction, groundwater discharge into the harbor resulted in estuarine circulation in the harbor, with discharge of brackish surface water from the harbor mouth, and subsurface inflow of coastal water into the harbor (Bienfang 1980).

B.3. Biological resources

B.3.a.i. Groundwater

Groundwater typically is not considered to contain significant biological resources. However, the mixohaline fauna found in KAHO's anchialine pools and fishponds includes hypogeal (subterranean) fauna that live in brackish groundwater, including the shrimp commonly found in anchialine pools. Their distribution in groundwater is not possible to quantify accurately, but they have been observed in groundwater samples collected from a well in the park (Brock and Kam 1997). Subterranean groundwater channels provide connectivity between anchialine pools and other park water bodies (fishponds and coastal waters), so groundwater may be an important pathway for dispersal and colonization of other mixohaline flora and fauna, including endemic and threatened and endangered species.

B.3.a.ii. Anchialine pools

Anchialine pools in Hawaiʻi harbor a distinct assemblage of organisms, including crustaceans (shrimps and amphipods), fishes, mollusks, a hydroid, sponges, polychaetes, tunicates, aquatic insects, algae, aquatic macrophytes, and a unique cyanobacterial mat community (Brock and Kam 1997). Native marine fish found in Kona coast anchialine ponds are listed in Table 1. Species of concern and species being considered for listing under the U.S. Endangered Species Act include the shrimp *Metabetaeus lohena* and a native damselfly (*Megalagrion xanthophelas*) (Pratt 1998; Else 2004).

Table 1. Native marine fish found in Kona Coast anchialine ponds. Common or Hawai‘ian name also is given in parentheses (Brock 1985)

Family and Species
Family Muraenidae
Gymnothorax flavimarginatus (puhi)
Family Congridae
Conger sp. (Puhi uha)
Family Holocentridae
Adioryx lacteoguttatus (ala'ihi)
Family Mugilidae
Mugil cephalus (ama'ama)
Neomyxus chaptalii (uouoa)
Family Kuhliidae
Kuhlia sandvicensis (aholehole)
Family Pomacentridae
Abudefduf sordidus (kupipi)
A. abdominalus (mamo)
Family Acanthuridae
Acanthurus achilles (paku'ikui)
A. triostegus (manini)
Family Eleotridae
Eleotris sandwicensis (o'opu akupa)
Asterropteryx semipunctatues (eleotrid)
Family Gobiidae
Kelloggella oligeolepis (goby)
Awaous stamineus (o'opu nakea)
A. genivittatus (o'opu)
Bathygobius fucus (goby)

B.3.a.iii. Ponds

Kaloko

Kikuchi and Belshe (1971) performed a survey of Kona coast ponds in 1970 and found that Kaloko pond waters could be characterized as a thin, brackish layer overlying a thicker, saltier layer, with phytoplankton and zooplankton concentrated in the upper portion of the more saline layer. Overall, the pond contained a “diverse biota” including mullet, milkfish, aholehole, manini, gobies, mosquito fish, and others despite not having been stocked in years. It also had “many small shrimp, ‘opae’, mussels in shoal areas, and some oysters on the sea wall”, and “a rich benthic algal mat … on the shallower parts of the pond floor [with] some filamentous algae … particularly in the northern sector”. Morin (1998) noted the presence of fireworms and “sharp oyster shells’ as deterrents to swimmers, and Marine Research Consultants (2000) noted that the “bottom composition of Kaloko pond is a hard sand/mud mixture that is largely covered with marine algae, primarily the introduced species *Acanthophora spicifera*” (Figure 8), and that sediments were anaerobic. Changes in pond biota and in the condition of bottom sediments may have been associated with dredging of pond sediments in 1971 (Bond and Gmirkin 2003), accumulation of detritus from mangroves that colonized Kaloko wetlands between 1971 and 1992, and with habitat and water quality changes associated with changes in the integrity of the fishpond wall and makahas.

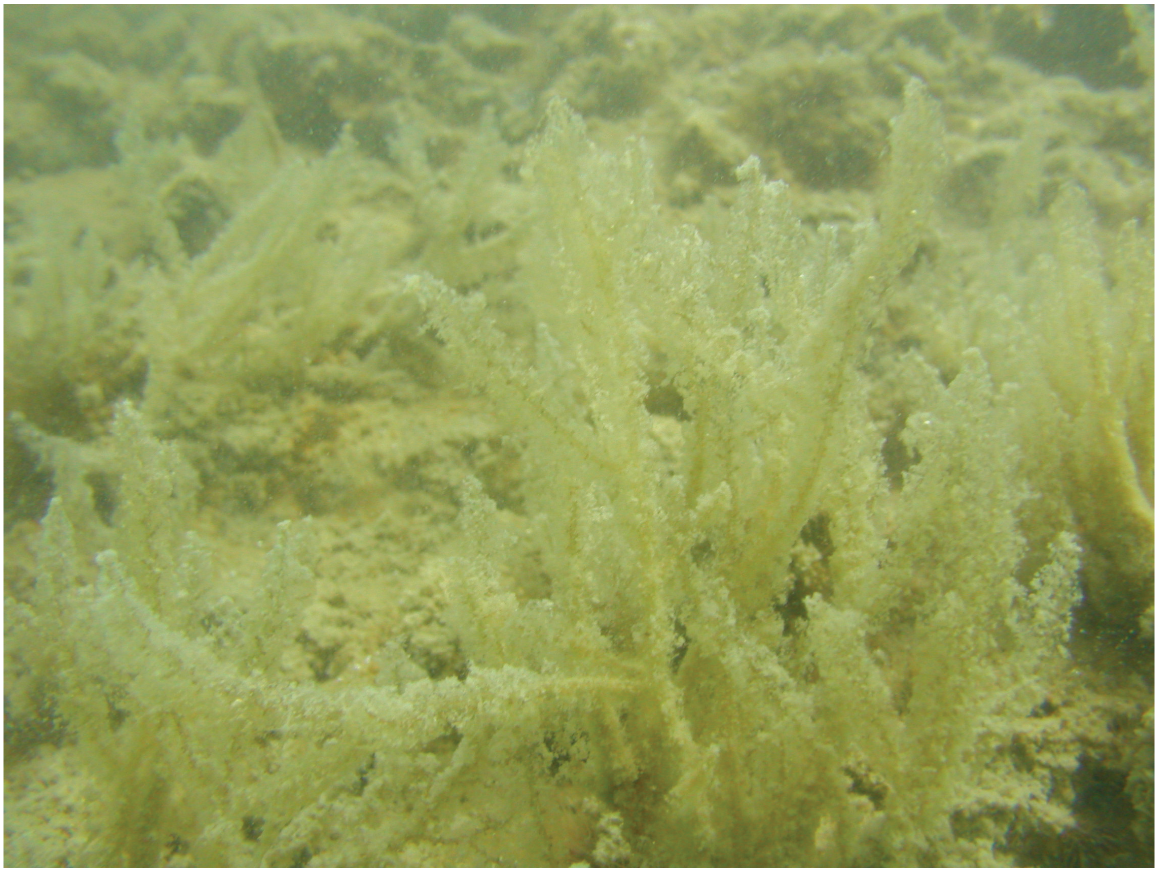


Figure 8. The alien alga, *Acanthophora spicifera*, in Kaloko pond. Photo by L. Basch.

Aimakapa

Sparks (1963) observed that Aimakapa fishpond contained large numbers of ‘awa (milkfish). Kikuchi and Belshe (1971) noted that benthic algae were common and sometimes found as floating mats. They also observed “several types of fish, small shrimp, and extensive aquatic microfauna”. Brock and Kam (1997) collected two adult grey mullet and two milkfish for tissue analyses, and Morin (1998) observed large fish in the pond that were suspected of preying on chicks of the endangered Hawai‘ian coot. Marine Research Consultants (2000) noted that the “bottom composition of Aimakapa pond consists of soft flocculent silty mud that is penetrable for at least one meter”, and that sediments were anaerobic. Large ‘awa (up to 1m) and mullet also were present in the pond in 2003 based on carcasses recovered from a one-day fish kill of undetermined cause (possibly low dissolved oxygen) (Sallie Beavers pers. comm. 2005).

Aiopio

The only mention of biological resources in Aiopio pond is by Kikuchi and Belshe (1971), who noted that “both fish and turtles freely and frequently enter the pond from the open sea”, and that “the bottom is sandy with little or no plant growth”.

B.3.a.iv. Wetlands

The extensive wetlands associated with Kaloko and Aimakapa fishponds and Aiopio fishtrap provide significant habitat for vegetation and for breeding, resting, and feeding of birds, including native endangered waterbirds and migratory and vagrant waterbirds (Morin 1998). KAHO's wetlands have been estimated to maintain 50 – 80% of the populations of endangered Hawai'ian coots and stilts in west Hawai'i (Morin 1998). Wetlands associated with anchialine pools provide habitat for associated insect fauna, including the orange-black damselfly (*Megalagrion xanthomelas*) (Pratt 1998; Cooper et al. submitted 2005; Foote et al. submitted 2005a; Foote et al. submitted 2005b), which currently is under consideration for listing by the U.S. Fish and Wildlife Service under the U.S. Endangered Species Act (David Foote pers. comm. 2005). Most of the wetlands in the park include a significant component of alien vegetation, but some areas of native sedge-dominated marsh remain that support many native species. These areas comprise some of the best wetlands remaining in the State (Pratt 1998). Park wetlands have been studied in conjunction with vegetation studies of the park (e.g. (Pratt and Abbott 1996; Pratt 1998), and with studies of bird habitat in the park (Morin 1996; Morin 1998).

Until recently, the marsh area north of and adjacent to Kaloko Pond was relatively unimpacted by human land use and invasive species (DeVerse and DiDonato 2005). However, mangroves became established in the area and had completely overgrown the northern marsh areas by 1987 (Canfield 1990). The mangroves were removed in 1992 (Canfield 1990; Morin 1998; Bond and Gmirkin 2003), resulting in an increase in foraging activity by the endangered Hawai'ian stilt (ae'o, *Himantopus mexicanus knudseni*) and other waterbirds. Ongoing mangrove control has prevented recolonization, but much of the improved foraging habitat was lost as the area subsequently was invaded by pickleweed (*Batis maritima*), which now is a focus of eradication efforts. Additional wetland habitat around the pond includes a large area of native makaloa sedge (*Cyperus laevigatus*) in shallow waters around the southeastern arm of the pond. Although marsh areas around Kaloko provide feeding and resting habitat for resident and transient waterfowl, no waterfowl nesting has been observed at Kaloko pond (Morin 1996; Morin 1998). Kaloko pond's high salinities, relatively deep water, and exposed conditions make it less suitable for feeding, and especially for nesting, than the fresher, shallower, and more sheltered waters of Aimakapa pond. Shallow-water and wetland habitats in Kaloko pond may become more suitable for waterbird use if salinities decline following restoration of the fishpond wall, and if pickleweed removal is successful. However, the new Kohanaiki residential/resort development currently being built adjacent to KAHO's northern boundary may affect wetland habitat on the north side of Kaloko pond, as well as the general suitability of the area for bird feeding and nesting.

Native vegetation still dominates many of the wetland areas around Aimakapa pond (Pratt 1998; Sallie Beavers pers. comm. 2005), although many areas include a mix of alien and native vegetation. Relatively little restoration work has been performed around Aimakapa with the exception of the removal of a small area of mangroves from the northern portion of the pond in 1992, removal of Kiawe trees along the southeastern margin of the pond, experimental removal of pickleweed and knotgrass (*Paspalum vaginatum*) from test areas (Pratt 1998), and ongoing mangrove control efforts (Sallie Beavers pers. comm. 2005). The limited restoration efforts reflect both scarce resources (Morin 1998) and the need to minimize disturbance to resident populations of endangered birds (Pratt 1998).

Because of the low salinity and high productivity of pond waters and the extensive shallow-water marsh habitats, Aimakapa provides the second most important bird habitat on the Kona coast (Morin 1998). In addition, areas such as the marsh and wet meadow north of the pond that contain mostly native vegetation are rare and thus valuable in their own right (Pratt 1998). Aimakapa pond is the only site in KAHO where waterbirds breed, including the endangered Hawai‘ian stilt (ae‘o, *Himantopus mexicanus knudseni*) and Hawai‘ian coot (*Fulica alai)*, and the Black-crowned Night Heron (*Nyctiocorax nyctiocorax*) (Pratt 1998; Wilson Okamoto & Associates 2000).

B.3.a.v. Rocky and sandy intertidal

KAHO’s rocky intertidal marine resources were surveyed in 1988 by Parrish et al. (1990). Tidepools, which serve as a valuable nursery for a variety of species, were most prevalent along the tip of Wawahiwa’a Point (Figure 1). This area is within the originally legislated park boundary, but currently is privately held. Two species of hard corals were found in the intertidal zone; the cauliflower color *Pocillopora meandrina*, and the lobe coral *Porites lobata*. Endemic Hawai‘ian limpets (opihi) appeared to be depleted in the intertidal areas, likely due to harvesting, but cowry beds (probably endemic *Cypraea sulcidentata*) still were present in the park. Sea urchins or wana (echinoids), sea cucumbers or loli (holothurians), and sea stars or peapea (asteroids) were the largest and most conspicuous animals found in KAHO’s intertidal zone (Parrish et al. 1990).

Little work has been done on the biological status of intertidal sand deposits in the park. Parrish et al. (1990) observed that sandy substrate in areas of “fairly high wave energy” provided minimal benthic habitat, and found few epibenthic macroorganisms on subtidal sands. They did not sample any of the sand substrate, and thus were unable to characterize interstitial macrofauna or meiofauna, but suggested that diversity and abundance probably were low. Sand beaches in the park are utilized by green sea turtles for basking and resting, and could provide nesting habitat for hawksbill turtles (Sallie Beavers pers. comm. 2005). Green sea turtles often also can be found grazing algae on shallow subtidal benches at the beach-sea interface. Comprehensive intertidal habitat, resources, and threats characterization, and inventory and mapping of intertidal geomorphology and biota by the NPS Pacific Islands Coral Reef Program (PICRP) is scheduled for KAHO and other National Parks in Hawai‘i in 2007 (Larry Basch pers. comm. 2005).

B.3.a.vi. Coastal waters

Biological resources in coastal waters occur as planktonic and pelagic flora and fauna, and as benthic flora and fauna associated with the various subtidal habitats.

Planktonic and pelagic biological resources

Coastal waters off KAHO provide habitat for planktonic and pelagic animals and phytoplankton. Plankton studies are relatively uncommon in Hawai‘ian coastal waters, so it is not surprising that few plankton data are available from park waters, but some data are available from two studies of Honokohau Harbor that included sites outside of the harbor mouth (Oceanic Foundation 1975; Bienfang 1983). Ongoing recruitment studies of benthic fauna and reef fish suggest that meroplanktonic larvae probably contribute significantly to plankton diversity and seasonal variation in plankton composition in the park (Larry Basch pers. comm. 2005). Pelagic resources have received more attention – Parrish et al. (1990) surveyed pelagic resources throughout park waters, Marine Research Consultants (2000) surveyed fish offshore of Kaloko and Aimakapa ponds, Tissot and Hallacher (2003) and the Hawaiʻi DLNR Division of Aquatic Resources (Walsh et al., ongoing) monitor fish repeatedly on permanent transects in park waters, and in 2005, park waters were surveyed for marine vertebrates (primarily reef fish) with stratification by habitat type and depth using the NPS Inventory and Monitoring criterion of 90% species identification (Beets and Friedlander in prep; Larry Basch pers. comm.. 2005). These studies provide insight into the population status and taxonomic composition of fishes over time, although methodological differences between earlier and more recent studies preclude complete quantitative analysis of trends.

- *Phytoplankton*

Phytoplankton biomass in and just outside Honokohau Harbor was relatively low (range: ~0.15 – 0.8 µg chl-*a*/l) during the five years following initial harbor construction, with the highest levels inside the harbor and the lowest at a site outside the harbor (site 1A in Figure 9). Sites inside the harbor also showed increases in chlorophyll-*a* concentrations with depth. Biomass at all sites varied significantly between high and low tide due to the accumulation or outflow of brackish groundwater in the surface layer and its effect on harbor circulation. The relatively low biomass values did not appear to be due to nutrient limitation; nutrient concentrations at all sites were well above levels that would be expected to limit phytoplankton production, especially inside the harbor. Low biomass values instead were attributed to control by zooplankton grazing (Oceanic Foundation 1975). Phytoplankton chlorophyll-*a* concentrations at site 1A (~0.2 – 0.4 µg chl-*a*/l) were similar to or only slightly higher than values observed in 1994-1996 and 2000 at coastal sites in the park 100 – 200 m offshore of Kaloko and Aimakapa ponds (~0.1 – 0.3 µg chl-*a*/l [Brock and Kam 1997, Marine Research Consultants 2000]). Thus, phytoplankton biomass at the outer harbor site in 1975 was rather similar to what would have been expected for park waters unaffected by discharges from Honokohau Harbor, or from groundwater from other areas. After harbor expansion in 1979, phytoplankton biomass increased dramatically in the new inner basin, but there was less change in the outer basin and at the harbor entrance (no data were collected outside of the harbor) (Bienfang 1983). Comparison of pre- and post- expansion data from site 4 at the harbor entrance (Figure 9) shows that phytoplankton chlorophyll-*a* concentrations increased significantly, from 0.16 – 0.18 µg/l at 1.5 m depth in 1975, to 0.76 – 0.93 µg/l at the same depth in 1982. While sampling was performed over just a 4-day period in 1982, and phytoplankton abundances can vary significantly over short timescales, it seems likely that harbor modifications have increased phytoplankton exports to KAHO coastal waters.

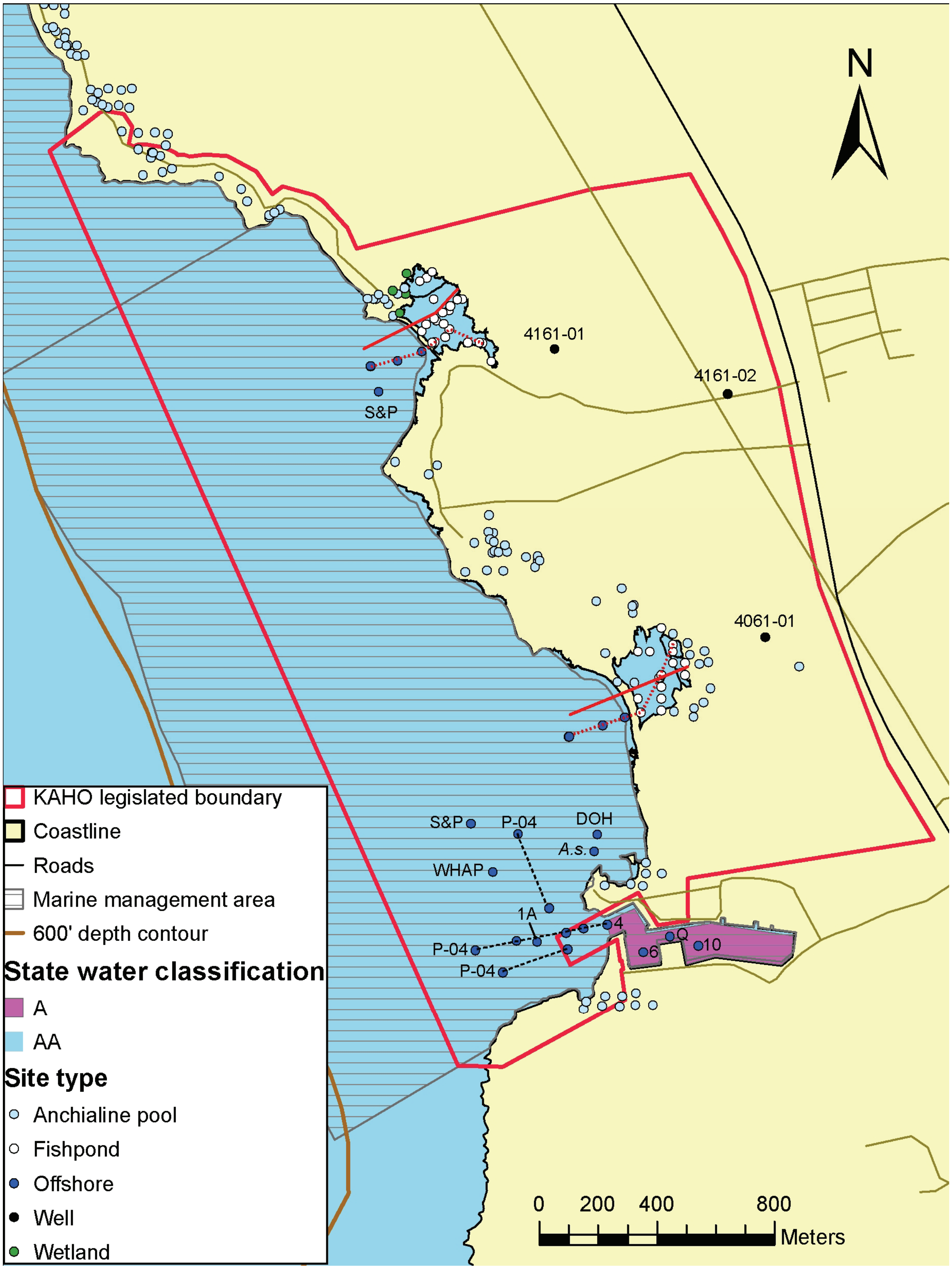


Figure 9. Historical and present-day water quality and biological monitoring sites in and adjacent to KAHO. Fishpond/offshore transects surveyed by Brock and Kam (1997) and by Marine Research Consultants (2000) are shown as dashed and solid red lines, respectively. Kaloko pond sites used by Weijerman (unpubl.) are omitted for clarity. See text for details.

- Zooplankton

Harbor construction initially increased zooplankton biomass inside the harbor compared to tows outside the harbor, with the highest values found in deep tows. Dry weights outside the harbor in 1975 were ~15-25 mg/m^3, while surface samples inside the harbor ranged from about 35 – 70 mg/m^3 and deep samples ranged from about 70 – 140 mg/m^3. Comparison of zooplankton abundances to concentrations of phaeophytin (a chlorophyll-*a* breakdown product associated with grazing by zooplankton) showed that zooplankton appeared to be food limited. Zooplankton community structure and abundance inside and outside the harbor in 1975 are summarized in Table 2. Unlike phytoplankton, zooplankton did not increase dramatically after harbor expansion: biomasses from tows outside the harbor in 1982 were comparable to those from 1975, and biomasses from tows inside the harbor actually were substantially lower than those observed in 1975 (Bienfang 1983). The low values inside the harbor are surprising given the greater productivity of marina waters in 1982, but may have been an anomaly given the significant fluctuations possible in zooplankton populations on short time scales (Bienfang 1983). No zooplankton studies have been conducted since 1982 in the harbor or else where in park waters, but ongoing benthic invertebrate and fish recruitment studies are collecting data that may provide insight into the zooplankton community in park waters (Larry Basch pers. comm. 2005).

Parrish et al. (1990) conducted extensive qualitative/semi-quantitative surveys of KAHO coastal waters on 6 days between 10/1/1988 and 12/4/1988, covering depths from 0 to 150 feet. Surveys were conducted visually, with divers estimating fish abundance using 4 descriptive classifications: abundant, common, few, and present. Results were presented separately for each of seven different subtidal habitat types: submerged sand, pinnacles and canyons, deep coral slope, shore cliff and shallow cliff, deep cliff, shallow pavement, and boulder and deep pavement. While the investigators made a conscious effort to avoid sampling bias by spending similar amounts of time in each habitat type, the lack of a rigorous sampling design makes the data difficult to use for quantitative analyses. For instance, all surveys were conducted during the day, so nocturnal species are underrepresented, as are cryptic species not easily identified using visual methods, and no size data were collected (Parrish et al. 1990). Nonetheless, the results of this study provide a reasonably thorough semi-quantitative view of the taxonomic composition of the reef fish assemblage present at that time. Overall, 150 species were observed in park waters, and fish were observed to be relatively abundant in KAHO waters compared to other parks, possibly due to reduced fishing pressure caused by limited road access for fishermen (Parrish et al. 1990).

Marine Research Consultants (2000) conducted ‘qualitative reconnaisance surveys’ of the fish community in the offshore area in front of Kaloko pond, out to 10 m depth. Although they state that “fish community structure can be divided into six general categories: juveniles, planktivorous damselfishes, herbivores, rubble-dwelling fish, swarming tetrodonts, and surge-zone fish”, not all of these categories are discussed in their results, and results for the fish discussed are presented only in the most general terms. Their overall conclusion was that the “fish community structure at Kaloko appeared fairly typical of the assemblages found in West Hawai‘i reef environments”. Because the surveys covered only a small portion of park waters and quantitative techniques were not used, the data are not suitable for quantitative assessment of fish community status or comparison with other data for trend analysis.

Table 2. Abundances (#/m^3) of selected zooplankton within and outside of Honokohau Harbor. Data are averages of 3 ~yearly samples collected between 9/1971 and 8/1973. ‘Within harbor’ data are averages of 3 tows performed between adjacent sites (4-6, 6-Q, Q-10 in Figure 9). S = surface, B = bottom. Table adapted from Oceanic Foundation (1975).

Location:	Outside Harbor (1A)		Inside Harbor (all stations)			
Tide:	High	Low	High	High	Low	Low
Sample depth:	S	S	S	B	S	B
Copepods	1685	4447	13604	28587	11004	29746
Invertebrate eggs	218	349	2842	8312	4845	11622
Copepod nauplii	140	194	226	352	246	621
Gastropod larvae	89	58	187	282	115	109
Chaetognaths	53	88	72	70	38	23
Arthropods	8		9			
Siphonophores	11	9		<1	<1	
Ctenophores	28	22	4	15	15	5
Mysids	3	4	2	8	18	2
Larvaceans	6	40	9	20	19	4
Doliolids	3	4			2	4
Larval fish	3			3	2	2
Fish eggs	196	62	30	30	30	30
Euphasids						
Polychaetes	3		4	13	3	5
Echinoderm larvae				10		
Heteropods			4		3	5
Tintinnids				3		
Crab zoea	6		23	10	21	9

- *Pelagic fauna*

Tissot and Hallacher (2003) surveyed 19 fish species along four permanent 50-m transects at depths of 10 – 15 m. Surveys were conducted at 2-5 month intervals from March 1997 to December 1998. Surveyed species included 10 aquarium species commonly targeted by commercial collectors and 9 non-targeted species in guilds ecologically similar to those of collected species. Results were compared to a control site where aquarium collecting had been prohibited since 1991, and showed significant depletion in aquarium species compared to non-targeted species. Although one aquarium species (*Naso lituratus*) in KAHO occurred at densities 66% higher than at the control site, the other 9 aquarium species occurred at 29% to 94% lower densities. In 2000, KAHO’s coastal waters were designated by the State of Hawai‘i as a Fish Replenishment Area (FRA) and aquarium collecting was prohibited. Subsequent surveys showed no significant change in the most targeted species (Yellow Tang – *Zebrasoma flavescens*), although significant increases were observed in some other FRAs. The lack of response in KAHO may have been due to the small size of the KAHO FRA and the relatively small amount of suitable habitat in KAHO compared to the other FRAs (Tissot et al. 2003; Tissot and Hallacher 2003; Division of Aquatic Resources 2004).

Recent and planned studies should provide significant new data on reef fish in KAHO coastal waters. The State of Hawai‘i DLNR, Division of Aquatic Resources (DAR) has been monitoring the entire reef fish assemblage along the Kona coast of Hawai‘i Island, including KAHO, for several years, collecting data on species composition, abundance and size frequency distribution (Larry Basch pers. comm. 2005). Recent surveys have included benthic habitat cover analysis, in order to ascertain fish habitat utilization and essential fish habitat. Simultaneously, the NPS has contracted work for a nearshore marine vertebrate (primarily reef fish) inventory that meets the NPS Inventory and Monitoring Program national standard of 90% species documentation (Beets and Friedlander in progress). Like the study by Parrish et al. (1990) this inventory is stratified from intertidal (0 m) to subtidal depths (to 30 m) but uses the NOAA benthic habitat classification scheme for the main Hawai‘ian Islands (established collaboratively by the local marine science community, including NPS, subsequent to the Parrish et al. (1990) study). This inventory is designed to be more quantitative than that by Parrish et al. (1990), but it will attempt to compare results between the studies to the extent possible. Starting in 2006, the NPS Inventory and Monitoring Program, and the Pacific Islands Coral Reef Program will implement statistically rigorous, quantitative peer-reviewed Vital Signs monitoring of marine benthic communities and associated reef fishes and ecosystem processes at KAHO (Larry Basch pers. comm. 2005).

In addition to fish, there are a number of other pelagic animals encountered in park waters that are of special interest. Threatened green sea turtles (*Chelonia mydas*) are abundant in the waters off KAHO, and the endangered hawksbill turtle (*Eretmochelys imbricata*) is known infrequently from waters off the Kona coast (Beavers and Marrack in prep 2005). Green sea turtles regularly feed in KAHO waters and rest on KAHO beaches, making them particularly vulnerable to changes in habitat and water quality in the park. KAHO is one of the relatively few areas in Hawai‘i where green sea turtles have not been observed to have fibropapilloma tumors. While the link has not yet been definitely proven, a connection between tumors and degraded water quality has been hypothesized (Herbst and Klein 1995). The National Marine Fisheries Service Marine Turtle Research Program and the Hawai‘i Preparatory Academy have monitored green sea turtles in the park since 1999; this work is ongoing and has expanded with NPS KAHO staff (Beavers and Marrack in prep 2005b; Beavers and Marrack in prep 2005a; Beavers and Marrack in prep 2005c). Sharks frequently are sighted offshore (Sallie Beavers pers. comm. 2005), and in recent years tiger sharks have been sighted inside, and near the mouth of Honokohau Harbor (Honebrink and Ward 2001; Thompson 2005), but no quantitative data are available on shark populations or activities in park waters. Likewise, giant manta rays transit park waters, and are the focus of commercial night diving and research activity in and near KAHO waters (T. Clark UH Manoa, Ph.D. dissertation research in progress; K. Osada UH Hilo, Masters thesis research in progress; Larry Basch pers. comm. 2005). Spotted eagle rays also are common transients (Larry Basch pers. comm. 2005), and spinner dolphins (*Stenella longirostris*) frequently can be found in park waters (Östman-Lind et al. 2004). Park waters also occasionally are visited by endangered Hawai‘ian monk seals (Sallie Beavers pers. comm. 2005).

Subtidal benthic biological resources

KAHO has a varied subtidal benthic geomorphology, often overlain with biogenically-structured habitats that combine to form a topographically complex range of substrates. These in turn provide the foundation for diverse benthic communities, ecological processes, and resources. For example, corals are found throughout coastal waters, but the most extensive colonies are found along nearshore submarine cliffs (the "Kona drop") and in deeper waters offshore of the cliffs (Parrish et al. 1990; Marine Research Consultants 2000). Shallow subtidal sands are comparatively rare and provide only minimal habitat for benthic organisms due to the relatively high wave energy in sandy areas and the unstable nature of the substrate (Parrish et al. 1990), but infauna and meiofauna have not yet been characterized. There are no significant areas of muddy sediments in park waters, but unconsolidated sand substrate offshore of the base of the forereef slope contains sufficient silt to allow for the occurrence of a dense population of burrow-dwelling garden eels (*Gorgosia hawaiiensis*) (Larry Basch pers. comm. 2005). Benthic resources in KAHO have been the subject of a number of surveys, including Parrish et al. (1990), Marine Research Consultants (2000), Tissot (2000), Cochran-Marquez (2004), Gibbs et al. (2004), Tissot et al. (2004), and recent and ongoing work by the West Hawaiʻi Aquarium Project, Hawaiʻi State DLNR Division of Aquatic Resources and Basch et al. (in prep.) (Larry Basch pers. comm. 2005).

While their primary focus was on reef fishes, Parrish et al. (1990) included some initial surveys of benthic flora and fauna in KAHO's coastal waters in their assessment of marine resources in the park (see <u>Planktonic and pelagic biological resources</u>, above). As for their fish surveys, methods were only semi-quantitative, with divers visually assessing the relative abundance of sessile invertebrates and benthic macroalgae as percent cover, or using the descriptive classifications 'abundant', 'common', 'few', or 'present'. Results are presented separately for each habitat type in the form of extensive species lists with notations on relative abundance. As for their fish data, the methods employed introduce some biases into the results (e.g. undersampling of nocturnal and cryptic species), and the lack of quantitative data make it difficult to compare their results to other studies. Nonetheless, the data provide an unusually thorough picture of KAHO's benthic resources as they existed in 1988.

Marine Research Consultants (2000) conducted 'qualitative reconnaisance surveys' of the benthic community in the offshore area in front of Kaloko and Aimakapa ponds, out to 10 m depth. Their results are presented in a relatively brief discussion that is reproduced below:

> "3.2.2 Coral Communities
>
> The predominant taxon (sic) of macrobenthos (bottom dwellers) throughout the reef zones off of Kaloko Pond are Scleractinian (reef-building) corals. In total, twelve species of "stony" corals, and two "soft" corals were observed throughout the region of study. The dominant species in all of the zones off Kaloko-Aimakapa was *Porites lobata*. The second and third most abundant species were *Porites compressa* and *Pocillopora meandrina*. Other species that were common in the shallow nearshore areas were *Montipora verrucosa*, *M. patula* and *Pavona varians*. It was estimated that coral cover on the shallow bench comprised approximately 15% of bottom cover at Kaloko and 5% at Aimakapa. It was not apparent that community structure in the shallow

> nearshore areas adjacent to the boulder rampart, or sand berm separating the ocean from the pond was affected by freshwater flow from the pond.
>
> The mid-depth reef platform zone had the highest number of coral species at both survey sites. In the mid-depth zone, dominant species were *Porites lobata* and *Porites compressa*. *Porites lobata* occurs in various growth forms including flat encrustations and large dome-shaped colonies, which are responsible for much of the true "reef" accumulation in the mid-depth zones. The abundance of suitable solid surfaces for coral settlement and growth, as well as the reduced wave stress compared to the shallower boulder zones provides a suitable setting for a variety of smaller encrusting coral species. Coral cover on the outer reef platform comprised approximately 40-60% of bottom cover.
>
> 3.23 Other Benthic Macroinvertebrates
>
> The other dominant group of macroinvertebrates are the sea urchins (Class Echinoidea). The most common urchin was *Echinometra matheai* (sic), which occurred in all reef zones. *E. matheai* are small urchins that are generally found within interstitial spaces bored into basaltic or limestone substrata. *Tripneustes gratilla*, and *Heterocentrotus mammillatus* were other species of urchins that occurred commonly throughout the reef. Both of these urchins occur as larger individuals (compared with *E. matheai*) that are generally found on the reef surface, rather than within interstitial spaces.
>
> Sea cucumbers (Holothurians) observed during the survey consisted of three species, *Holothuria atra*, *H. nobilis*, and *Actinopyga obesa*. Individuals of these species were distributed sporadically across the mid-reef and deep reef zones. Numerous sponges were also observed on the reef surface, often under ledges and in interstitial spaces.
>
> Frondose benthic algal zonation was not apparent at the study area off of Kaloko. However, encrusting red calcareous algae (*Porolithon spp*., *Peysonellia rubra*, *Hydrolithon spp*.) were common on the boulders and exposed rocks throughout the study area. These algae were also abundant on bared limestone surfaces, and on the non-living parts of coral colonies.
>
> The design of the reef survey was such that no cryptic organisms or species living within interstitial spaces of the reef surface were enumerated. Since this is the habitat of the majority of mollusks and crustacea, detailed species counts were not included in the assessment. No dominant communities of these classes of biota were observed during the reef surveys at any of the study stations."

While neither the Marine Research Consultants (2000) results nor the Parrish et al. (1990) results are quantitative, there appear to be no major differences in the general distribution of corals and other invertebrates surveyed between the studies. For example, Parrish et al. (1990) and Marine Research Consultants (2000) both indicate that the corals *Porites lobata*, *Porites compressa*, and *Pocillopora meandrina* were abundant in shallow areas, with *P. lobata* and *P. compressa* most abundant in deeper waters, and observations of visible echinoderms (holothurians and sea urchins) are similar between the two studies.

Much of the more recent work that includes information on benthic biota (i.e., the NOAA benthic habitat characterization maps [Figure 7], Cochran-Marquez (2004) and Gibbs et al. [2004)] contains only descriptive information on the presence and distribution of various organisms, or does not contain sufficient detail to determine quantitatively whether the observed distributions have changed significantly from those observed by Parrish et al. (1990) and by Marine Research Consultants (2000). Thus, while the general condition of KAHO's benthic biotic communities does not appear to have changed dramatically from 1988 to 2004, no quantitative trends can be established at this time. However, Tissot et al. (2000, 2004) conducted quantitative surveys of benthic cover along replicate transects at an 11-14 m depth site in park waters (WHAP site, Figure 9) in the spring of 2000 (Table 3). The data obtained by Tissot (2000) generally are consistent with qualitative observations made by earlier investigators, but one notable difference is that an associated reconnaisance survey of nearby nearshore waters did observe significant cover (10%) of the invasive alien alga, *Acanthophora spicifera* (http://www.hawaii.edu/ssri/hcri/rbi/hawaii/honokohau_bay.htm). The transect data are particularly valuable as they provide a baseline against which future changes in benthic community structure can be measured.

Table 3. KAHO benthic cover, spring 2000 (Tissot 2000).

Substrate	Mean % cover
Boulder	2.6
Flat	3.7
Macroalgae	0.2
Montipora spp	0.1
Old dead *P. compressa*	7.8
Old dead *P. lobata*	21.5
Pocillopora meandrina	0.3
Porites compressa	14.1
Porites compressa hole	0.5
Porites lobata	34.5
Rubble	11.8
Sand	2.5
Unknown coral	0.4

B.3.a.vii. Honokohau Harbor

Honokohau Harbor is outside of the park, but biological resources in the harbor are of interest as they may affect adjacent KAHO resources. Investigations following harbor construction assessed colonization and development of planktonic, pelagic, and benthic communities inside the harbor (Bienfang 1983). Prior to harbor expansion in 1979, the water column and benthic communities inside the harbor had developed to be quite similar to what would be expected for comparable natural coastal waters and benthic habitats. For the planktonic and pelagic communities, the relative similarity to expected natural communities was attributed to the low residence time of water in the harbor (Oceanic Foundation 1975). Following harbor expansion, circulation in the newly excavated mauka basin was degraded considerably compared to the initial harbor basins, resulting in greater residence time and dramatically reduced water quality in the mauka basin. However, conditions in the original basins were not affected greatly, so that areas adjacent to the marina entrance and KAHO coastal waters continued to display characteristics similar to those expected from a natural system (US Army Corps of Engineers 1983).

C. ASSESSMENT OF COASTAL WATER RESOURCES

C.1. Sources of pollutants

C.1.a. Point and non-point sources

No point source discharges are present in KAHO, but a number of non-point sources in and around the park have the potential to affect coastal water resources. Around the park, disposal of wastewater from the Kealakehe treatment plant in a leach pit just inland and south of the park could be considered a point source, and new point sources may result from the Kohanaiki development currently being built immediately north of the park, for instance if wastewater is disposed of via injection wells.

Groundwater is a critical resource in KAHO, as it plays a major role in determining water quality in anchialine pools and Aimakapa pond, and to a lesser degree in Kaloko pond and Aiopio fishtrap and in coastal waters. Non-point and possible point sources that might affect groundwater quality include the industrial park and adjacent urban developments upslope of the park, the Kealakehe wastewater treatment plant disposal site south of the park, sources associated with the Kohanaiki resort/residential development north of the park, and sources associated with Honokohau Harbor to the south. Activities within the park also could affect park groundwater, or could affect surface water resources directly. Sedimentation from non-point sources could affect park resources if sediment from the Kohanaiki development reaches park waters, or if harbor maintenance (e.g. dredging) or planned expansion results in sediment deposition in park waters. Airborne pollutants, including dust, also can be deposited in KAHO, and light and noise pollution may impact biological resources.

C.1.a.i. Groundwater contamination

Because of the high permeability of soils and rocks in KAHO, virtually all freshwater transport in the park occurs as groundwater (Oki et al. 1999). Rainfall in the KAHO area is greater inland than along the coast, so most natural groundwater recharge occurs inland of the park, and groundwater should flow in a generally seaward direction through the park and into coastal waters (Oki et al. 1999). Groundwater in KAHO thus will be affected by activities both in, and inland of, the park, and groundwater pollutants ultimately will pass through KAHO's anchialine pools and ponds enroute to discharging into coastal waters.

Groundwater pollutants can be separated into two general classes – nutrients (usually nitrogen and phosphorus) that have the potential to enhance primary production (i.e., the growth of phytoplankton, benthic micro- and macroalgae, and aquatic plants), and toxic pollutants that may interfere with biological activity. The latter includes a wide variety of chemicals related to human activities, such as metals, pesticides, solvents, and pharmaceutical compounds and their byproducts. Because of the difficulty and expense of analyzing water samples for industrial and pharmaceutical contaminants, these analyses are performed only rarely, and the effects of many compounds on biological systems are poorly known. Nutrients are measured more frequently, but their effects on natural systems also can be complex.

Contamination of groundwater upslope of and in the park may occur due to infiltration of wastewater from cesspools and septic leach fields, fertilizer use, stormwater runoff from developed areas, and improper disposal or spills of toxic substances. The impacts of these contaminants on KAHO ecosystems will depend on the type and extent of contamination and the vulnerability of receiving ecosystems. There are two unique and potentially important aspects of groundwater contamination in the KAHO area that may affect impacts on receiving ecosystems: 1) contaminants infiltrating to the water table may not mix extensively with underlying uncontaminated water during transport downslope, limiting the effectiveness of dilution as a natural remediation process, and 2) contaminant inputs to groundwater are likely to be highly localized, rather than dispersed, resulting in contaminated groundwater flowing downgradient as potentially narrow plumes superimposed on underlying, otherwise ‘typical’, groundwater. Downgradient monitoring wells thus may not detect contamination unless they fortuitously are located in plumes, and samples are collected near the surface of the water table.

C.1.a.ii. Garbage and animal waste

There are no streams or significant areas of surface runoff in the park, and wind transport of solid waste probably is a minor source, so most of the garbage impacting coastal resources in the park likely will be due to local inputs. Inputs probably will be focused around areas with high visitor use, such as the area around Aiopio fishtrap, the parking area at the coast next to Kaloko pond, and at preferred picnicking and recreational sites along the beach. Some garbage may reach KAHO’s coastal waters and beaches from offshore sources and from sources in Honokohau Harbor. Plastics can be a significant problem in marine environments, as turtles, seabirds and other marine vertebrates may ingest some items, and others represent entanglement hazards for marine birds and other wildlife. Animal waste probably will be most significant around high-use areas, particularly if dogs are not leashed. Impacts on KAHO’s ecosystems due to animal wastes probably are minor, but aesthetic impacts may be significant, and wastes may carry pathogens that could adversely affect the quality of coastal waters for recreational use. Leashing has been required since about 1994 to prevent harassment of endangered birds (Morin 1998), but enforcement is limited and compliance is poor (Sallie Beavers pers. comm. 2005), so animal waste may be a problem in some areas of the park.

C.1.a.iii. Sedimentation

Soil is scarce in and around KAHO, and there are no streams or other significant sources of surface runoff that could transport soil particles to KAHO’s anchialine pools, ponds, or coastal waters. As a result, most of the sediments in KAHO’s waters are derived from biological sources, both in the waters themselves and from adjacent terrestrial vegetation. Some sediment arrives as windblown dust, but this source is likely to be quantitatively minor and impacts small, unless the dust contains unusually toxic organisms (e.g. fungi), elements, or compounds. The most significant potential contaminant sediment sources in and around the park probably are the sediments in Kaloko fishpond and in Honokohau Harbor. Restoration work in the fishpond or dredging in Honokohau Harbor might lead to remobilization of sediments and deposition in adjacent park coastal waters, but impacts on adjacent waters probably would be minor unless very significant quantities of sediment were deposited, or unless the sediments contained toxic contaminants. Very limited sediment analyses in Kaloko pond have not detected significant contamination (Wolff unpubl. 2005), but harbor sediments often do contain high levels of metals and other toxic compounds (Grovhoug 1992; Raine et al. 1995). Significant sedimentation impacts might result from development of coastal zone areas immediately north of the park, and from the proposed expansion of Honokohau Harbor and associated coastal zone development just south of KAHO in the near future. Both dredging and construction-related sediment issues should be small if activities are conducted according to established guidelines for prevention of sediment mobilization and transport, but poor management, implementation, or maintenance, or unusual events such as heavy rainfall or winter storm conditions could result in significant sediment inputs.

C.1.a.iv. Air, noise, and light pollution

Air pollution may impact park water resources via the deposition of particulate contaminants in park waters or the dissolution of contaminant gases in park waters. While development in the area doubtless is affecting air quality somewhat, quality still is relatively good and prevailing winds in the area normally are onshore, so the park probably receives only very modest inputs of anthropogenic airborne contaminants. A more significant source may be natural contaminants from emissions from the nearby Kilauea volcano (DeVerse and DiDonato 2005). Volcanic emissions include a number of constituents that could affect KAHO's coastal resources, including compounds that increase the acidity of waters and toxic constituents such as mercury (Brock and Kam 1997). However, VOGNET monitoring has shown that a relatively clean layer of air normally is present near sea level in the KAHO area, with no evidence of volcanic particulates, and that volcanic emissions affect air quality primarily at higher elevations (Ryan 2003). Thus, impacts due to deposition of volcanic contaminants probably also are minor.

Noise pollution might affect the suitability of park waters and wetlands for use by dolphins, whales, birds, and other organisms sensitive to noise. Significant noise sources might include air traffic associated with the nearby airport (Sallie Beavers pers. comm. 2005), and recreational and commercial boats traveling to and from the adjacent harbor or using park waters. A one-year (September 2004 – October 2005) sonobuoy deployment recently was completed by researchers from Cornell University, who also collected background noise data in park waters from small boats. These data are now being analyzed and results will published in future reports (Sallie Beavers pers. comm. 2005).

Light pollution also has been noted as a potential issue for some animals. Light pollution can affect birds, turtles, and other organisms that navigate using the night sky, or that require darkness for certain activities. Artificial lights also can alter ecosystem function in coastal waters by attracting plankton, resulting in behaviorial impacts on plankton predators such as giant manta rays. Light pollution has not been studied in the park, but seems likely to be a relatively minor issue in most areas, although there probably is a significant amount of artificial lighting near KAHO's southern boundary in the area around Honokohau Harbor.

C.1.a.v. Honokohau Harbor

The presence of a small boat harbor immediately adjacent to park waters represents a potentially significant source of non-point source pollutants (McCoy and Johnson 1995). The harbor currently includes 216 moorings, 3 boat ramps (two 30-foot (~ 9 m) wide, one double-wide), a vessel wash-down facility, a fuel dock, the harbor office, fish landing and cleaning areas, and two comfort stations (http://www.hawaii.gov/dlnr/dbor/hawaiiharbors/honokohau.htm). The harbor is heavily used for charter sport fishing, scuba diving, and other tour operations and by local boaters. Nutrients, metals, petroleum products, marine debris, offal from fish cleaning, and other pollutants are found in and around the harbor on a regular basis, and boats transiting park waters enroute to and from the harbor doubtless release some pollutants directly to park waters.

Initial studies of harbor water quality from 1971 to 1975 showed that the combination of relatively low inputs of pollutants and rapid flushing resulted in surprisingly good water quality inside the marina, with only modest increases in phytoplankton populations and turbidity, and low levels of enteric bacteria, despite significant nutrient loading from groundwater and evidence of sewage leakage into the harbor. While some potential pollutants were not measured (e.g. oil and gas), the favorable flushing dynamics suggests these pollutants probably also would have occurred only at relatively low concentrations. Water quality outside the harbor was virtually indistinguishable from background coastal ocean water quality in the area, consistent with the relatively good quality of water being flushed from the marina and the rapid mixing and dilution characterizing coastal waters in the area (Bienfang and Johnson 1980; Dollar and Atkinson 1992).

Harbor expansion in 1979 reduced flushing rates and degraded water quality inside the harbor, particularly in mauka (upland) portions of the marina where the residence time of water was estimated to reach or exceed 10 days (Bienfang 1983). However, flushing of the makai (seaward) portions of the marina still was relatively good and water quality in areas adjacent to the harbor entrance was not markedly different from earlier studies, suggesting that marina water exported to KAHO coastal waters probably did not represent a major source of pollutants.

In the two decades since the last study, increased usage and possible recent changes in groundwater inputs and quality may have further degraded water quality in and around the harbor. For instance, a recent study of water quality off the harbor entrance (transects and sites labeled P-04 in Figure 9) found that nitrate concentrations in brackish water discharging from the harbor were higher than in earlier studies, possibly due either to sources in the harbor itself or to increased quantities of sewage nitrate in groundwater discharging to the harbor (Parsons et al. 2005). An area of current harbor operations that might be a significant source of contaminants is the vessel wash-down facility, where the dry well that is supposed to collect runoff frequently is clogged by objects swept into the drain (Sallie Beavers pers. comm. 2005). In addition there are no best practices manuals or signs indicating best practices for boat users at the facility, and no sewage pumping facility is present at the marina. Boat operators are expected to dump wastes outside of the three-mile limit, but there is little, if any, enforcement, and dumping inside the marina has been observed (Bienfang 1983) and probably also occurs in nearshore waters (Daniel and Minton 2004). Table 4 summarizes the environmental impacts of some pollutants commonly associated with boat harbors.

Table 4. Environmental impacts of boating pollutants. Modified from McCoy and Johnson (1995).

Pollutant	Sources and Characteristics	Environmental Activity	Environmental or Human Health Effects
Detergents	Most cleaning agents, detergents and soaps Oil spill dispersants Breaks down oils and greases on boats	Accumulates in sediments Broken down by microorganisms	Toxic to marine plants and animals Impairs breathing in fish Reduces oxygen in affected waters Produces unsightly foam on the water surface
Marine Debris	Commercial and recreational boating Plastics, food wastes, packaging, lines, nets, fish cleaning wastes Some wastes become nutrients	Persistent in the environment	Can choke/strangle sea animals Can transport harmful non-native species Snagged by props and engines Ruins recreational beaches
Metals	Paint particles from hydro-washing, metal shavings from engine wear, and consumer products containing metals Dissolves according to water conditions	Accumulates in sediments, marine plants, and animals Persistent in the environment Some metals broken down by microorganisms	Toxic to marine plants and animals Changes the food web in the marine environment by eliminating certain species
Copper (Cu)	Used as a toxic agent in antifouling paints Dissolves according to water conditions	Accumulates in sediments, marine plants, and animals Persistent in the environment	Very toxic to fish when combined with zinc Long term toxicity to marine plants and animals
Acidic & Alkaline Substances	Battery acid, lye and other strong acids or bases in vessel cleaning products Dissolves easily in water	Increases natural acidity or alkalinity of water	Toxic to marine plants and animals Increases the toxicity of other toxic substances, metals, other pollutants and chemicals Can irritate or damage skin
Tributlytin (TBT)	Used as a toxic agent in antifouling paint on aluminum hulls, outboard motors and lower drive units	Accumulates in sediments, marine plants, and animals Persistent in the environment	Toxic even in small amounts to animals, especially bottom feeders
Zinc (Zn)	Anticorrosive zinc and paint pigments Dissolves slowly in water, clings to particles and sediments in marine environments	Accumulates in sediments, marine plants, and animals Persistent in the environment	Toxic to marine plants and animals, even in small amounts
Oil/Fuel	Normal boat operation, fueling, engine maintenance, spills, runoff, and bilge discharge Dissolves slowly in water, clings to particles and sediments	Fuels evaporate in air Broken down by sediment microorganisms Accumulates in sediments, marine plants, and animals High accumulation in estuaries and intertidal areas	Some components toxic to animals even at low concentrations Some components cause cancer, mutations Discoloring and bad taste in flesh of fish
Dusts and sediments	Vessel scraping and sanding, erosion during construction and urban runoff Heavy metals, nutrients, hydrocarbons, etc., adhere to dusts and sediments	Accumulate in areas near runoff inputs Sediment-bound contaminants released to water if disturbed	May reduce amounts of oxygen General lowering of water quality Burial of habitat, food and/or organisms Increased turbidity can clog gills of fish
Nutrients	Runoff, sewage, erosion, garbage & detergents containing (P)hosphorus or (N)itrogen	Used by marine plants and organisms for food (P,N) Accumulates in sediment (P)	Increase in algae growth which decreases light and oxygen in the water (N) can be toxic in higher concentrations

C.2. Assessment of biological resources with respect to water quality

Water quality can affect biological resources in a variety of ways. Dissolved nutrients can stimulate plant growth, toxic substances can inhibit growth and reproduction of plants and other organisms, and pathogens can infect biota and humans. Physical and chemical parameters such as temperature, pH, turbidity, and dissolved oxygen levels also can inhibit or promote biological activity. Direct water quality effects on aquatic plants and animals can propagate through aquatic food webs, resulting in indirect effects on other resources, and potentially on humans. In the following three sections, water quality in KAHO’s coastal resources is assessed 1) with respect to existing State of Hawai‘i water quality standards, 2) with respect to observed or potential effects of water quality on associated ecosystems (flora, fauna, and habitat), and 3) with respect to human health issues. Because groundwater impacts on coastal resources depend on the quantity of groundwater as well as the quality, groundwater flow through the park also is considered as a water 'quality' issue.

C.2.a. Water quality standards

Water quality standards in Hawai'i are promulgated through Chapter 54 of the Hawai'i revised statutes (Department of Health 2004). All of Hawai'i's waters are subject to a "…general policy of water quality anti-degradation…," including the provision that "…where high quality waters constitute an outstanding national resource, such as waters of national and state parks …, that water quality shall be maintained and protected…" Narrative criteria also prohibit the introduction of "…substances attributable to domestic, industrial, or other controllable sources of pollutants…," including pathogens, chemical contaminants, and sediment, and allowable concentrations for some toxic contaminants are specified. Additional narrative and numeric criteria are provided for individual classes of water resources within 'inland' and 'marine' categories, and for various levels of protection.

'Inland' waters in KAHO include anchialine pools, Kaloko and Aimakapa fishponds, Aiopio fishtrap, and wetlands. All of KAHO's inland waters are designated Class 1a and are subject to narrative criteria that specify their protection for "scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class." (Department of Health 2004). Inland waters used for recreation also are subject to specific criteria for allowable levels of Enterococcus and sewage contamination (Department of Health 2004).

'Marine' waters in KAHO include intertidal areas, coastal waters, and associated benthic habitats. Marine water classifications include coastal waters, sandy and rocky intertidal areas, marine pools and coves, reef flats and reef communities, and soft bottom communities. All of KAHO's marine waters are designated as Class AA coastal waters by the State of Hawai'i (Department of Health 2004). Honokohau Harbor, which is not technically within park waters, is considered an embayment and is designated Class A. Class AA marine waters are protected such that they "…remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions". Class A waters are maintained for "…recreational purposes and aesthetic enjoyment…", with the stipulation that uses be compatible with "…the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters…", and that they not be subject to "…any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class". In addition to narrative criteria applicable to all Hawai'ian waters, KAHO's coastal waters are subject to area-specific criteria established for the Kona coast of the island of Hawai'i. These include numeric criteria for nutrients (nitrogen and phosphorus), chlorophyll-*a*, turbidity, pH, dissolved oxygen, temperature, and salinity. Criteria for nutrients include adjustments for salinity to reflect the effects of groundwater inputs to coastal waters in this area. Marine waters used for recreation are subject to specific criteria for allowable levels of Enterococcus and sewage contamination (Department of Health 2004). Criteria also are provided for benthic habitats, including sand beaches, rocky intertidal areas, marine pools and coves, reef flats and reef communities, and soft bottom communities. Standards relevant to KAHO's coastal water resources are excerpted in Appendix B and discussed in the following sections as they relate to specific resources.

Although the water quality criteria outlined above clearly are intended to maintain KAHO's water resources in or near to their pristine state, data suitable for assessment of water quality relative to numeric standards are very limited. Existing data compilations in the KAHO "Horizon" report (National Park Service 2000) and in a recent USGS data compilation (Wolff unpubl. 2005) contain a significant amount of data, but they are from a number of studies and the parameters measured and methods used frequently differ between studies, making comparison difficult. Sampling frequencies also generally are too low for computation of the statistics required for comparison to State standards. However, combining these data with additional data from published reports and ongoing studies does provide insights into water quality in KAHO, and into the degree to which park waters comply with narrative criteria. New data currently being collected at or near KAHO by the State of Hawaiʻi, NPS, NPS PICRP, USGS, and researchers from the University of Hawaiʻi, Hilo and Manoa campuses will facilitate assessment of status and trends in water quality in coastal water resources in the future (Larry Basch pers. comm. 2005).

C.2.a.i. Groundwater

Groundwater flow

The details of groundwater flow in the park are poorly known, but flow probably is complex due to the highly heterogeneous permeability of the lava substrate. Although overall permeability in KAHO lavas is very high, even compared to other areas along the Kona coast (Oki et al. 1999), groundwater flow through lavas occurs preferentially along the more permeable beds separating successive vertically layered flows, and through the many cracks and other passageways that riddle the substrate. Lava tubes, which are common features of Hawaiʻian pahoehoe flows, can form extremely effective conduits for groundwater flow (Halliday 2003). Lava tubes can range in diameter from centimeters to tens of meters, and extend in some cases for many kilometers. Barriers that restrict or divert groundwater flow also may occur in the form of dikes and other subsurface features. Thus, while the overall direction of groundwater transport through KAHO should be seaward, the details of groundwater transport and the fate of associated contaminants are less predictable. Groundwater from the upslope industrial park area can be expected to pass through the park and to discharge into park coastal waters, and groundwater affected by activities adjacent to the park, such as disposal of effluent from the Kealakehe wastewater treatment plant and the Kohanaiki and proposed harbor expansion developments, also may enter the park and affect coastal water resources. Wastewater inputs from these sources seem likely to be significant compared to the diluting potential of natural groundwater flow in the area; for instance, in 2001 the Kealakehe Wastewater treatment plant produced approximately 1 Mgal/d of secondary treated sewage, 97% of which was pumped to a disposal pit upslope of Honokohau Harbor (Figure 2) (Van Dyke 2001). Groundwater discharge rates in the area are only on the order of 3 Mgal/d per mile of coastline (Oki et al. 1999), so wastewater inputs at this site almost certainly result in significant increases in local groundwater flow and contaminant concentrations.

Groundwater flows in this area seem especially likely to affect groundwater discharging into Honokohau Harbor, with subsequent impacts on harbor, and potentially adjacent park, ecosystems and water quality. Less dramatic but potentially significant changes in groundwater flow through KAHO also may occur due to localized recharge in the park and upslope from cesspools, septic leach fields, irrigation, and infiltration of stormwater runoff from developed areas. If local groundwater is utilized for irrigation or other uses, withdrawals also will affect local groundwater flow, as will construction activities that increase or decrease the permeability of soils and rocks subject to infiltration and groundwater flow. Long-term changes in groundwater flow are suggested by historical water quality data, which show that salinities in both Kaloko and Aimakapa pond were lower, and stratification was more pronounced, in 1971 than they were in more recent sampling (Kikuchi and Belshe 1971; Maciolek and Brock 1974; Brock and Kam 1997; Nance 2000). Significant changes also may occur on timescales of months to years, based on variability observed in park ponds and coastal waters (Brock and Kam 1997, Marine Research Consultants 2000, Bienfang unpubl., Weijerman unpubl.) and in Honokohau Harbor (Oceanic Foundation 1975). Changes may be related to changes in local climate that affect natural recharge, to human activities in the watershed, or both.

Groundwater quality

There are three groundwater monitoring wells in KAHO (Figure 9). The wells were installed by the USGS in 1996 and subsequently have been utilized for groundwater quality monitoring on five occasions. The USGS sampled the wells from 1996-1998 for salinity, metals and organic contaminants (Oki et al. 1999). Brock and Kam (1997) analyzed 4 samples from each well in 1996 for nutrients and for silica, salinity, turbidity, temperature, pH, and dissolved oxygen. Nance (2000) analyzed 2 samples from each well in 2000 for nutrients and salinity, USGS sampled the wells again in 2002 for semi-volatile organic compounds and organochlorine compounds (Tribble 2003), and in January 2005, an NPS-funded study started collecting samples on a roughly monthly basis for nutrients, silica, turbidity, pH, and dissolved oxygen analyses (Bienfang unpubl.). Nutrients, silica, salinity, turbidity, temperature, dissolved oxygen, and pH data from these studies are plotted in Figures 10 - 12 to illustrate possible long-term variations in groundwater quality, with data from a high-level aquifer well inland of KAHO shown in Figure 13 for comparison. Linear regression slopes, R-squared values, and the results of statistical tests for significance of slopes are given in Table 5. It should be noted that the use of linear regression analysis for these and other time-series data discussed in this report is primarily as a tool for visualizing variation in water quality over time, rather than as a rigorous assessment of trends. In most cases, the temporal distribution of data available for this study is too sparse and uneven to determine true trends. However, plotting all available data on a time axis and providing reference fits provides information on both variability in the data on different time scales, and on the statistical significance of apparent shifts over time. Also note that in most water quality studies, nitrate (NO_3^-) is measured as nitrate-plus-nitrite because the method actually measures total nitrite (NO_2^-) after reduction of nitrate to nitrite, and nitrite concentrations normally are very small compared to nitrate. However, to avoid possible confusion, results of nitrate-plus-nitrite analyses will be denoted henceforth as NO3+, while discussions of nitrate and nitrite individually will use the abbreviations NO3 and NO2 respectively. For simplicity, these and other abbreviations of ionic species omit the charge superscripts normally associated with each.

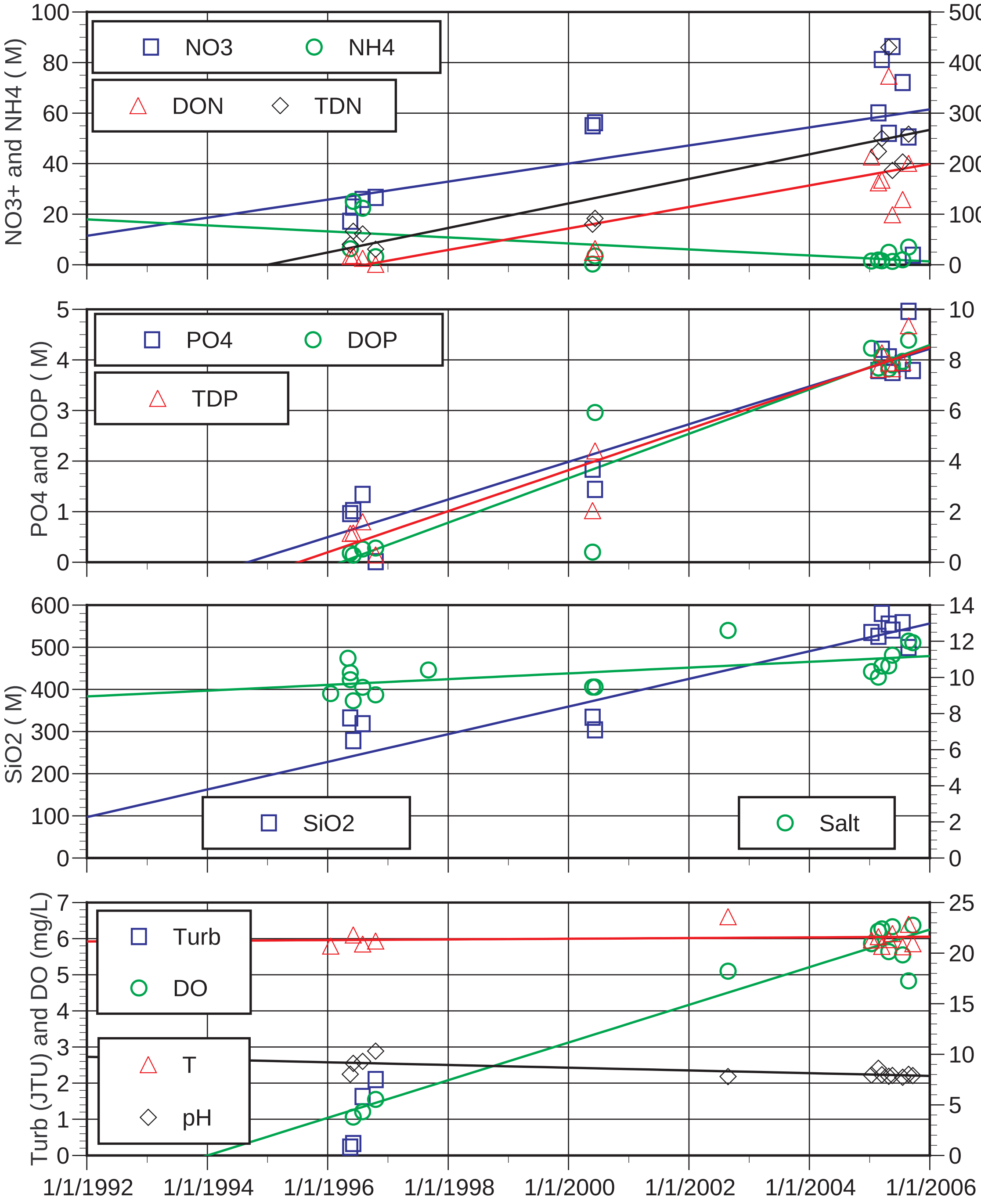


Figure 10. Groundwater quality data from well 4061-01, inland of Aimakapa pond. Parameters with records exceeding 5 years include linear fits to highlight possible long-term changes in groundwater quality. Data from Brock and Kam (1997), Oki et al. (1999), Nance (2000), Bienfang (unpubl.), and Wolff (unpubl.).

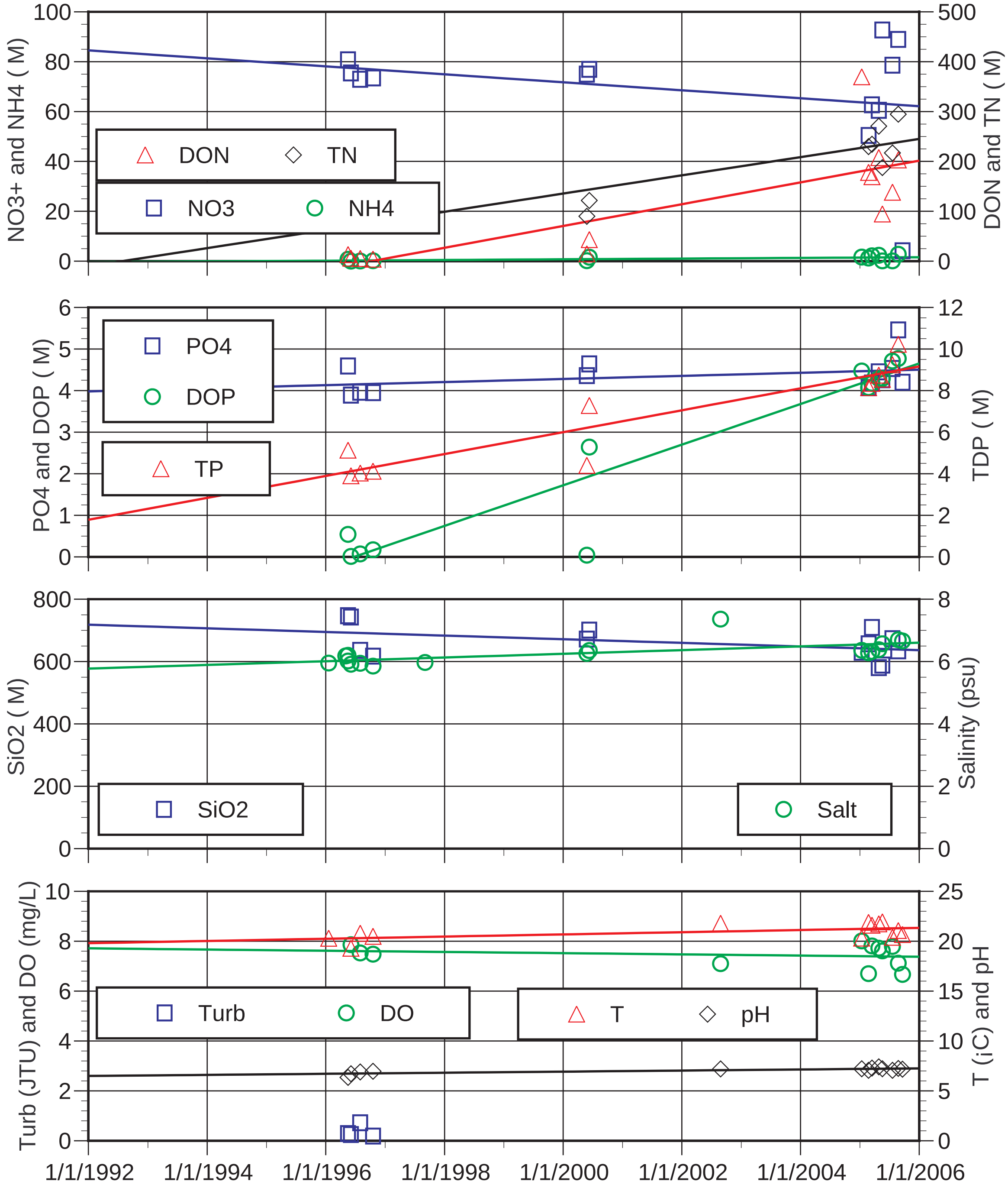


Figure 11. Groundwater quality data from well 4161-01, inland of Kaloko pond. Parameters with records exceeding 5 years include linear fits to highlight possible long-term changes in groundwater quality. Data from Brock and Kam (1997), Oki et al. (1999), Nance (2000), Bienfang (unpubl.), and Wolff (unpubl.).

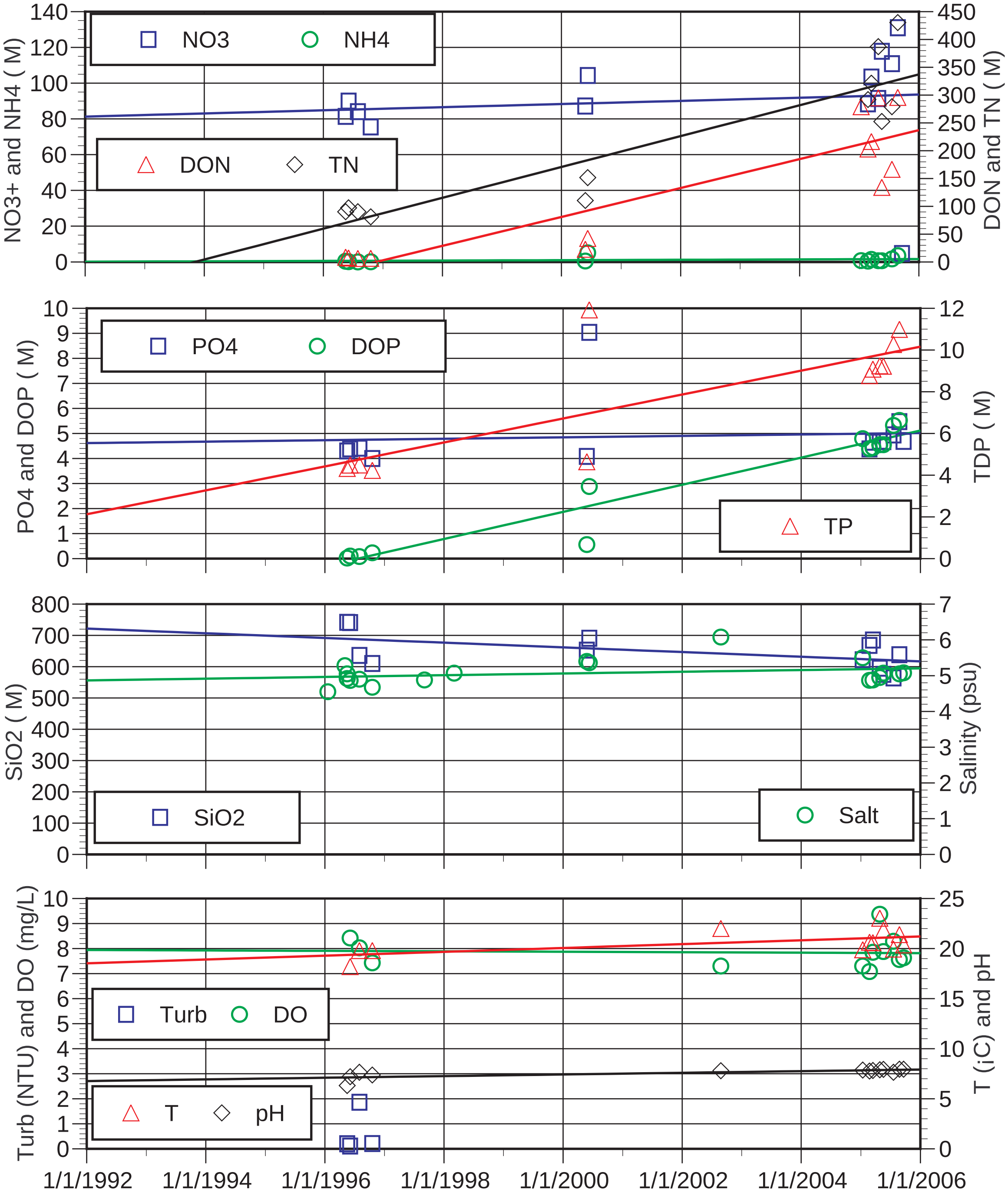


Figure 12. Groundwater quality data from well 4161-02, inland of and between Kaloko and Aimakapa ponds. Parameters with records exceeding 5 years include linear fits to highlight possible long-term changes in groundwater quality. Data from Brock and Kam (1997), Oki et al. (1999), Nance (2000), Bienfang (unpubl.), and Wolff (unpubl.).

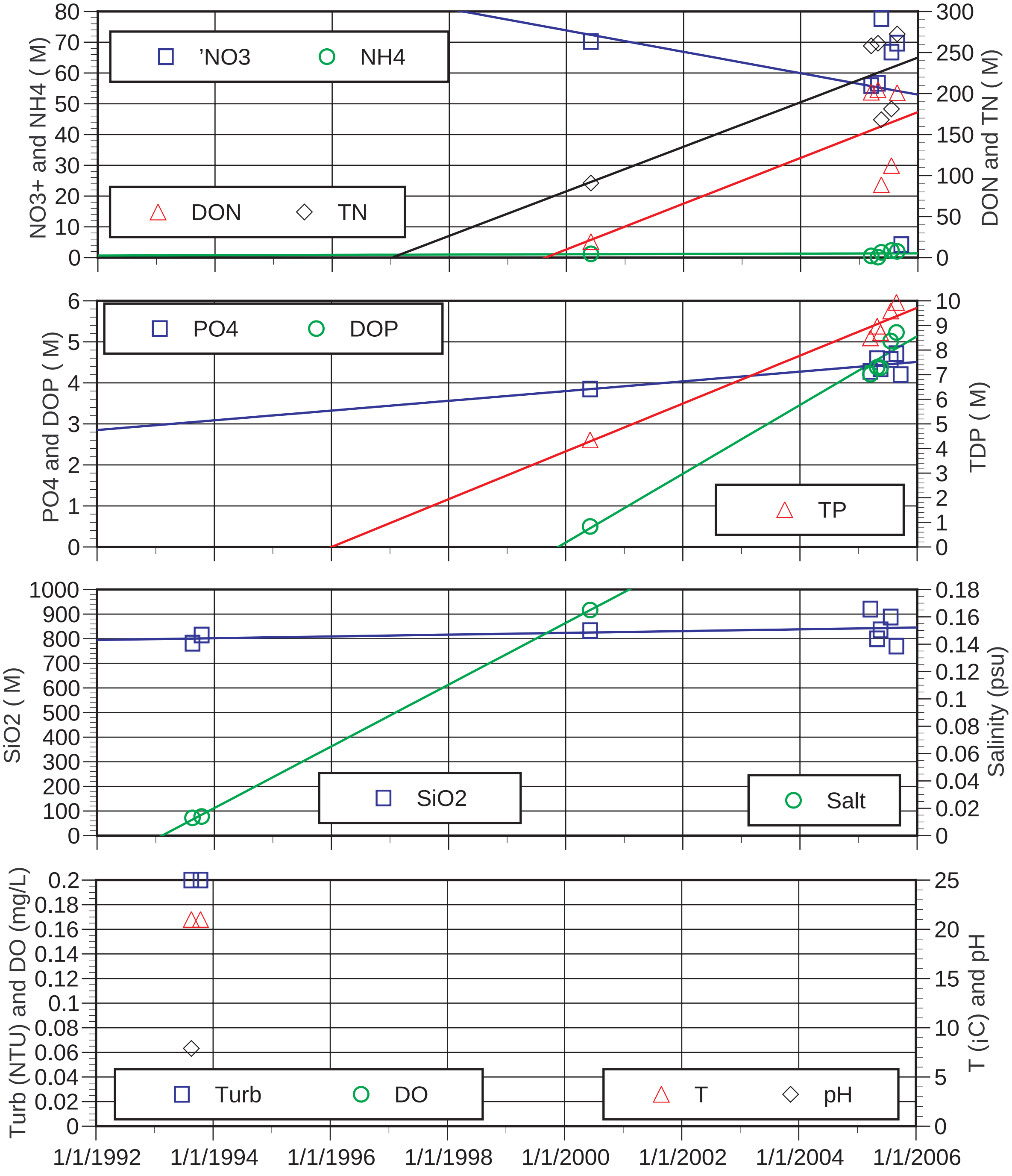


Figure 13. Groundwater quality data from well 4258-03 in the high-level aquifer ~6 km inland of KAHO. Parameters with records exceeding 5 years include linear fits to highlight possible long-term changes in groundwater quality. Data from Nance (2000), Bienfang (unpubl.), and Wolff (unpubl.).

Table 5. Linear regression results for groundwater quality trends plotted in Figures 10-13. Statistically significant trends ($p \leq 0.05$) are shown in bold.

		4061-01 (inland of Aimakapa)				4161-01 (inland of Kaloko)			
	units	Interval	slope	R^2	p	Interval	slope	R^2	p
NO3+	μM/y	96-05	4.8	0.74	**0.00**	96-05	-1.6	0.09	0.33
NH4	μM/y	96-05	-1.2	0.37	**0.03**	96-05	0.14	0.33	**0.04**
DON	μM/y	96-05	21	0.63	**0.00**	96-05	22	0.64	**0.00**
TDN	μM/y	96-05	24	0.71	**0.00**	96-05	18	0.85	**0.00**
PO4	μM/y	96-05	0.37	0.91	**0.00**	96-05	0.037	0.14	0.21
DOP	μM/y	96-05	0.44	0.90	**0.00**	96-05	0.49	0.91	**0.00**
TDP	μM/y	96-05	0.81	0.95	**0.00**	96-05	0.53	0.87	**0.00**
SiO2	μM/y	96-05	33	0.82	**0.00**	96-05	-5.8	0.20	0.12
Salinity	psu/y	96-05	0.16	0.37	**0.01**	96-05	0.059	0.45	**0.00**
DO	mg/L/y	96-05	0.56	0.99	**0.00**	96-05	-0.024	0.04	0.51
T	°C/y	96-02	0.40	0.89	**0.02**	96-02	0.26	0.63	0.11
T	°C/y	96-05	0.033	0.02	0.61	96-05	0.11	0.33	**0.04**
pH	pH/y	96-05	-0.13	0.46	**0.03**	96-05	0.054	0.65	**0.00**

		4161-02 (inland of/between ponds)				4258-03 (~6 km inland of KAHO)			
	units	Interval	slope	R^2	p	Interval	slope	R^2	p
NO3+	μM/y	96-05	0.88	0.01	0.69	00-05	-3.5	0.07	0.56
NH4	μM/y	96-05	0.11	0.08	0.34	00-05	0.052	0.02	0.81
DON	μM/y	96-05	26	0.80	**0.00**	00-05	28	0.55	0.09
TDN	μM/y	96-05	28	0.83	**0.00**	00-05	27	0.61	0.07
PO4	μM/y	96-05	0.029	0.01	0.76	00-05	0.12	0.61	**0.04**
DOP	μM/y	96-05	0.54	0.94	**0.00**	00-05	0.83	0.97	**0.00**
TDP	μM/y	96-05	0.57	0.65	**0.00**	00-05	0.97	0.96	**0.00**
SiO2	μM/y	96-05	-7.5	0.29	0.06	93-05	3.6	0.14	0.36
Salinity	psu	96-05	0.024	0.08	0.23	93-00	0.023	1.00	**0.01**
DO	mg/L/y	96-05	-0.009	0.00	0.86				
T	°C/y	96-02	0.46	0.80	0.11				
T	°C/y	96-05	0.19	0.34	**0.04**				
pH	pH/y	96-05	0.082	0.57	**0.00**				

Changes in nutrient concentrations are most evident for dissolved organic N and P, and for total N and P, which increased dramatically in the 2005 samples compared to samples collected in 1996 and 2000. The increases occurred at all of the wells in KAHO (Figures 10 - 12), as well as at the high-level aquifer well (Figure 13). Dissolved organic N and P (DON and DOP) actually are not determined directly, because it is virtually impossible to quantify the complex mixture of organic compounds making up DON and DOP. Instead, they are determined as the difference between the total amount of inorganic nitrogen and phosphorus measured in a fully oxidized sample (i.e. a sample where all of the organic forms have been converted to inorganic forms), and the amount of inorganic nitrogen and phosphorus present in the sample before oxidizing. Thus, the increase in calculated DON and DOP actually is the direct result of a measured increase in TDN and TDP, so these parameters are expected to covary. However, DON and DOP generally are much less reactive than the inorganic nutrients, and concentrations normally are much less variable in natural systems. Thus, the increase observed in the high-level aquifer samples, which should be relatively unaffected by human activities, is surprising. In fact, no natural or anthropogenic process is known that would preferentially increase DON and DOP at all four wells, so it is much more likely that the apparent increase actually is an analytical artifact. Artifacts might occur due to simple calculation errors or due to a change in methods that resulted in more efficient conversion of DON and DOP to the inorganic forms actually measured. Sample digestion efficiencies can vary with the method used, and while differences normally would be expected to be relatively small, quality control samples processed by the laboratory running the 2005 samples show no calculation errors and relatively good sample digestion efficiencies (Paul Bienfang pers. comm. 2005). Thus, it seems most likely that the 1996 and 2000 samples were not digested completely, although this conclusion cannot be tested and the issue still is somewhat troubling.

Inorganic nutrients (NO3+, NH4, and PO4) are less variable at all wells. No significant changes are evident at the high-level aquifer well, as would be expected in a system that should be relatively unaffected by anthropogenic effects. Two of the KAHO wells show modest but statistically significant changes in inorganic nutrient concentrations: NH4 appears to be increasing slightly in the well inland of Kaloko pond (4161-01), and NO3+ is increasing at the well inland of, and between Kaloko and Aimakapa ponds (4161-02). Salinity also is increasing at well 4161-01, a change that is consistent with the parallel (but not statistically significant) decline in silica. However, NH4 concentrations are low compared to NO3+, so possible changes in NH4 at well 4161-01 are unlikely to affect inorganic nitrogen in receiving waters significantly. At well 4161-02, the increase in NO3+ is fairly rapid (~2 µM/y), and although the salinity and Si trends are not statistically significant, both suggest that groundwater salinity is increasing. This trend is the opposite of what would be expected if the increase in NO3+ was due to a simple shift in groundwater composition due to dilution, because seawater has a much lower NO3+ concentration than fresh groundwater. Thus, the NO3+ increase suggests another source, possibly from human activity in the watershed upslope of the well. In fact, the most recent NO3+ concentrations in wells 4061-01 and 4161-02 plot well above the mixing line between high-level groundwater and seawater (Figure 14), indicating a significant NO3+ source to groundwater downslope of the high-level aquifer. However, the relatively modest change in NO3+ concentrations suggests that the effects of this additional NO3+ on KAHO coastal resources probably are small. Changes in these two wells thus suggest that groundwater at these sites has not changed a great deal in the last 10 years and that changes in nutrient content over this period likely would have only minimal impacts on KAHO coastal resources. However, the persistent and anomalously high NO3+ concentrations that already existed in 1996 may already have affected coastal resources, particularly Aimakapa and Kaloko ponds, which appear to be nitrogen limited [Marine Research Consultants (2000)]. Surprisingly, Marine Research Consultants (2000) concluded that "even though there are subsidies of NO3 to groundwater, likely as a result of human activities, the nutrient is still limiting to biotic activity in the ponds. As a limiting nutrient, it is not likely that there are negative impacts associated with the present concentrations in groundwater that enters the ponds", but this argument clearly is spurious. If NO3 was not limiting, additions would have no effect on receiving systems, as they argued (reasonably) for NO3 impacts on most anchialine pools. If NO3 is limiting, the biotic system will, by definition, respond to added NO3. Thus, there is little doubt that the additional NO3 has increased primary production, and other effects are possible such as changes in ecosystem structure. Kaloko Pond should be less susceptible to nutrient additions than Aimakapa because of the more efficient exchange of pond waters with offshore waters, but its susceptibility likely will increase when the fishpond wall restoration is complete (Bond and Gmirkin 2003), increasing the residence time of groundwater in the pond. In addition, while the impacts of increased groundwater nitrogen on the

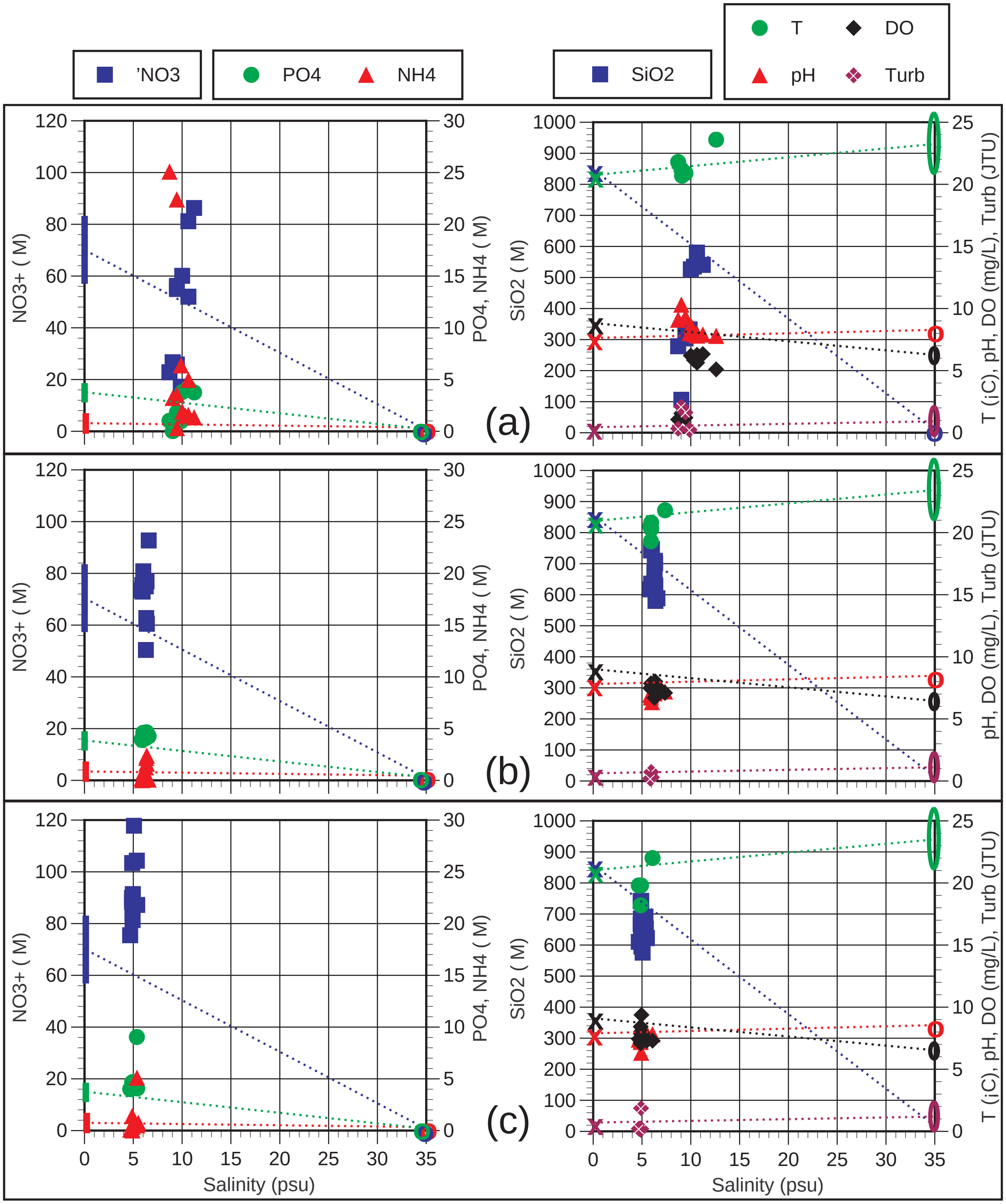


Figure 14. Groundwater quality versus salinity in (a) well 4061-01, (b) well 4161-01, (c) well 4161-02. Approximate range of values for high-level aquifer well 4258-03 are shown in left panels by colored lines and in right panels by x's at S ~ 0, with theoretical mixing lines between high-level groundwater and estimated seawater values (o's and ovals at S = 35) shown by dashed lines. Data from Brock and Kam (1997), Oki et al. (1999), Nance (2000), Bienfang (unpubl.), and Wolff (unpubl.)

Kaloko pond ecosystem depend to a significant degree on factors affecting water exchange in the pond, macroalgae growing near groundwater discharge sites are less affected by water exchange processes, so macroalgae, including the *Acanthophora spicifera* currently infesting the pond, may be affected more directly.

The largest changes in inorganic nutrients in the three KAHO wells are seen at well 4061-01, inland of Aimakapa pond. Significant increases are evident for both NO3+ and PO4, while NH4 declined. Silica concentrations nearly doubled between 2000 and 2005, an increase too large to be due simply to a change in the relative contributions of upslope freshwater and seawater, especially given the simultaneous increase in salinity. Instead, these data require a significant change in the quality of the freshwater component of groundwater at the site. The change may reflect increased nutrient loading to groundwater upslope of the well, or it could reflect a change in local groundwater flow, with a new, higher nutrient plume entering the area sampled by the well. Such a change might result from changes in the amount and areal distribution of recharge and withdrawals upslope of the site.

Groundwater contamination by toxics is a particularly problematic subject because so few data are available and because the effects of many contaminants are poorly known. Single groundwater samples from the three wells in the park (4061-01, 4161-01, 4161-02) and from one upslope high-level aquifer well (4358-01) were collected in 1997 and 1998 and analyzed for trace metals and organic contaminants. All analytes were below detection limits except chromium and copper, which were detected at low concentrations in all four wells, and phenol, which was detected only in the three park wells (Oki et al. 1999). Semipermeable membrane devices also were deployed for about a month in each of the three park wells in 2002 and resulted in the detection of pentachloroanisole in one well, but phenol was not detected (Tribble 2003).

Overall, existing water quality data indicate that park groundwater is contaminated by anthropogenic nutrients, and suggest that contaminant concentrations probably will continue to increase as upslope development continues. There is no evidence to date of significant contamination by pesticides, solvents, or heavy metals, but the heterogeneous nature of groundwater flow and the sparse sampling (in space and time) make this a tentative conclusion at best.

C.2.a.ii. Anchialine pools

Because anchialine systems exist in areas of brackish groundwater, and are influenced by tidal fluctuations, water quality varies considerably in natural systems, particularly with respect to salinity and nutrients (Brock and Kam 1997). There are no numeric water quality standards for anchialine pools, but a 1994-1996 survey of anchialine pools in and adjacent to KAHO showed that salinities and nutrients were within ranges found in undisturbed systems, and concluded that there was no evidence of contamination by human activities (Brock and Kam 1997). However, the mixing line analyses in that report used water quality in upslope park wells (wells 4061-01 and 4061–02, Figure 9) as the low-salinity endpoint for the mixing analyses. Comparison of water quality in these wells to water quality in high-level aquifers upslope of the park shows that these wells appear to already have been contaminated by nutrients in 1996, and well samples from 2000 and 2005 show that groundwater nutrient contamination has increased significantly since then (see discussion in *Groundwater* above). Thus, groundwater data suggest that water quality in anchialine pools already was degraded in the 1994-1996 samples, and that water quality probably has continued to decline since then.

Historical water quality data for a significant number of the anchialine pools in and around KAHO are available from Maciolek and Brock (1974), Maciolek (1987), Chai (unpubl.), Brock and Kam (1997), and from an ongoing study (Bienfang unpubl.) (Figure 15). Each of these studies focused on different areas of the park, and pool identification often is not consistent between studies, so it is difficult to construct long-term time series of water quality in individual pools. However, pools in specific areas seem likely to have generally similar water quality, allowing comparisons over time, and a long-term time series can be established for at least one pool, providing some insight into changes in anchialine pool water quality over the last thirty years.

Salinity is the only parameter measured in all of the above studies, and salinities in anchialine pools should depend on the total groundwater flow through the system, so salinity data may provide some insight into groundwater flow in the park over time. Plotting salinity data by year shows that two areas in the park have data from at least three studies spanning periods of 24 to 33 years (Figure 16). The first area, a coastal site immediately north of Kaloko pond, has measurements from 1972, 1988, and 1994-1996. The highest salinities in this area occur in the latter two time periods, suggesting that salinities overall may have increased from 1972 – 1996, but it also is possible that the observed variability is due to differences in sampled pools, as pools near the coast often show greater between-pool variability than more inland pools. The second area, midway between Kaloko and Aimakapa ponds (Figure 16), is more inland and thus less likely to exhibit significant interpool variability. This area has measurements from all four studies and shows a similar trend from 1972 – 1996, with higher salinities from 1988 – 1996, but salinities appear to decline in the 2004-2005 measurements. The apparent increase at both areas between 1972 and 1988, and the decline between 1994-96 and 2004-5 at the second may reflect long-term variations in groundwater supply, but some or all of the apparent changes also may be due to sampling artifacts if short-term variability is large. For instance, Brock and Kam (1997) sampled 15 anchialine pools in the park from 1994 - 1996, including pools in both of the areas discussed above. Pools inside the park showed significant variability on sampling intervals of ~2 - 14 months (Figure 17), and sampling over a single tidal cycle by Chai (unpubl.) shows comparable changes in pool salinities within a single day, so the long-term changes in pool salinities suggested by Figure 16 may be at least partially an artifact associated with tidal effects or short-term fluctuations and low-frequency sampling.

Water quality data for parameters other than temperature and salinity are only available from the two most recent studies. Given the similar areas sampled by these two studies (Figure 16), it seems likely that they sampled a number of the same pools, but only one, Queen’s Bath, is definitely known to have been sampled by both (Paul Bienfang pers. comm. 2005). Time-series plots of water quality data from this pool (Figure 18) show temporal variability similar to that observed in groundwater in park wells (Figures 10 – 12). Like the groundwater results, total dissolved nitrogen and phosphorus (TDN and TDP), and dissolved organic nitrogen and phosphorus (DON and DOP) all are much higher in the most recent study, but this difference

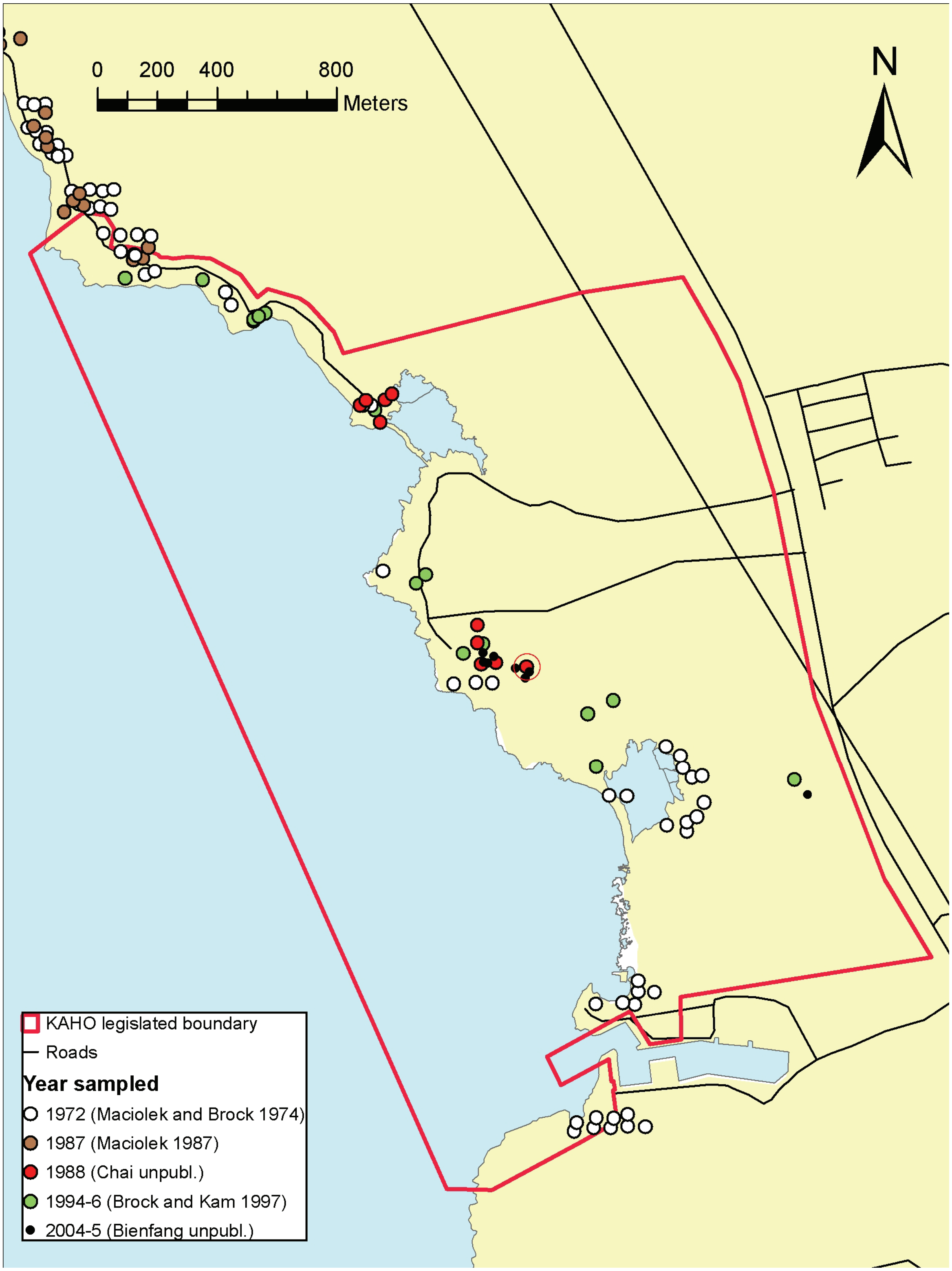


Figure 15. Anchialine pools sampled in and adjacent to KAHO. Location accuracies vary due to differences in methods used for each study, so some sites plotted separately in different years may actually be the same site. One site, Queen's Bath (circled in red), was sampled by four separate studies in 1972, 1988, 1994-1996, and 2004-2005. See text for details.

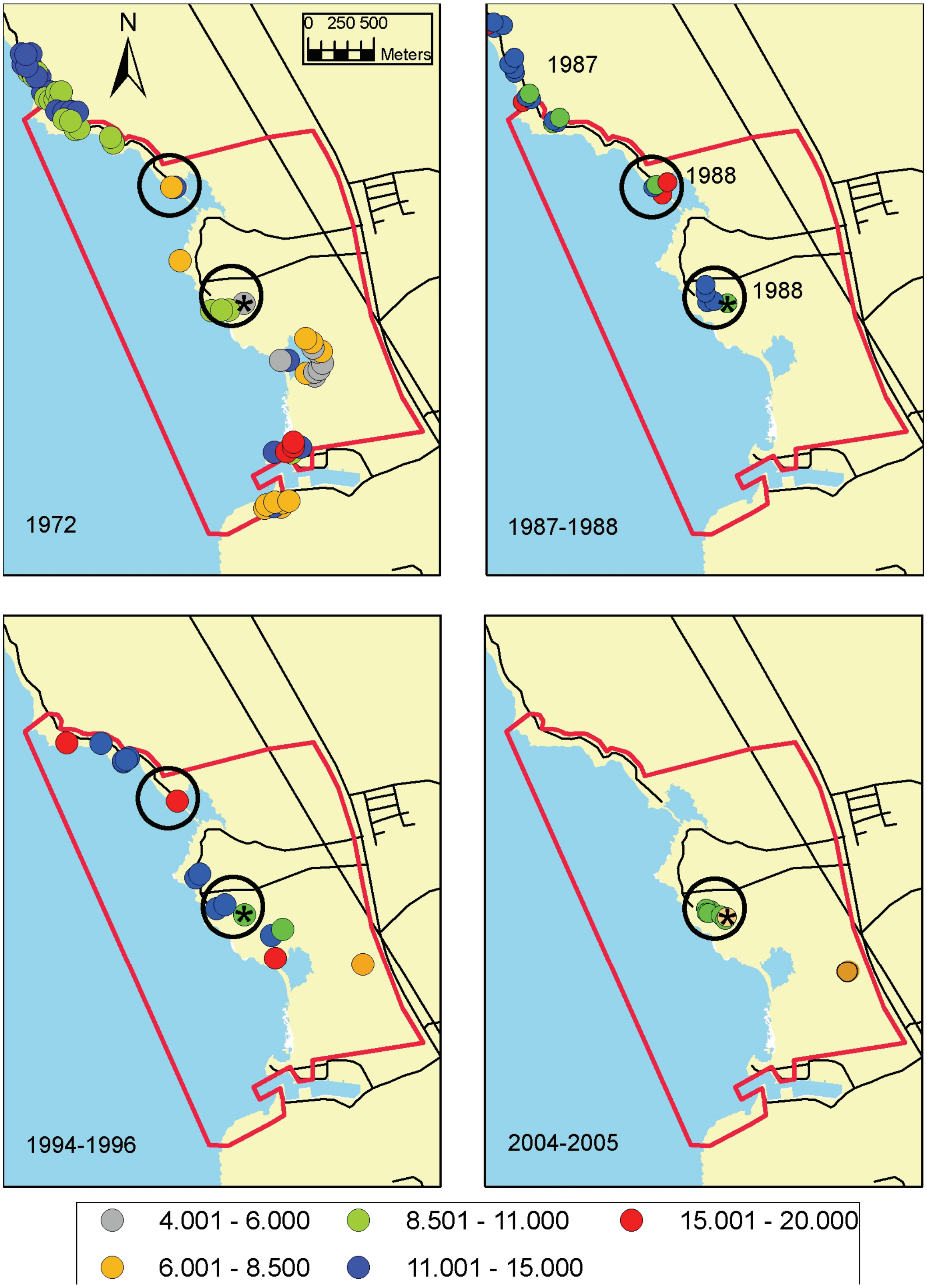


Figure 16. Anchialine pool salinities in and adjacent to KAHO. Salinities in legend are in ppt. Location accuracies vary due to differences in methods used for each study, so some sites plotted separately in different years actually may be the same site. Circled areas denote areas inside the park that were sampled in more than one year. One site, Queen's Bath (asterisk), was sampled in 1972, 1988, 1994-1996, and 2004-2005. See text for details.

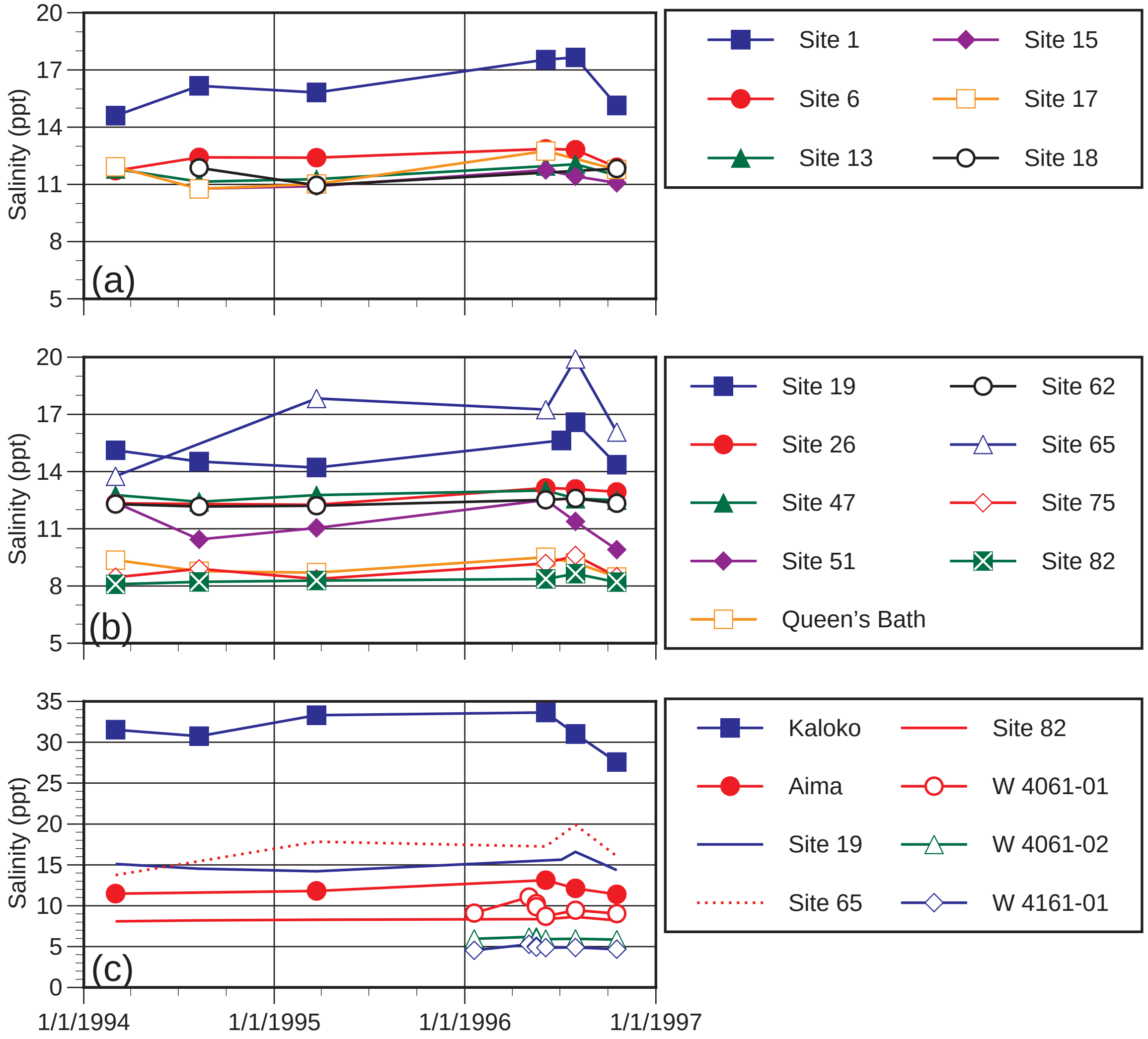


Figure 17. Time series (2.6 y) of salinity measurements in (a) anchialine pools north of the park boundary, (b) anchialine pools within the park boundary, and (c) in Kaloko and Aimakapa ponds. Pond data are from sites near center of ponds. Data from nearby anchialine pools and park wells also are plotted in (c) for comparison to other data. Data from Brock and Kam (1997).

likely is due primarily to analytical issues rather than real changes, as discussed previously for groundwater. Of the other parameters, the most noteworthy changes are the much lower salinity in 1972 compared to later studies, and increases in inorganic nutrients (NO3+, NH4, and PO4) between 1994-1996 and 2004-2005. Except for PO4, all of these changes are statistically significant (Table 6). However, the salinity trend probably should be viewed cautiously, as the significance of the trend is controlled entirely by the 1972 measurement, which was made using a refractometer (Maciolek and Brock 1974), a less accurate and precise method than methods used for later studies.

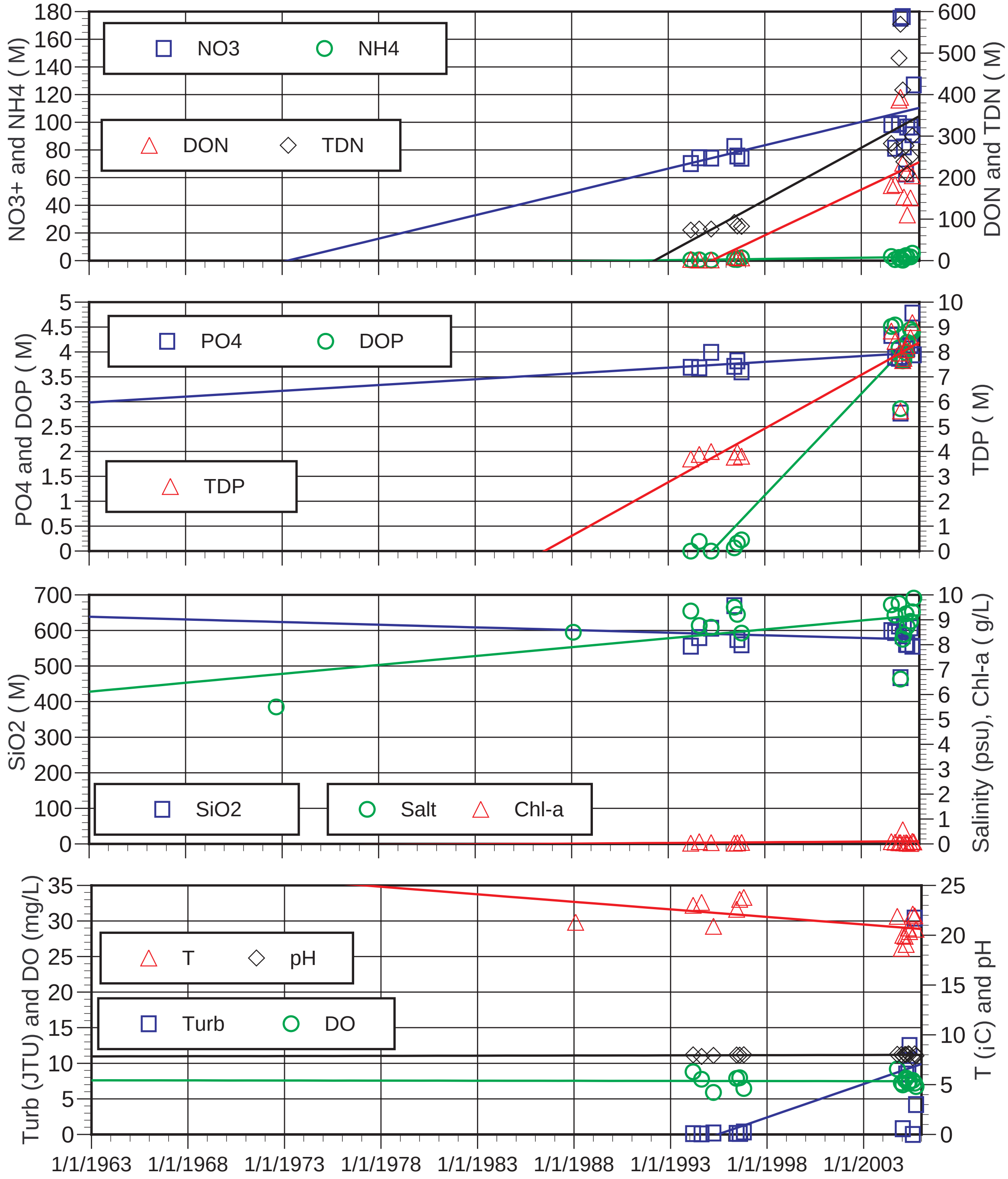


Figure 18. Water quality data from the 'Queens Bath' anchialine pool. Data from Maciolek and Brock (1974), Brock and Kam (1997), Chai (unpubl.), and Bienfang (unpubl).

Table 6. Linear regression results for Queen's Bath anchialine pool water quality trends plotted in Figure 18. Statistically significant trends ($p \le 0.05$) are shown in bold.

	units	Interval	slope	R^2	p
NO3+	µM/y	96-05	3.38	0.230	**0.051**
NH4	µM/y	96-05	0.173	0.330	**0.020**
DON	µM/y	96-05	22.0	0.654	**0.000**
TDN	µM/y	96-05	25.4	0.620	**0.000**
PO4	µM/y	96-05	0.023	0.076	0.285
DOP	µM/y	96-05	0.409	0.945	**0.000**
TDP	µM/y	96-05	0.431	0.873	**0.000**
SiO2	µM/y	96-05	-1.490	0.029	0.531
Salinity	psu/y	72-05	0.072	0.327	**0.011**
Salinity	psu/y	96-05	-0.011	0.005	0.796
Turb	JTU/y	96-05	0.939	0.303	**0.051**
DO	mg/L/y	96-05	-0.003	0.000	0.949
T	°C/y	88-05	-0.152	0.313	**0.019**
T	°C/y	96-05	-0.229	0.482	**0.003**
pH	pH/y	96-05	0.004	0.030	0.521
Chl-*a*	µg/L/y	96-05	0.005	0.041	0.436

Despite the difficulties in comparing water quality data between studies, and the probable confounding effects of short-term variability on elucidation of trends, there is little doubt that water quality in KAHO's anchialine pools is being affected by human activities upslope of the park, and that water quality in park pools does not meet State criteria, due to the presence of "substances attributable to domestic, industrial, or other controllable sources of pollutants", and the resulting degradation of their ability to support "scientific and educational purposes", and to provide "baseline references from which human-caused changes can be measured" (Department of Health 2004). The importance of these changes to anchialine ecosystems is not known. Research in other areas suggests that anchialine ecosystems are rather tolerant of changes in salinity and nutrients (Brock and Kam 1997), but the possibility of a significant increase in salinities between 1972 and 1988, and clear increases in dissolved inorganic nutrients from 1996 - 2005, particularly NO3+, suggests that impacts are possible. Unfortunately, no ecosystem data exist to assess trends in ecosystem status, so the effects of changing water quality will remain unknown until such data become available. Similarly, there are no data on possible contamination by toxic elements or compounds, so water quality and possible ecosystem effects relating to those contaminants cannot be assessed at present.

C.2.a.iii. Ponds

Kaloko pond

Under State of Hawai'i water quality criteria, Kaloko pond is considered a developed estuary due to the artificial wall separating the pond from the adjacent ocean. As such it is subject to specific numeric criteria for nutrients (nitrogen and phosphorus), chlorophyll-*a*, turbidity, pH, dissolved oxygen, temperature, salinity, and for EH (oxidation-reduction potential, a quantitative measure of the tendency toward anoxia) in pond sediments (Appendix B). Although data for some of these parameters are available, application of State criteria generally requires the calculation of geometric means, and while the frequency of sample collection, the total number of samples required, and the applicable time interval are not specified in these particular State criteria, sampling criteria for other State criteria generally are much more frequent than the available data. Thus, existing data probably cannot be used for direct comparison to State standards. However, existing data do provide some insights into water quality in Kaloko pond over the last 34 years.

Kikuchi et al. (1971) observed that Kaloko pond waters were stratified into two or possibly three distinct layers: a fresher surface layer 5 - 18" (13 - 46 cm) thick (S ~ 18 -24 ppt, T ~ 20 - 24°C (68 - 75 °F), DO ~ 5 - 8 ppm), an underlying saltier layer (S ~ 25 -29 ppt, T ~ 28 - 31°C (82 - 88 °F)), and a near-bottom layer that occasionally could be identified based on a strong depletion in DO (25 - 33% reduction) and detectable sulfide (>0.2 to sometimes > 5 ppm). A shallow back region near springs entering the pond had salinities of 4 - 8 ppt and temperatures of 18 - 20°C (64 - 68 F). They noted that 'considerable' fresh water entered the pond in the area of the small inland cove at the southern end of the pond.

Maciolek and Brock (1974) noted that salinity in the pond was 7 - 18 ppt, but the location or locations where salinity was measured was not reported.

Chai (unpubl.) measured temperature and salinity in surface and near-bottom (1 – 6 m) waters at 4 sites along a mauka/makai transect through Kaloko pond (Figure 19). Measurements were made twice on one date (1/29/1988), in the morning (8:00 AM) and in the afternoon (3:00 PM). Salinities of deep samples ranged from 30.5 – 34.5 psu. Surface salinities at the two mid-pond sites were close to offshore values (~35 psu), while salinities at both the mauka and makai ends of the transect were depressed significantly (Figure 20), resulting in significant stratification in the mauka and makai regions. While the relatively high salinities overall suggest that the pond may have been somewhat saltier than when salinity was measured by Maciolek and Brock in 1972, significantly higher salinities in some surface samples than in deep samples (a situation very unlikely to occur in a natural system) suggest that there may have been errors in measurements or data recording, and that these results should be treated with caution.

Brock and Kam (1997) measured water quality at three sites in Kaloko pond on six occasions from March 3, 1994 - October 18, 1996. Surface (~20 cm /~ 9 in depth) samples were collected at a nearshore site along the mauka margin in the vicinity of the 'cove' at the southern end of the pond, at a central pond site, and at a site close to the fishpond wall in the southern portion of the pond (Figure 19). Deep samples (1.5 m depth) also were collected at the mid-pond site. Samples from the mid-pond site had surface salinities of ~ 27.6 - 33.6 ppt, temperatures of 27.7 - 29.7°C (~81.8 - 85.5 °F), and dissolved oxygen concentrations of 5.8 - 7.5 ppm (Figure 20). While the Kikuchi et al. (1971) site and the Brock and Kam (1997) mid-pond site may have been in different locations, pond waters do appear to have been somewhat saltier and warmer in 1994-1996 than in 1970, while oxygen concentrations were similar. Deep samples from the Brock and Kam (1997) mid-pond site had salinities of 31.6 – 33.7 ppt, temperatures of 28.0 – 30.1°C (82.4 - 86.2 °F), and dissolved oxygen concentrations of 5.6 - 7.0 ppm. Deeper waters thus also appear to have been saltier and perhaps slightly cooler than they were in 1970. Samples from the mauka/cove site had salinities of 11 – 34 ppt and temperatures of 27.3 – 32.5°C (81.1 - 90.5 F), significantly saltier and warmer than Kikuchi et al.'s (1971) spring-affected sample, which could indicate less intense spring discharge into the pond, or perhaps just differences in sampling location. Surface samples from the site close to the fishpond wall had salinities of 29.9 – 33.7 ppt, and temperatures of 27.8° - 30.7°C (82 - 87.3 °F), similar to or slightly fresher and cooler than the mid-pond site, probably reflecting the effects of strong coastal spring discharges to the ocean just south of the pond (see Coastal Waters). Overall, the temperature and salinity data suggest that pond waters contained significantly less groundwater in 1994 - 1996 than in 1971.

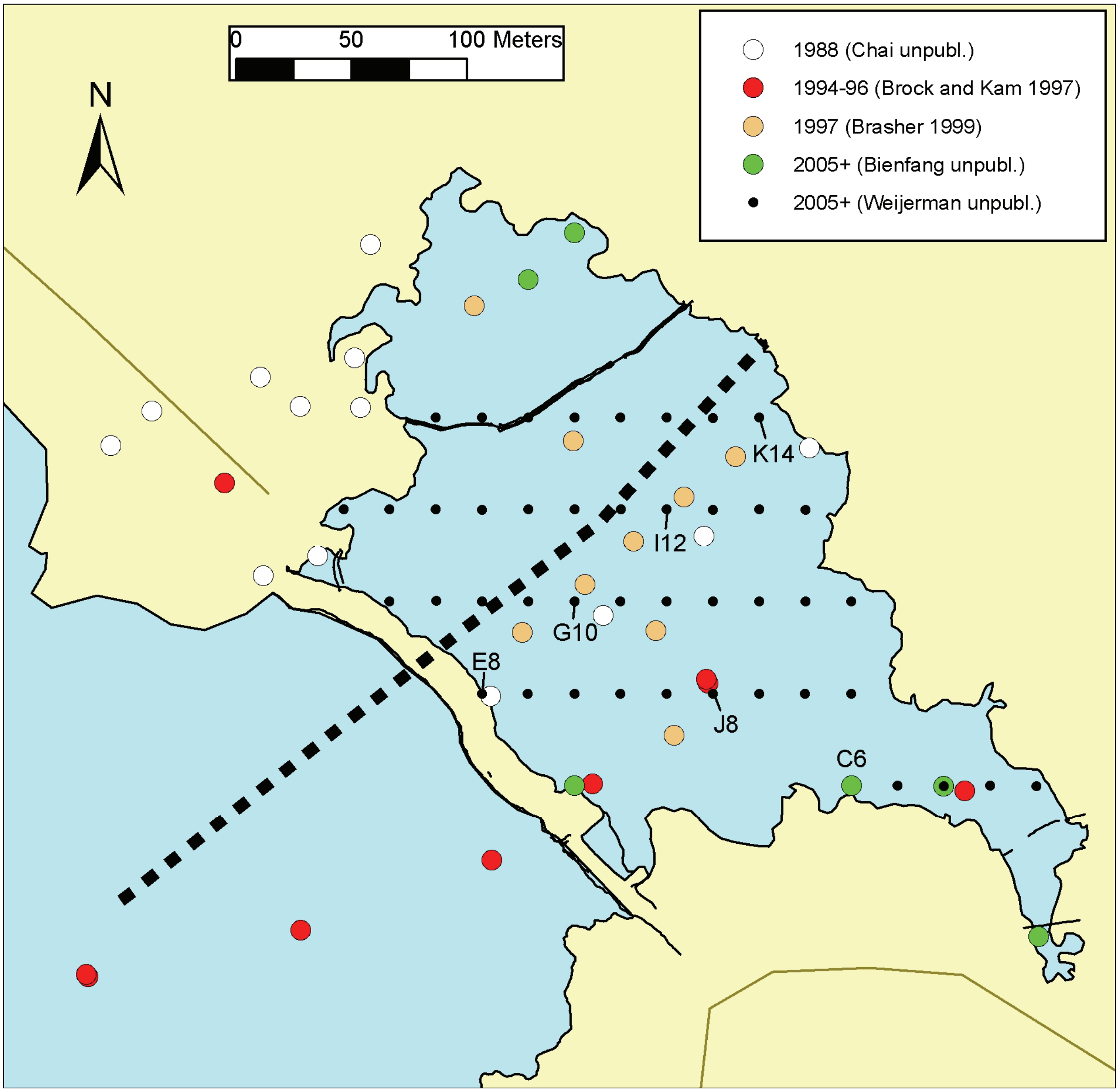


Figure 19. Historical and present-day sampling sites in and around Kaloko pond. Dashed line shows approximate location of transect sampled in 2000 by Marine Research Consultants (2000). Locations of sites used by Chai (unpubl.) and Brock and Kam (1997) are shifted from the latitude/longitude positions listed in those studies to match the locations described in the studies as closely as possible.

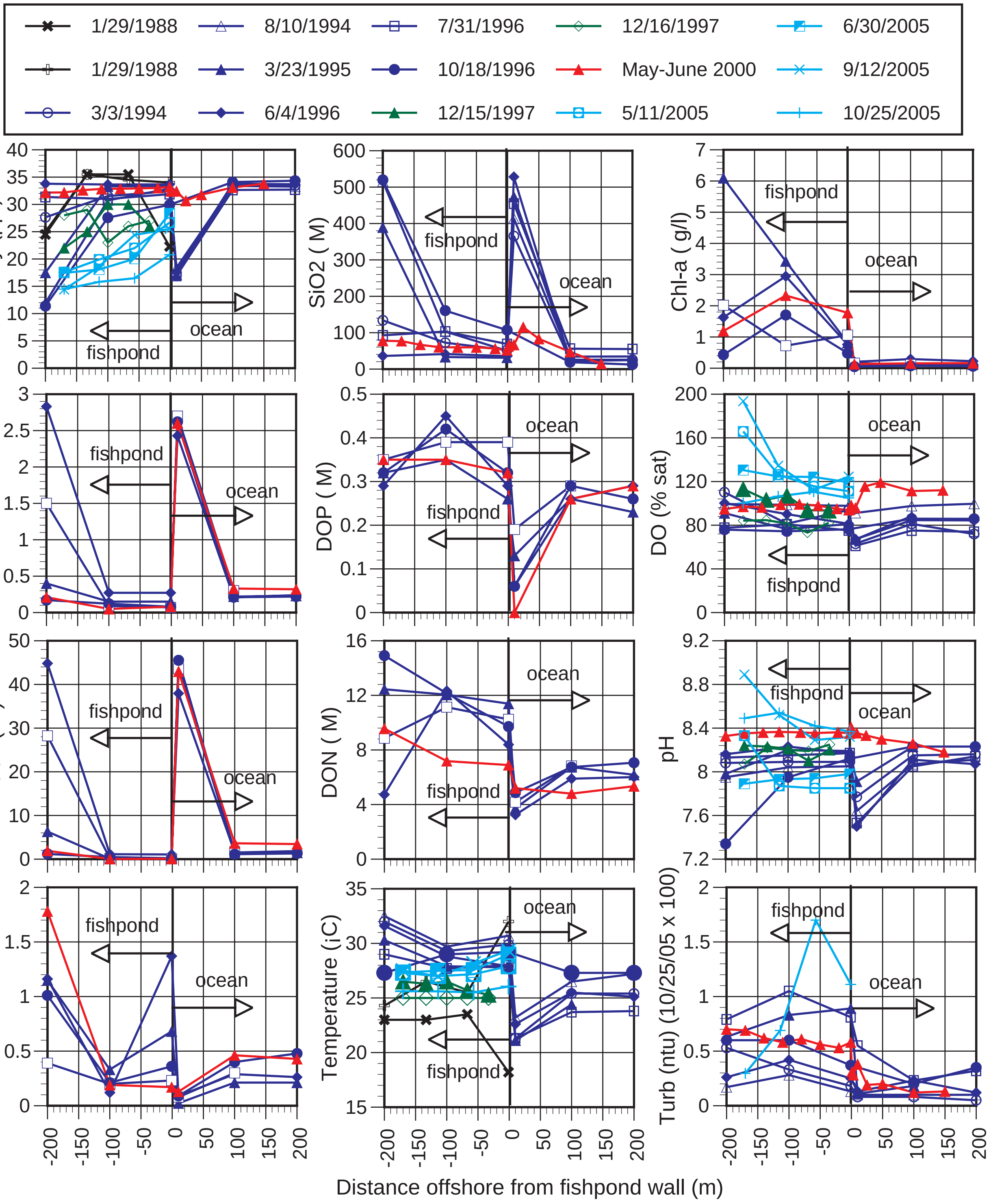


Figure 20. Water quality in shallow (20 cm depth) samples collected along transects through and offshore of Kaloko fishpond in 1988 (Chai unpubl.), 1994-96 (Brock and Kam 1997), 1997 (Brasher 1999), between May 26 and June 10 2000 (n = 1, Marine Research Consultants 2000), and in 2005 (Weijerman unpubl.). Note the 100 x factor for the 10/25/05 data in the turbidity panel.

This change could have been due either to a decrease in groundwater inputs to the pond, or an increase in the exchange of pond waters with offshore ocean waters. The latter possibility could have resulted from damage or changes to the fishpond wall that affected seawater flow into the pond.

Bhambare (1996) measured water quality (temperature, salinity, dissolved oxygen, pH, and redox potential) in Kaloko pond on 31 occasions in November 1995 using a remotely controlled data acquisition system equipped with sensors. Data were collected at a range of depths and are presented primarily as color-coded plots along the vehicle track so they are difficult to compare to other data, but surface water quality varied significantly depending on the location of the vehicle in the pond, while water quality from deeper measurements was much less variable.

Brasher (1999) measured surface water quality at an array of sites in Kaloko pond on 12/15/97 at 6:00 PM and 12/16/1997 at 6:00 AM (Figure 19). Salinities along the mauka/makai transect follow a pattern similar to that observed by Brock and Kam (1997), although salinities near the center of the pond are lower than all but one of Brock and Kam's mid-pond salinities. (Figure 20). Temperatures also were lower than those observed by Brock and Kam (1997), but similar to those observed by Chai (unpubl.) (Figure 20). Dissolved oxygen levels were similar to the Brock and Kam (1997) results in the early morning dataset, but were elevated significantly in the evening dataset, while pH values were similar in both datasets (Figure 20).

Marine Research Consultants (2000) analyzed surface and near-bottom samples along a transect close to those used by Chai (unpubl.) and Brasher (1999), from roughly the midpoint of the mauka margin of Kaloko pond out through the center of the pond to the fishpond wall (Figure 19). Transect data also should be reasonably comparable to data from Brock and Kam (1997), particularly data from the makai and mid-pond sites. Pond surface waters were quite saline along the entire transect (32.2 – 33.2 ppt) and the pond showed little vertical stratification, with deep samples having salinities of 32.2 – 33.7 ppt, and a maximum difference between surface and deep samples of only ~1.3 ppt. Samples apparently were collected on only one date [sampling in the park at these and other sites was conducted in "May – June 2000" (Marine Research Consultants 2000)], so these data may not be representative of 'typical' conditions in the pond. However, deep (1.5 m) mid-pond samples from Brock and Kam (1997) had salinities of 31.6 – 33.7 ppt, and stratification was similar in the Brock and Kam (1997) dataset on days with surface salinities similar to those in the Marine Research Consultants (2000) dataset, so hydrologic conditions in the pond may not have changed significantly between 1996 and 2000. Comparing surface water quality from the 2000 transect to earlier data shows that salinities and silica concentrations are relatively similar to values in the Brock and Kam (1997) 6/4/1996 and 7/31/1996 transects, but some differences are apparent in other water quality parameters (Figure 20). Chlorophyll-*a* is higher in the 2000 transect, and inorganic nitrogen (nitrate and ammonia) appear lower. Phosphate also is higher in the 2000 transect, as are both DON and DOP. Turbidity and dissolved oxygen are similar between the two studies, but pH is elevated in the 2000 transect. The differences suggest that the biological condition or status of the pond may have changed between 1996 and 2000, although the elevated chlorophyll-*a* and nutrient drawdown observed in 2000 may have been associated with a transient phytoplankton bloom event in the pond, and thus may not have been indicative of a change in the overall status of the pond. Alternatively, restoration of the southern portion of the fishpond wall and the southern makaha around the time of the 2000 sampling may have caused a shift in the biological status in the pond, as suggested by Bond and Gmirkin (2003), or there may simply be consistent and significant differences in water quality related to differences in the two transect locations.

Bienfang (unpubl.) is collecting water quality data from 6 sites in Kaloko pond, two of which are close to the endpoints of the Brock and Kam (1997) transect (Figure 19). The lack of a central pond site makes it difficult to characterize overall pond water quality, so these data are not included in Figure 20. However, project personnel will be adding a site close to the Brock and Kam (1997) mid-pond site (Figure 19), so future data from this project should be suitable for comparison to the Brock and Kam (1997) data.

Weijerman (unpubl.) also is collecting water quality data in Kaloko pond as part of a project focused on control of the alien alga *Acanthophora spicifera* in the pond. Data are being collected using a multiparameter water quality instrument at an extensive array of sites (Figure 19), with data collected from the surface to the bottom at increments of roughly one meter. Preliminary surface data (Figure 21a) show significant variability in both space and time, but deeper data (Figures 21b, c, and d) are less variable, consistent with the controlling roles that freshwater supply and mixing and dilution processes play in surface water quality in the pond. Surface salinity data from the first three surveys show strong spatial gradients, with fresher waters along the inland margin of the pond and saltier water near the fishpond wall, but the data from the fourth survey are much more homogeneous, with relatively fresh water at all of the sampled sites. This change is noteworthy, as ongoing restoration of the fishpond wall apparently resulted in the elimination of seawater inputs along the northwestern portion of the fishpond wall around this time (Mariska Weijerman pers. comm. 2005). Brasher (1999) noted that pond waters responded most significantly to tidal cycling only at mid- to high tides when seawater flowed into the pond over a low spot in the northwestern end of the deteriorated wall. The most recent salinity data suggest that the elimination of seawater inputs in this area has reduced dilution of groundwater inputs to the pond, and may have reduced mixing in the pond as well, increasing the residence time of groundwater in the pond and possibly the stability of the fresher surface layer as well. Spatial and temporal variability in both surface and deeper samples also reflects the importance of biological processes, particularly primary production and respiration, which produce significant spatial gradients in dissolved oxygen and pH.

The sites being sampled by Weijerman (unpubl.) overlap most of the transect sites used by Chai (unpubl.), Brock and Kam (1997), and Brasher (1999). Sites E8, G10, I12, and K14 (Figure 19) in particular provide a transect suitable for comparison to these prior studies (Figure 20). Of the 5 parameters available for comparison, only temperature is relatively similar to previous data. Surface salinities in the Weijerman (unpubl.) data are both notably lower than earlier data, and follow a different pattern along the transect, increasing steadily with distance from the landward margin of the pond. Salinities in the most recent survey are the lowest of all, with values at the two central pond sites that are roughly half of typical values observed in earlier studies conducted from 1988 to 2000. These results are consistent with the reduction in seawater inflow

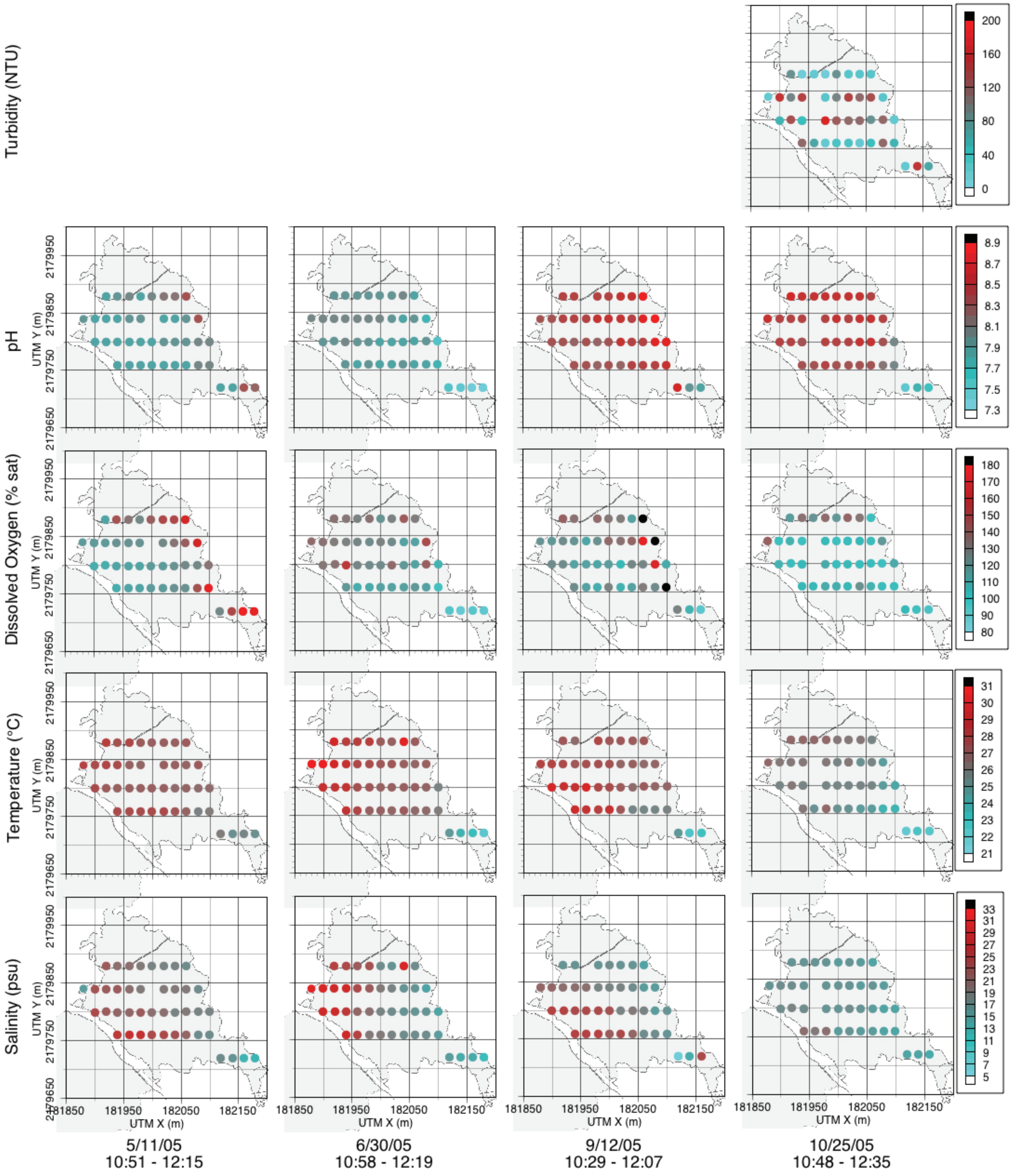
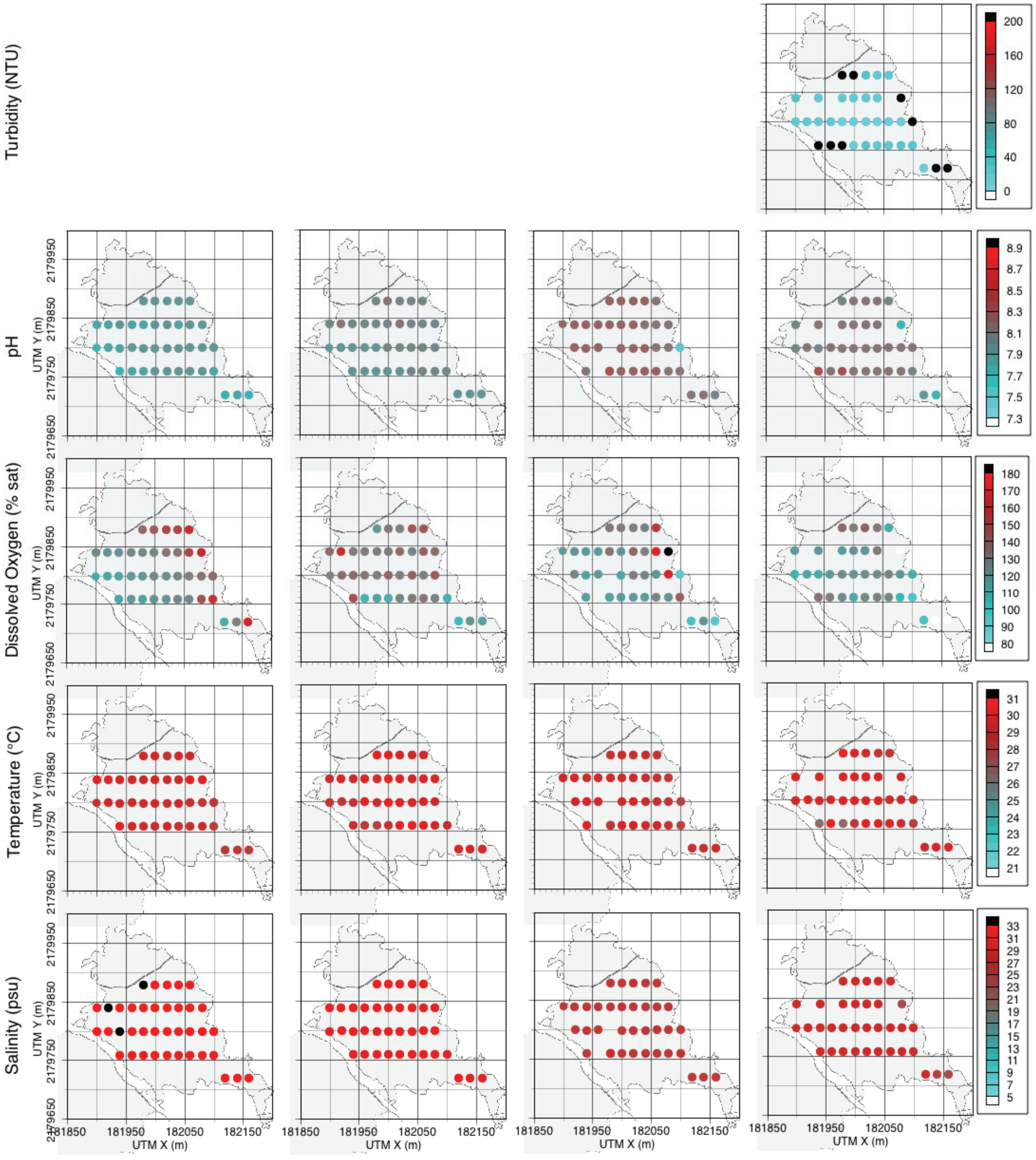


Figure 21a. Water quality data from surface (0 – 0.5 m) measurements in Kaloko pond from 5/11/05 – 10/25/05 (Weijerman unpubl.).



5/11/05
10:51 - 12:15

6/30/05
10:58 - 12:19

9/12/05
10:29 - 12:07

10/25/05
10:48 - 12:35

Figure 21b. Water quality data from ~1m (0.5 – 1.3 m) measurements in Kaloko pond from 5/11/05 – 10/25/05 (Weijerman unpubl.).

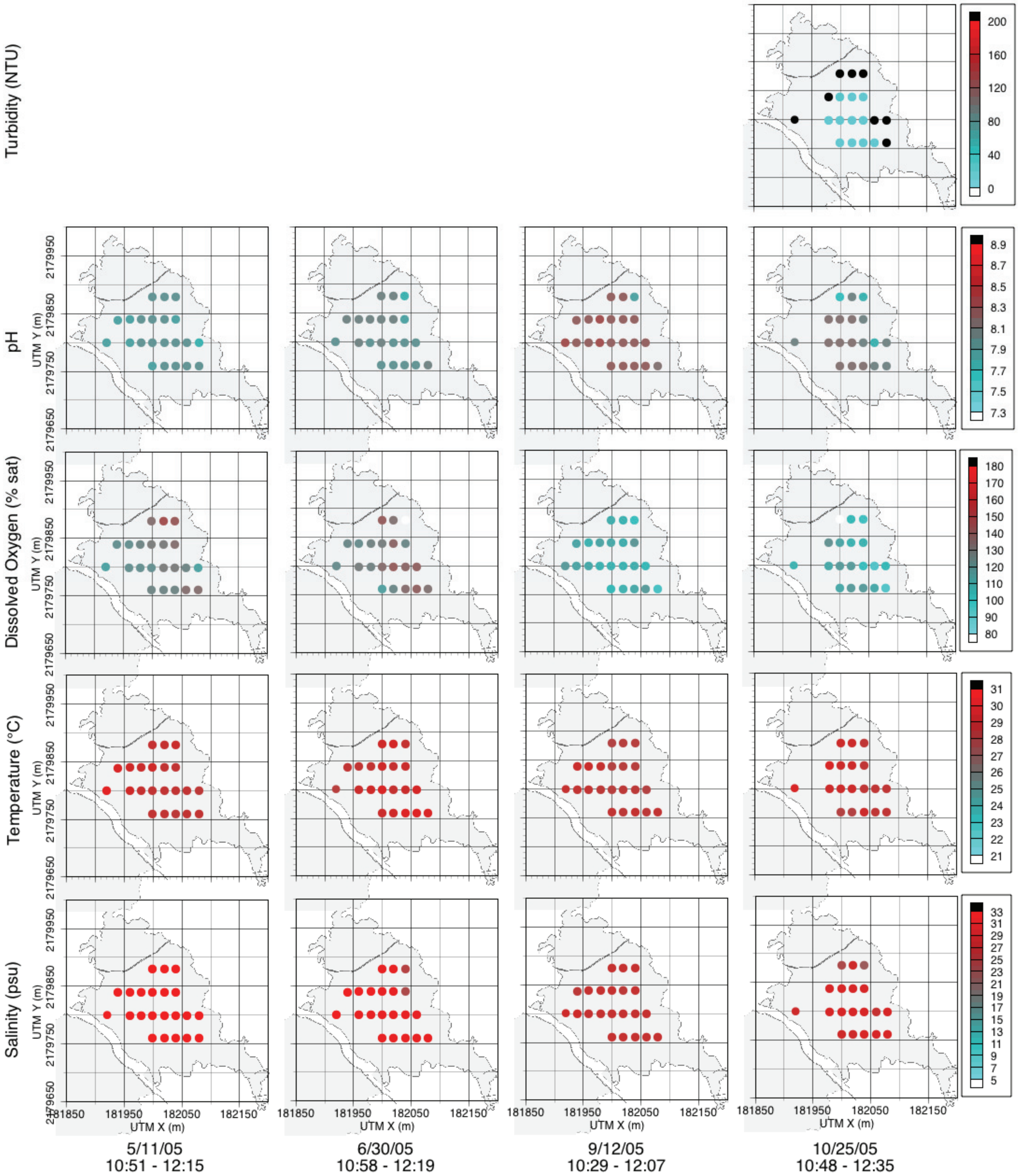


Figure 21c. Water quality data from ~2m (1.3 – 2.3 m) measurements in Kaloko pond from 5/11/05 – 10/25/05 (Weijerman unpubl.).

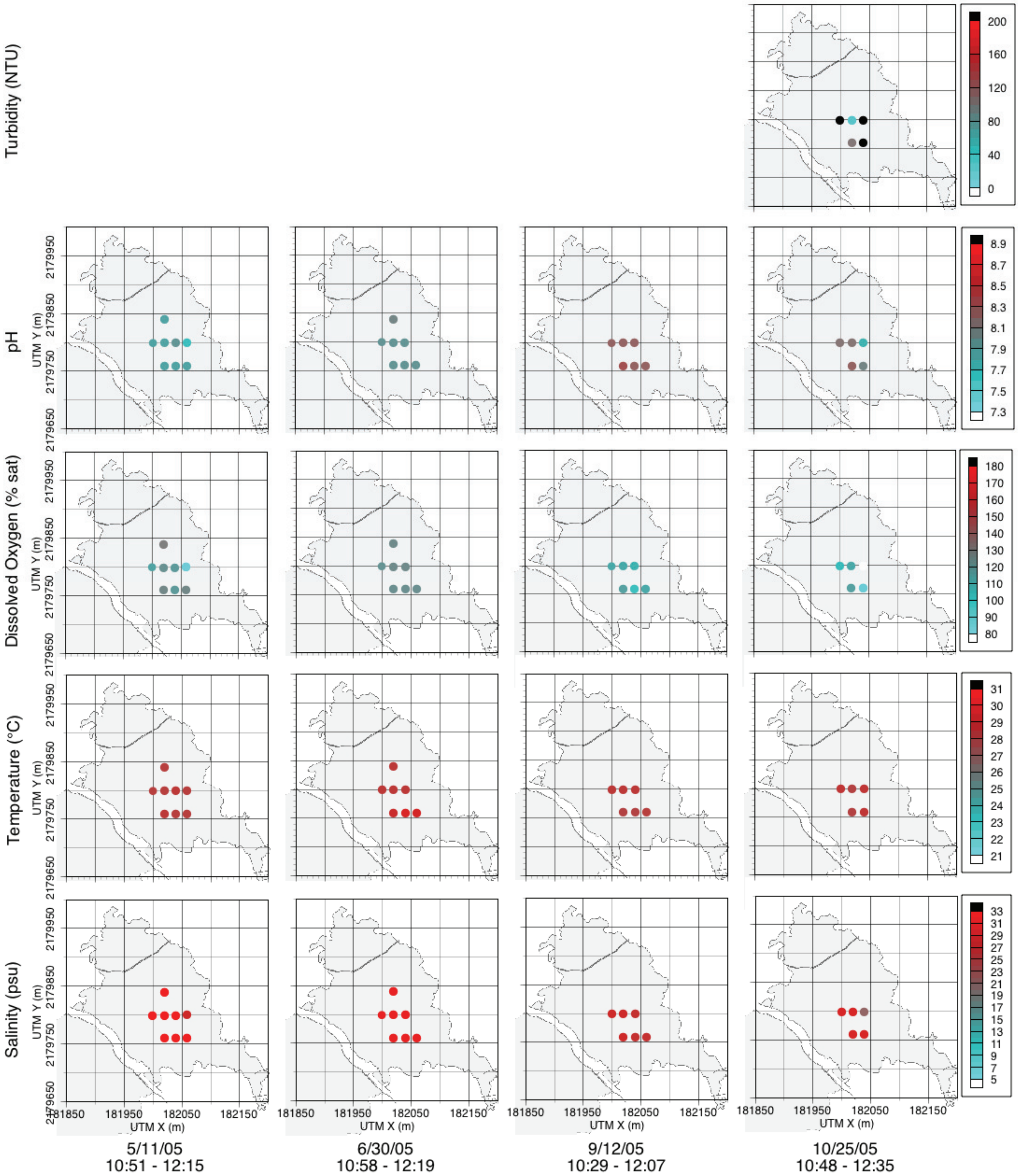


Figure 21d. Water quality data from ~3m (1.3 – 2.3 m) measurements in Kaloko pond from 5/11/05 – 10/25/05 (Weijerman unpubl.).

suggested above, but the low salinities in the first three surveys also show that pond waters already were significantly fresher at the start of the Weijerman (unpubl.) study than they were in earlier studies, presumably due either to an increase in groundwater inputs or to declining seawater inputs due to wall restoration, or both. The processes resulting in fresher surface waters also appear to have affected productivity in the pond, increasing dissolved oxygen concentrations across the entire transect, but most dramatically at the mauka site. Productivity and increased freshwater also appear to be having significant effects on pond pH, which is variable but particularly high in the most recent two surveys, and possibly on turbidity in the pond, although the 100-fold increase in the Weijerman (unpubl.) data compared to previous studies seems unreasonably large and may be due at least partially to methodological or other differences rather than differences in conditions in the pond.

Figure 22 combines suitable data from all of the above studies to highlight long-term variations in water quality in Kaloko pond. Salinity, temperature, and dissolved oxygen have the longest records, spanning 34 years. Salinities measured in 1971 – 1972 were significantly lower than values measured from 1988 to 2000, but are similar to recent values measured in 2005 by Weijerman (unpubl.) (Table 7). The increase probably reflects reductions in groundwater inputs after 1972, while the recent decrease probably reflects both increased groundwater inputs associated with higher than normal rainfall in 2004 (Sallie Beavers pers. comm. 2005) and increased retention of groundwater in the pond due to ongoing restoration of the pond wall (Mariska Weijerman pers. comm. 2005). Temperatures increased significantly between 1971 and 1994 (Figure 22, Table 7), but were relatively constant from 1994 to 2005. The increase could reflect declining contributions of groundwater to the pond, climatic effects, or could simply be an artifact due to differences in sampling locations. Groundwater temperatures are available from 1996 to 2005 from well 4161-01, inland of the pond, and show a slight but significant increase over that period (Figure 11, Table 5). Pond temperatures over the same period actually declined slightly (Figure 22), but salinities also declined significantly, so the decrease could be due simply to the greater proportion of groundwater in pond waters rather than changing groundwater quality, or to climatic factors. Dissolved oxygen in 1971 was well within the range of values measured from 1994 – 1996, but recent measurements are significantly higher (Table 7), suggesting that biological production in the pond has increased significantly, possibly due to more efficient retention of groundwater and associated nutrients in the pond by the restored pond wall.

Nutrients and pH have records spanning 11 years, from 1994 to 2005. No significant change occurred in the silica or pH data (Figure 22, Table 7), but significant increases are evident in all of the nitrogen and phosphorus parameters. As previously noted, increases in DOP, DON, TDP, and TDN probably are due in large part to analytical artifacts. Although increases in inorganic species are significant, the increases are due primarily to high values in the most recent data, which are from nearshore site 16, rather than a central pond site (Figure 19). Salinities at this site were similar to salinities associated with earlier nutrient data (Figure 22), so the higher nutrient concentrations may reflect increased nutrient concentrations in groundwater entering the pond, but they also may be elevated simply because nutrients at this site have not yet been consumed by phytoplankton to the degree that they are at central pond sites more distant from groundwater inputs. Future sampling from site J8 should provide better characterization of the overall nutrient status of the pond and of possible trends in nutrient concentrations. Chlorophyll-*a* and turbidity have relatively short records, from 1994 to 2000, and show no significant changes over that period, although more recent turbidity data were excluded from the regression analysis because they appeared unreasonably high, suggesting analytical artifacts rather than real differences.

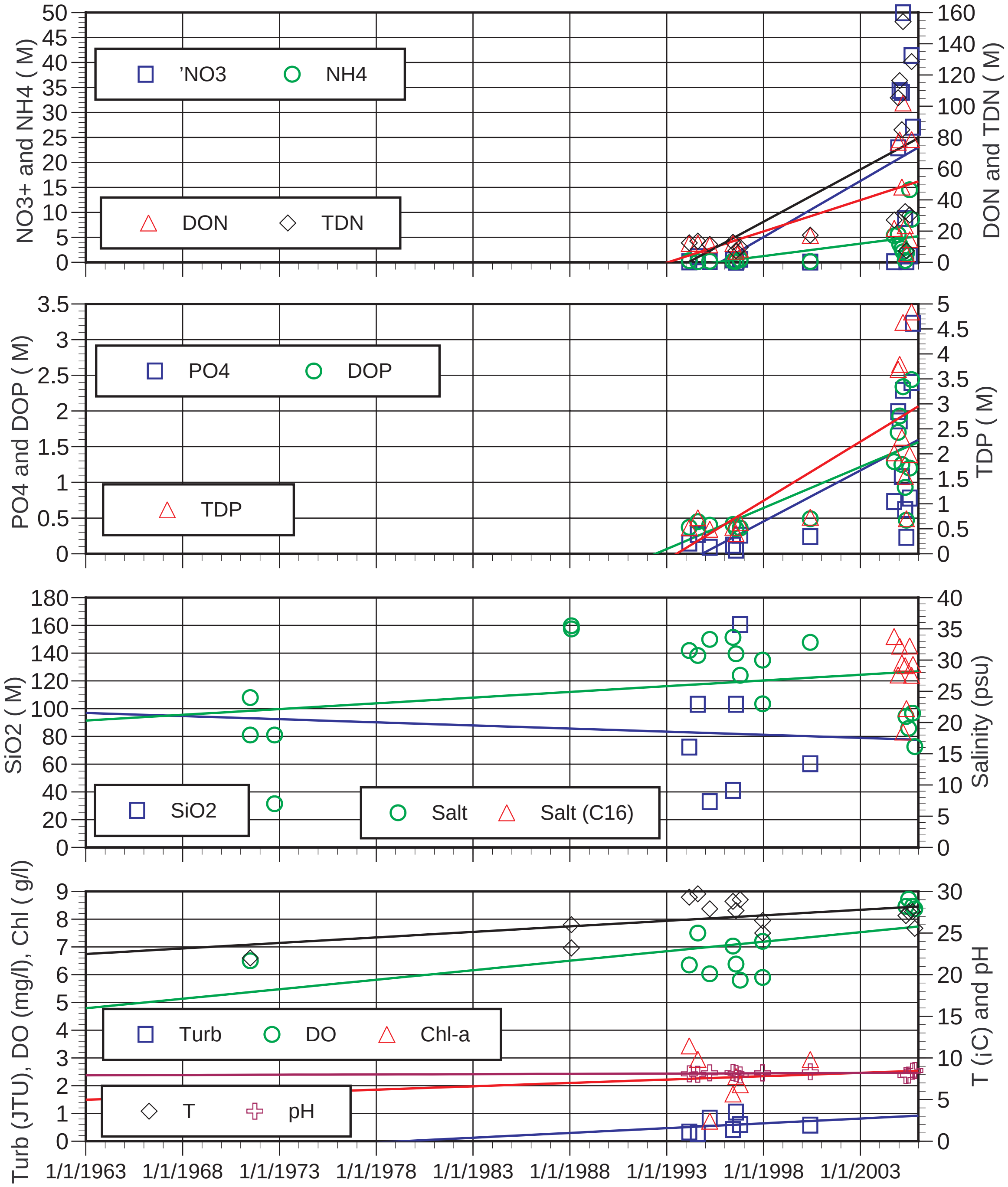


Figure 22. Surface water quality data from sites near the center of Kaloko pond. Data from Kikuchi and Belshe (1971), Maciolek and Brock (1974), Chai (1991), Brock and Kam (1997), Brasher (1999), Nance(2000), Bienfang (unpubl.), and Weijerman (unpubl.). Note that nutrient data and fits include 2004-05 data from Bienfang (unpubl.) site C16. Other plots and fits use averaged data from Weijerman (unpubl.) sites G10 and I12. See text for details.

Table 7. Linear regression results for Kaloko pond water quality data plotted in Figure 22. Note different time intervals for individual regressions. Statistically significant slopes ($p \leq 0.05$) are shown in bold.

	units	Interval	slope	R^2	p
NO3+	µM/y	94-00	-0.064	.109	.470
NO3+	µM/y	94-05	2.25	.362	**.011**
NH4	µM/y	94-00	-0.008	.014	.799
NH4	µM/y	94-05	0.499	.353	**.015**
DON	µM/y	94-00	.715	.214	.296
DON	µM/y	94-05	4.01	.347	**.016**
TDN	µM/y	94-00	.643	.180	.343
TDN	µM/y	94-05	6.69	.391	**.010**
PO4	µM/y	94-00	0.010	.053	.620
PO4	µM/y	94-05	0.143	.454	**.003**
DOP	µM/y	94-00	0.012	.249	.254
DOP	µM/y	94-05	0.115	.548	**.001**
TDP	µM/y	94-00	0.022	.139	.410
TDP	µM/y	94-05	0.236	.511	**.002**
SiO2	µM/y	94-00	-0.45	.000	.964
Salinity	psu/y	71-00	0.523	.519	**.002**
Salinity	psu/y	71-05	0.183	.077	.249
Salinity	psu/y	88-05	-0.937	.744	**.000**
Turb	JTU/y	94-00	0.034	.067	.576
DO	mg/L/y	71-05	0.068	.327	**.041**
DO	mg/L/y	94-05	0.195	.705	**.000**
T	°C/y	71-05	0.133	.286	**.040**
pH	pH/y	94-05	0.007	.028	.586
Chl-*a*	µg/L/y	94-00	0.024	.003	.907

Overall, water quality data from 1971 to 2005 suggest that while groundwater inputs to the pond may have declined overall as predicted by Oki et al. (1999), water quality in the pond and associated biological productivity probably depend at least as strongly on the integrity of the fishpond wall. Because the integrity of the wall has varied over the last 50 years, it is not possible to use historical water quality data to infer changes in groundwater supply, but future data should be more suitable.

In addition to the water quality data discussed above, limited analyses have been performed for pesticides and other contaminants in Kaloko pond sediments. Sediments from three sites around the perimeter of the pond were sampled by the USGS on 8/27/02 and 8/29/02 and analyzed for 96 pesticides and other contaminants. Five compounds were detected but only at very low concentrations (Table 8). On 8/29/02, hourly samples were collected from the NE shore site and screened for 28 pesticide compounds with no detection of any contaminants (Tribble 2003). While the sample sizes are small, these data suggest that pollutant inputs to Kaloko pond probably have not been significant to date.

One striking feature of the Brock and Kam (1997) data is the temporal variability in water quality in Kaloko pond. Spatial variability is to be expected given the heterogeneity in the locations and intensity of groundwater and seawater inputs into the pond, and biological processes can result in significant changes in some parameters. However, the lack of direct surface runoff to the pond and the expectation that groundwater discharges should vary relatively slowly would suggest that ‘conservative’ parameters like salinity and silica should be relatively

Table 8. Contaminants detected in sediments sampled on 8/27/02 at 3 nearshore sites in Kaloko pond ("Northeast" – NE, "West" – W, "Southeast" – SE). All values are in µg/kg (ppb) and include notation "Estimated value". ND = not detected. Data from Wolff (unpubl.).

Compound	NE	W	SE
2,6-Dimethylnaphthalene	98	120	290
Di-n-butyl phthalate	140	270	190
Bis(2-ethylhexyl) phthalate	200	320	270
1,6-Dimethylnaphthalene	ND	90	80
Diethyl phthalate	ND	ND	4

stable, with only modest fluctuations associated with long-term, seasonal, or storm event-scale changes in groundwater recharge and seawater mixing into the pond. Instead, water quality varied dramatically throughout the 2.6 years studied (Figure 20), with significant changes even on the shortest interval sampled (57 days). Because groundwater and seawater supply to the pond control pond salinity, changes in either or both of these could have contributed to the observed variability. If changes in groundwater supply were responsible, then groundwater flow rates in the park clearly can be quite variable on relatively short timescales, and thus appear to be very susceptible to changes in local and upslope hydrology and recharge. Changes in seawater inputs to the pond seem likely to be less important, although damage to the fishpond wall coupled with long-term (i.e. spring-neap) cycles in tidal forcing might have resulted in significant changes in seawater inputs to the pond.

Aimakapa pond

Aimakapa pond is classified as an anchialine pool under State criteria and thus would be subject to the inland water quality criteria listed above for anchialine pools. However, the large size of Aimakapa pond compared to most anchialine pools results in a much longer residence time for groundwater in the pond, and thus for much larger potential impacts from groundwater contaminants.

The earliest water quality data available for Aimakapa pond are from Sparks (1963), who observed that salinity in the pond was about 9 ppt. Kikuchi and Belshe (1971) measured a salinity of 7.9 ppt, a temperature of 27.8°C, a pH of 8.5, and a dissolved oxygen concentration of 11 ppm, while in 1972-1973 Maciolek and Brock (1974) recorded a salinity of 7 – 8 ppt, although the location or locations where salinity was measured is not specified.

Brock and Kam (1997) measured water quality at 3 sites in Aimakapa pond on six occasions between March 3, 1994 and October 18, 1996. Surface (~20 cm depth) samples were collected at a nearshore site along the mauka margin, at a central pond site, and on the pond side of the beach berm toward the southern end of the berm (Figure 23). Deep samples (0.75 m depth) also were collected at the mid-pond site. Surface samples from the mid-pond site had salinities of ~11.4 – 12.1 ppt, temperatures of 26 – 29.5°C, and dissolved oxygen concentrations of 5.6 – 9.8 ppm. Data from deep samples at the central pond site and from the other two surface sites were quite similar, indicating that there was little stratification and that water quality was much more homogeneous than in Kaloko pond. Aimakapa pond waters appear to have been slightly saltier in 1994-1996 than they were in 1963, 1971, and 1972-73, and dissolved oxygen concentrations may have been lower, although differences in dissolved oxygen may have been due to short-term variability, as dissolved oxygen in enclosed aquatic systems can vary significantly on short time scales (~hours). pH also may have been lower, although the precision and accuracy of the single 1971 measurement likely are less than the later measurements, and pH also can vary significantly on short time scales. Although temperature and salinity data show that Aimakapa pond was more homogeneous in 1994-96 with respect to groundwater and seawater inputs than Kaloko pond, nutrients, chlorophyll-*a*, and turbidity did vary significantly between transects, indicating that biological processes have a major but variable influence on water quality (Figure 24). In

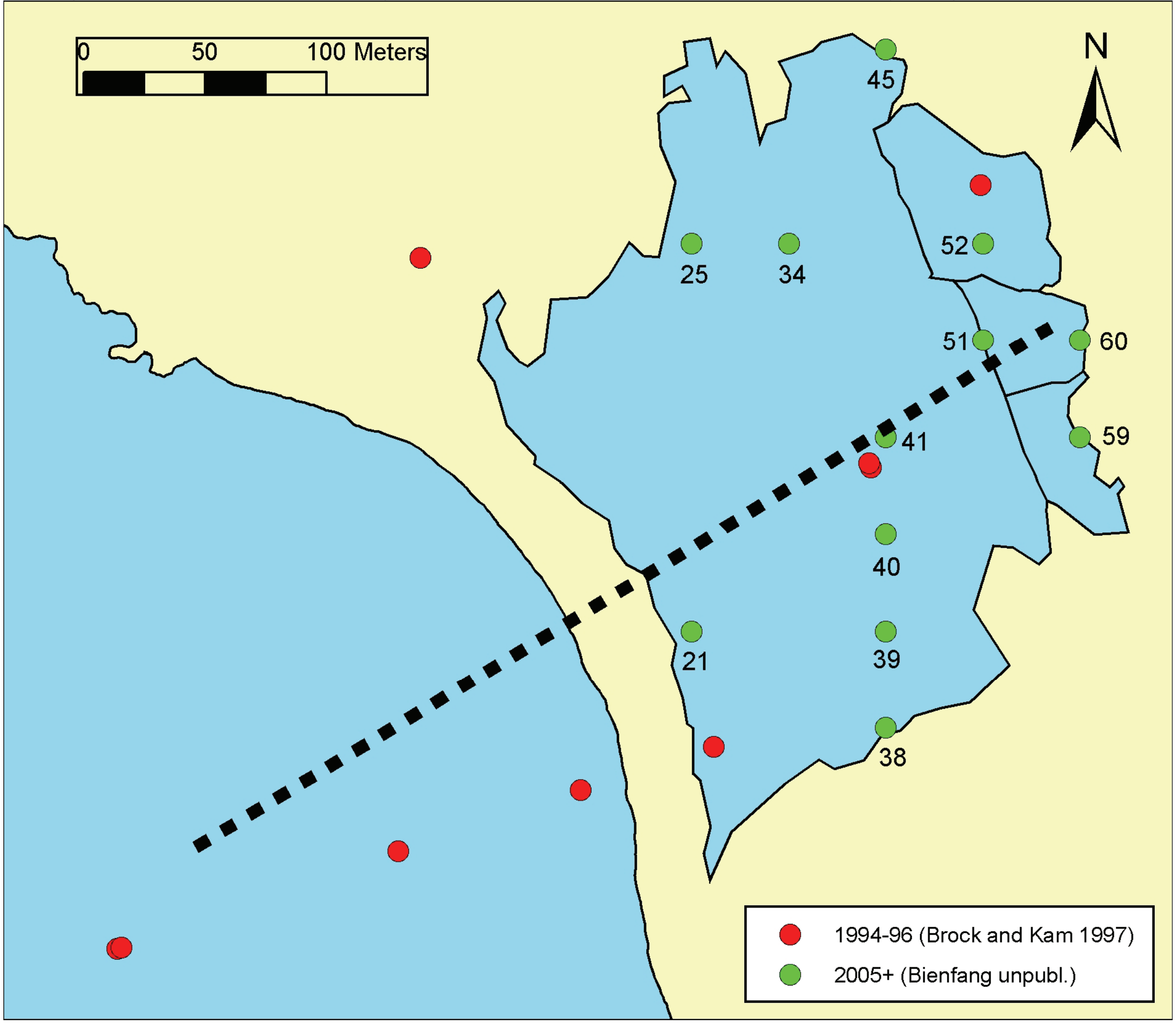


Figure 23. Historical and present-day water quality sampling sites in and around Aimakapa pond. Dashed line shows approximate location of transect sampled in 2000 by Marine Research Consultants (2000). Brock and Kam (1997) site locations are shifted from published latitude/longitude coordinates to match actual locations as closely as possible.

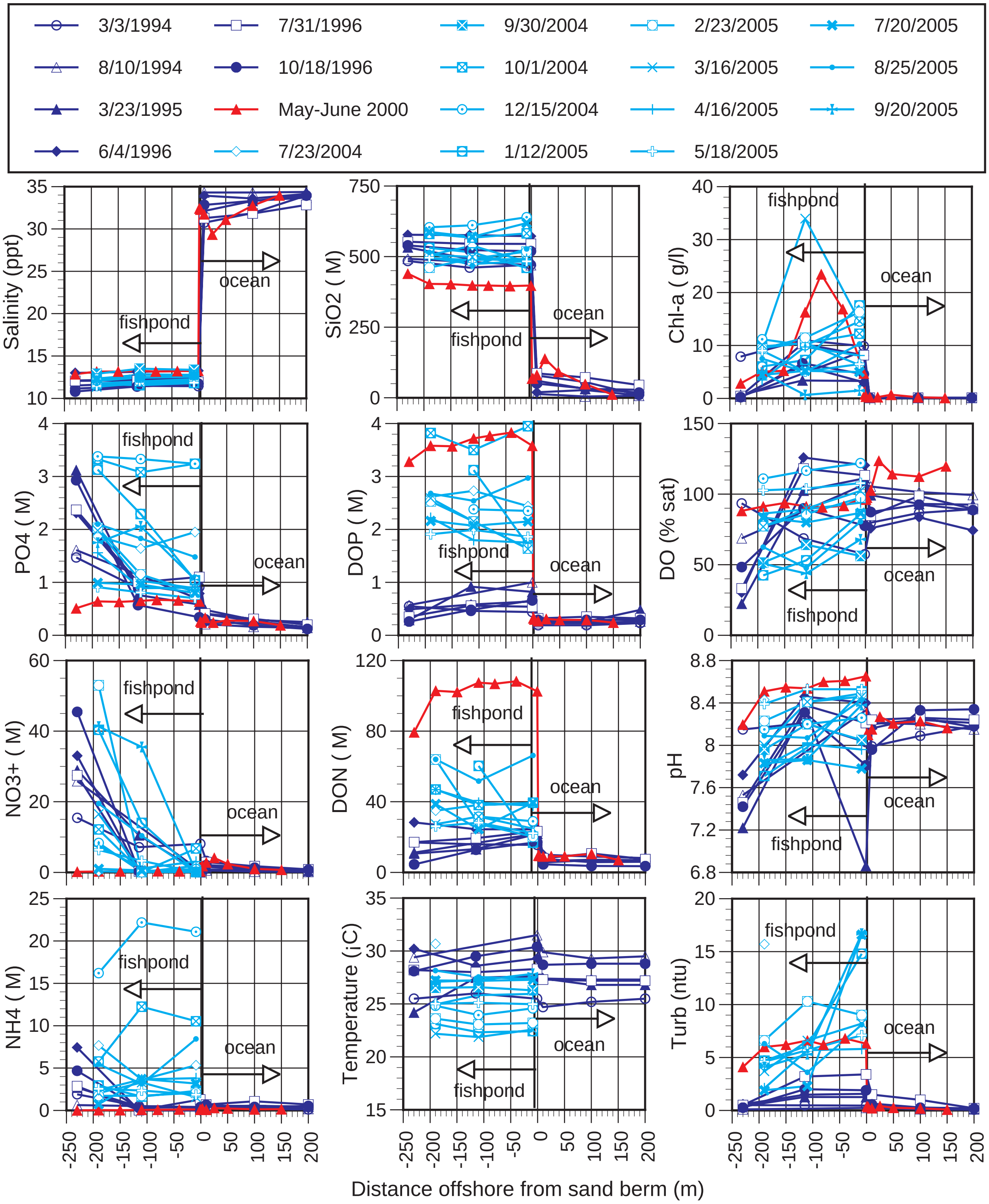


Figure 24. Water quality in shallow (20 cm depth) samples collected along transects through and offshore of Aimakapa fishpond in 1994-96 (Brock and Kam 1997), between May 26 and June 10 2000 (n = 1, Marine Research Consultants 2000), and in 2004-05 (Bienfang unpubl.).

addition, while salinity data show little variability within a given transect, differences between transects suggest significant variations in groundwater supply on the timescale of sampling (~2 – 14 months). Changes in seawater mixing into the pond also could contribute to the observed differences, but the low permeability and relative stability of the beach berm suggest that changes due to differences in seawater inputs should be small.

Marine Research Consultants (2000) analyzed surface and near-bottom samples along a transect from roughly the midpoint of the mauka margin out through the center of the pond to the beach berm (Figure 23). Salinities at sites inside the pond ranged from 12.9 –13.4 ppt, with the lowest values at the mauka nearshore site (12.855 –12.864 ppt), and the other sites exhibiting a very narrow range of salinities (13.158 –13.369 ppt) with almost no evidence of vertical stratification (max difference 0.116 ppt). Salinities in the pond were only slightly higher than salinities measured in groundwater sampled approximately 700 m inland of the pond (Marine Research Consultants 2000), indicating that pond waters consist mostly of brackish groundwater with only minor inputs of seawater through the sand berm. Comparison to salinity data from Brock and Kam (1997) show that pond waters appear to have increased in salinity from 1996 to 2000. Other water quality parameters measured by Marine Research Consultants (2000) also show little lateral variability in the pond, but virtually all show significant differences between shallow and deep samples [figures 2 – 5 in Marine Research Consultants (2000)]. Given the rather well-mixed condition of the pond with respect to contributions by groundwater and seawater, these differences must be due primarily to biological activity within the pond. The one exception, nitrate, occurred at low concentrations (0.16 – 0.35 μM) in both shallow and deep samples and probably was recycled rapidly, as inorganic nitrogen appears to have been limiting to biological production in the pond.

Comparing data from 2000 to data from 1994-96 (Figure 24) shows that, as for Kaloko pond, the 2000 salinity data are most similar to the 6/4/96 transect, but that corresponding silica concentrations were about 30% lower in 2000 than would have been expected from the 1994-96 data. The salinity data suggest that groundwater flows to the pond in 2000 probably were at the low end of flows in 1994-96. The unusually low silica concentrations could reflect either a change in the quality of the groundwater reaching the pond, or possibly silica drawdown by diatoms and other plants that require silica. The difference seems larger than would be expected from biological uptake alone, so a change in groundwater quality seems more likely. Significant differences are apparent in many of the other water quality parameters as well, although the coarser spatial resolution of the 1994-96 data make it difficult to interpret differences near the pond shore, where water quality could vary significantly over short distances. Data from the mid-pond and more seaward sites should be less variable – at these sites, chlorophyll-*a*, turbidity, pH, DON, and DOP are elevated in the 2000 transect, while phosphate concentrations are similar to those in the 1994-96 transects, and inorganic nitrogen is strongly depleted. This pattern is similar to that observed in the Kaloko pond data, although the increases in chlorophyll-*a*, turbidity, DON and DOP are much larger, suggesting that greater biological activity (as evidenced by the very high chlorophyll-*a* concentrations and virtual absence of inorganic nitrogen) probably was responsible for most of the differences in the 2000 data.

Bienfang (unpubl.) collected surface water quality data from 12 sites in Aimakapa pond at roughly monthly intervals (range 21 to 75 days) from July 2004 to September 2005 (Figure 23).

Data from sites 52, 41, and 21 can be compared to transect data obtained by Brock and Kam (1997) and Marine Research Consultants (2000) (Figure 24). Like the earlier studies, salinity and temperature data show only slight variations across the pond, indicating that the pond is relatively well-mixed with respect to groundwater inputs. Silica concentrations were similar to those observed by Brock and Kam (1997), suggesting that groundwater inputs to the pond were similar during these two studies. Other parameters show significant variability between surveys, likely due to effects of biological processes, but many of the values fall within the ranges observed previously by Brock and Kam (1997). Some differences suggest that conditions in the pond may have changed somewhat since the 1994-96 surveys: inorganic nutrients (NO3+, NH4, and PO4) were higher, and dissolved oxygen saturations were lower, on many of the recent surveys compared to the Brock and Kam (1997) surveys, and surface waters were cooler and more turbid in the recent surveys than in 1994-1996. Dissolved organic nitrogen and phosphorus concentrations also consistently were higher than observed by Brock and Kam (1997), and generally were significantly lower than those measured by Marine Research Consultants (2000), but as previously noted, dissolved organic measurements may be subject to significant analytical artifacts. Some or all of the increase in turbidity may reflect differences in measurement methods, as *in situ* measurements can differ significantly depending on the type of instrument used, and field and lab measurements also often vary (Hoover pers. obs.). The increases in inorganic nutrients suggest either less complete uptake by pond biota, or increased supply, which would be consistent with the increased NO3+ and PO4 concentrations observed in groundwater from well 4061-01, inland of the pond. However, groundwater NH4 concentrations actually declined in well 4061-01 from 1996 – 2005 (Figure 10, Table 5), and recent concentrations in the pond are comparable to, and often higher than groundwater values. In addition, recent measurements consistently are high at the center of the pond and at the makai sampling site, where values were low in previous studies. These results suggest that NH4 is not being taken up and recycled as efficiently by pond biota as it was in 1994-1996, or that internal pond sources (i.e. pond sediments) are stronger than they were in 1994 - 1996. The existing data are insufficient to resolve the question completely, but the reduced oxygen concentrations observed in some recent surveys do suggest that the ratio of primary production in the pond to respiration may have declined, which would be consistent with the observed increase in inorganic nutrients. If the recent turbidity data are correct, high turbidity may be reducing light availability and limiting production, but the reason for the increased turbidity is unclear, as chlorophyll-*a* concentrations are rather similar between the 1994-6 study and in the recent data, suggesting similar phytoplankton population densities.

Figure 25 uses data from all of the above studies to highlight long-term variations in water quality in Aimakapa pond. Salinity, temperature, pH, and dissolved oxygen have the longest records, spanning 34 – 42 years. Salinity was significantly lower from 1963 – 1972 than from 1994 – 2005 (Table 9), consistent with the reduced groundwater inputs to the pond in recent years suggested by Oki et al. (1999). The single temperature measurement from 1971 is similar to values observed in 1994-1996, but temperatures declined significantly between 1994-1996 and 2004-2005 (Table 9). Temperatures in well 4061-01, inland of the pond, did not change significantly over this time period (Figure 10, Table 5), so the decline seems likely to be related to climatic factors rather than changing groundwater quality unless the source of groundwater to the pond changed over this time period. Dissolved oxygen may have been higher in 1971 than in recent years, but dissolved oxygen varies significantly on short time scales due to biological

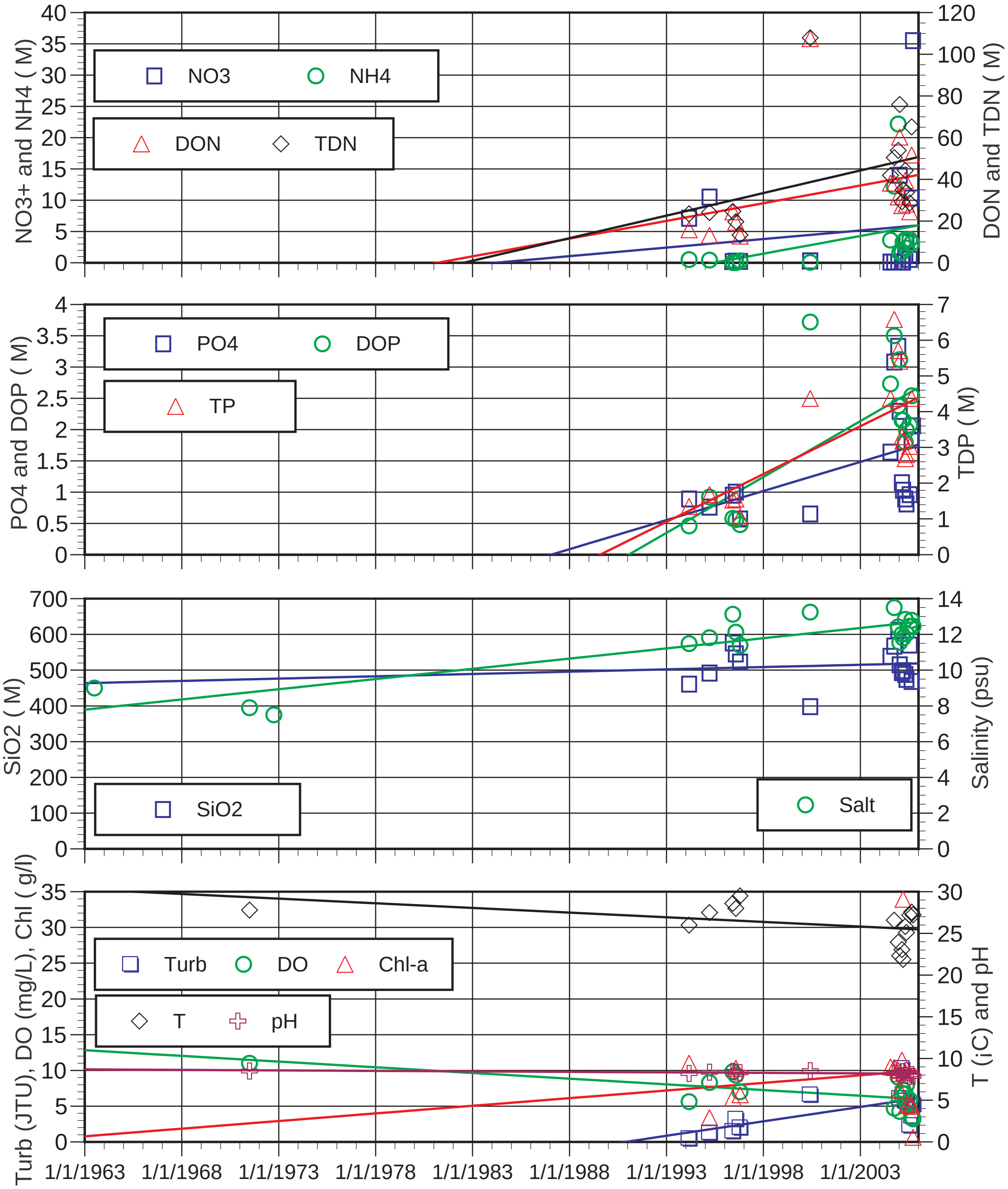


Figure 25. Surface water quality data from sites near the center of Aimakapa pond. Data from Sparks (1963), Kikuchi and Belshe (1971), Maciolek and Brock (1974), Brock and Kam (1997), Nance (2000), Bienfang (unpubl.), and Wolff (unpubl).

processes, so the single data point in 1971 is insufficient to demonstrate a long-term trend. Recent 2004-2005 data obtained by Bienfang (unpubl.) generally are somewhat lower than values from 1994-1996 obtained by Brock and Kam (1997), but the trend is not statistically significant (p = .08, Table 9). The pH of surface waters has not changed significantly over the period of measurement.

Table 9. Linear regression results for Aimakapa pond water quality data plotted in Figure 25. Statistically significant slopes ($p \leq 0.05$) are shown in bold.

	units	Interval	slope	R^2	p
NO3+	µM/y	94-05	0.274	.018	.611
NH4	µM/y	94-05	0.565	.191	.090
DON	µM/y	94-05	1.70	.106	.219
TDN	µM/y	94-05	2.16	.155	.131
PO4	µM/y	94-05	0.093	.238	**.047**
DOP	µM/y	94-05	0.179	.546	**.001**
TDP	µM/y	94-05	0.268	.498	**.002**
SiO2	µM/y	94-05	1.29	.012	.691
Salinity	psu/y	63-05	0.114	.774	**.000**
Salinity	psu/y	94-05	0.039	.074	.308
Turb	JTU/y	94-05	0.404	.480	**.006**
DO	mg/L/y	71-05	-0.159	.380	**.011**
DO	mg/L/y	94-05	-0.207	.214	.083
T	°C/y	71-05	-0.112	.189	.092
T	°C/y	94-05	-0.268	.289	**.039**
pH	pH/y	71-05	-0.012	.202	.070
pH	pH/y	94-05	-0.021	.179	.103
Chl-*a*	µg/L/y	94-05	-7.17	.093	.363

Nutrients, turbidity, and chlorophyll-*a* have records spanning 11 years, from 1994 to 2005. Significant increases occurred in PO4, DOP, TDP, and in turbidity, but as previously noted, increases in DOP and TDP probably are due to analytical artifacts. DON and TDN also increased, but the increase was not statistically significant due to the anomalously high values obtained in 2000 by Marine Research Consultants (2000). NH4 clearly increased from 1994 to 2005, but the trend is not statistically significant due to the large scatter in the 2004-2005 data. NO3+ is extremely variable throughout the record (range: below detection (<0.1 µM) to 36 µM) and no significant trends are evident. Turbidity increased significantly (Table 9), but no trends were observed in chlorophyll-*a* concentrations. These results all are consistent with the expectation that nutrient loading to the pond has increased due to contamination of groundwater upslope of the pond, but any biological response has not been sufficient to produce significant changes in the measured water quality parameters. As noted above, the increased turbidity and decreased dissolved oxygen concentrations may reflect a shift in the biological functioning of the pond, but more detailed study would be needed to discriminate between the effects of external forcing and internal biological and physical processes on pond ecosystem function.

In addition to their water quality sampling, Brock and Kam (1997) collected sediment samples from three sites in Aimakapa pond for metal and pesticide analyses, as well as two adult grey mullet or ama‘ama (*Mugil cephalus*) and two milkfish or ‘awa (*Chanos chanos*) that were collected for tissue analyses. Tissue subsample composites from the ama’ama and ‘awa and one of the sediment samples (surface sediment from the center of the pond) were tested for four standard EPA screening schedules covering a total of 159 analytes, including 26 chlorinated pesticides, 21 organophosphate pesticides, 53 volatile organic compounds, and 59 acid/base/neutral extractables, with no analytes detected [Appendix 4 in Brock and Kam (1997)]. Elemental analysis of the three sediment samples and the fish tissue composites also produced no significant evidence of contamination, although there were large differences in the results from sediment samples obtained in 1994 from sites near the mauka and makai pond margins, and in a 1997 sample that was obtained from the center of the pond that may have been due to analytical problems (Brock and Kam 1997). Mercury was not analyzed in the 1994 samples, but was detected in the 1997 sediment sample, and low concentrations (technically below the method detection limit) were found in the tissue composites. Even if present, mercury may not reflect anthropogenic contamination, as mercury commonly is elevated in environmental samples from areas affected by deposition of volcanic emissions. Arsenic also was detected at significant concentrations in both the 1997 sediment sample and in the fish tissues, but Brock and Kam (1997) argue that these results also probably reflect natural sources. Other elements analyzed all appear to be within ranges consistent with natural sources (Brock and Kam 1997). Overall, these data suggest that contaminant inputs to Aimakapa pond prior to 1996 –1997 probably were not significant.

Aiopio pond

Like Kaloko pond, under State of Hawaiʻi water quality criteria Aiopio pond would be considered a developed estuary. Aiopio pond thus would be subject to the same water quality criteria noted above for Kaloko pond, although the much smaller size of Aiopio pond and differences in the pond ecosystems suggest that the pond might have a much different response to contaminant inputs. The only water quality data available from Aiopio pond are from Kikuchi and Belshe (1971) who noted that water temperature was 23.4°C, pH was 8.6, and the dissolved oxygen content was 7 ppm, and that salinity varied from "about 12 ppt at low tide to 27 ppt at high tide", indicating both significant groundwater inputs to the pond and rapid exchange with the offshore ocean. The pH measurement is considerably higher than would be expected for normal mixtures of seawater and brackish groundwater, but the measurement may not be reliable given the poor precision and accuracy available from field measurements of pH in 1971. The other parameters appear to be within 'reasonable' ranges, but the lack of additional data, particularly from more recent surveys, precludes any meaningful assessment of current conditions in the pond.

C.2.a.iv. Wetlands

There are no specific numeric criteria for water quality in wetlands. There are a few data on salinities in wetlands around Kaloko pond - in 1988, salinities at four sites ranged from 9.5 -26.0 ppt (Chai 1991), and in 1994, Oki et al. (1999) measured salinities ranging from about 10 to 34 ppt. Variable salinities are to be expected in coastal wetlands affected by groundwater, so the values observed do not provide any significant insights into the quality of water in wetland areas, except to demonstrate the presence of brackish groundwater that might carry contaminants.

C.2.a.v. Rocky and sandy intertidal

Intertidal rocky shoreline

Rocky intertidal areas along KAHO's coastline are designated Class II by the State of Hawaiʻi and are subject to specific criteria relating to deposition of flood-borne sediment. These criteria are related to water quality through the potential presence of fine, organic-rich sediment in overlying waters and the subsequent deposition of that sediment on intertidal areas. No data are available for quantitative evaluation of these criteria in KAHO's rocky intertidal areas, but given the general lack of sediment sources and transport mechanisms in and adjacent to the park, it seems unlikely that the criteria have been violated to any significant extent in the recent history of the park.

Intertidal sand beaches

Sand beaches in KAHO also are designated Class II by the State of Hawaiʻi and are subject to specific criteria relating to deposition of flood-borne sediment that are similar to those noted above for rocky intertidal areas. Although no data are available for evaluation of these criteria on KAHO's beaches, it seems unlikely that sufficient fine sediments have been present in KAHO's coastal waters to result in significant violations.

C.2.a.vi. Coastal waters

Planktonic and pelagic resources

The overall quality of KAHO's coastal waters probably is most affected by inputs of brackish groundwater along the shoreline, with less significant effects associated with inputs of contaminants from boats and individuals using park waters, and from contaminants from Honokohau Harbor. Few data are available to quantify the actual degree of impact associated with each of these sources, but the persistent, strong natural discharge of brackish ground water along the shoreline (Fischer et al. 1966, Adams et al. 1969, Parrish et al. 1990, Hoover pers. obs. 2005), and offshore at shallow subtidal reef depths (Basch unpubl. data) suggests that this will be a major factor. In contrast, contamination from boats and people in the water is episodic and localized, and should be diluted rapidly, and while human activities and biological processes within Honokohau Harbor affect water quality there (Bienfang 1980; Bienfang and Johnson 1980; Bienfang 1983), the harbor itself is outside of park waters, and contaminated harbor waters entering park waters near the harbor mouth also should be diluted fairly rapidly. Contamination from these sources seems unlikely to affect park waters significantly unless contaminants are not dispersed by dilution, for instance if pesticides or heavy metals accumulate in benthic biota.

- Groundwater discharge

Significant groundwater discharge to KAHO coastal waters was observed by Fischer et. al. (1966) and Adams et al. (1969), and more recently in 2002 and 2003 by a research group from the Massachusetts Institute of Technology using infrared imaging (Figure 26). Groundwater in West Hawaiʻi typically is significantly colder than coastal ocean surface waters: for instance, in

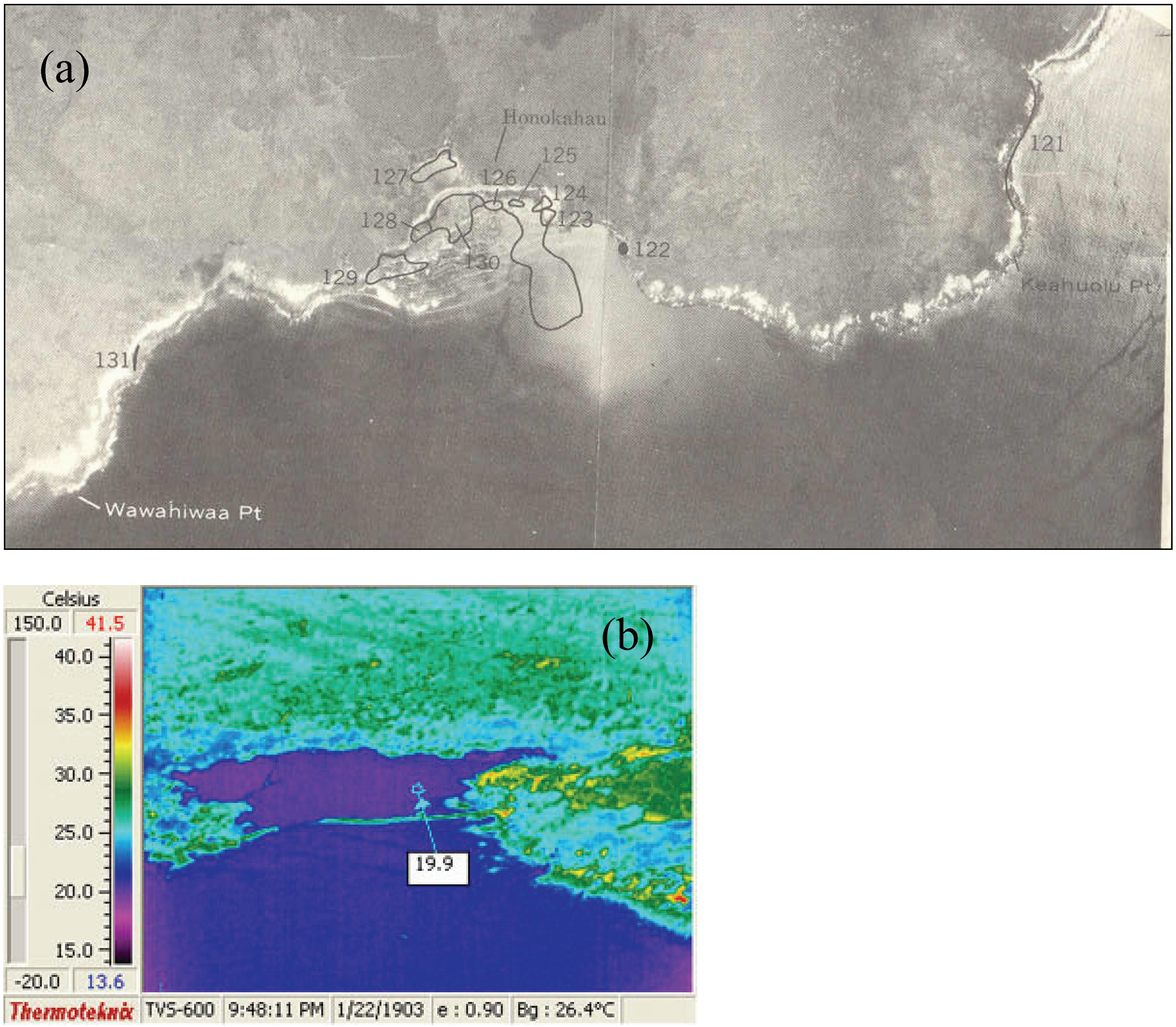


Figure 26. (a) Freshwater intrusions/springs (light areas) in the KAHO area in 1966 (Fischer et al. 1966). (b) Thermal image of Kaloko Fishpond and Bay taken by a FLIR (Forward Looking InfraREd) camera in 2003. Lower temperatures indicate presence of cooler groundwater (http://web.mit.edu/trex/www/trex4/trex03rsrch.htm)

1996 groundwater temperatures in KAHO monitoring well 4161-02 (Figure 9) were 18.2 – 19.8°C, with corresponding salinities of 4.7 – 4.9 ppt, while surface ocean temperatures offshore of KAHO vary seasonally from about 23° – 27°C (Juvik and Juvik 1998). Groundwater discharging at the coast contains more seawater than the groundwater measured at well 4161-02, so temperatures probably are somewhat warmer than those observed in well samples, although some of the diluting seawater comes from subsurface seawater flowing inland and mixing with overlying brackish groundwater, and subsurface seawater is significantly colder than surface seawater (Oki et al. 1999). Total freshwater discharging to KAHO coastal waters has been estimated to be on the order of 3.4 – 6.5 million gallons/day based on numerical modeling of groundwater dynamics in the region (Oki et al. 1999). However, actual discharge to KAHO waters has not been studied quantitatively and may be significantly different depending on local hydrology. A cooperative study between NPS and USGS has begun to address water quality and circulation in KAHO coastal waters, and preliminary results show a complex pattern of freshwater and subterranean ground water discharges across the reef off KAHO (Gibbs et al. 2004), with temperature and salinity variations indicative of groundwater effects even at 14 m depths off of Kaloko and Aimakapa ponds (Storlazzi and Presto 2005). A new project in the park will be using quantitative analysis of infrared aerial images and chemical characterization of groundwater to quantify groundwater discharge to KAHO coastal waters (Craig Glenn pers. comm. 2005).

Both the quantity and quality of groundwater reaching KAHO coastal waters are affected by natural and human activities that affect recharge within and upslope of the park (i.e. withdrawals and additions, see *Groundwater* above), but water quality also is affected by processes occurring in subaerial groundwater exposures in the park, i.e. in Kaloko and Aimakapa fishponds, Aiopio fishtrap, and in the numerous anchialine pools in the park. Groundwater passing through these features is warmed and chemically altered by biogeochemical processes in the pools and by exposure to the atmosphere. As a result, the quality of groundwater reaching coastal waters may vary significantly from that found in monitoring wells. In addition to variability associated with spatial variability in upslope processes (contaminant inputs and reactions in subaerial pools and ponds), groundwater quantity and quality probably vary temporally, both on long time scales due to changes in natural recharge and human impacts, and on short time scales, such as those associated with storm events and tidal cycles. Groundwater heads in KAHO are small, with water levels inside the park typically only 1 –2 feet above mean sea level (Oki et al. 1999), so storm events might result in significant changes in groundwater heads and associated discharge, and Oki et al. (1999) noted that groundwater flows near the coast probably vary significantly with tidal level, with flows actually reversing and flowing inland during high tides.

- Water quality

Water quality data for KAHO coastal waters are quite limited. A significant amount of synoptic data are available from Honokohau Harbor for two time periods (1971 – 1975 and 1982), but the harbor itself is not within park waters and water quality inside the harbor probably has minimal effects on park waters except in the area immediately adjacent to the harbor entrance. Historical water quality near the mouth of the harbor generally has been close to that observed in comparable coastal waters (Oceanic Foundation 1975; Bienfang 1983), and dilution should disperse pollutants effectively in KAHO's coastal waters (Dollar and Atkinson 1992), so historical harbor data likely are of only limited value in assessing the quality of KAHO's coastal waters. South of the park, the nearest long-term sampling sites are at Kailua pier in Kailua Harbor (with data from January 1973 to December 1998), and at Banyans surf site (July 1989 to December 1998). Long-term data also are available from the Keahole Point area north of the park, from monitoring conducted by the Natural Energy Lab of Hawai'i (NELHA) (National Park Service 2000), but all of these sites are too distant to be useful in addressing the status of KAHO park waters.

Within the park, the most useful synoptic and time-series data in coastal waters are from studies conducted by Brock and Kam (1997), and by Marine Research Consultants (2000). Brock and

Kam (1997) analyzed water samples on six occasions from March 1994 – October 1996 at three sites along onshore-offshore transects off of Kaloko and Aimakapa fishponds (Figure 9), including deep samples from the two offshore sites in each transect. Marine Research Consultants (2000) collected samples on one occasion (in May – June 2000) from seven sites along each of two transects (Figure 9). A water quality monitoring program has been initiated in park coastal waters adjacent to the Kohanaiki development project, but data are not yet available from that study (Daniel and Minton 2004, Eadie 2005).

Brock and Kam's (1997) coastal water quality data are plotted in Figures 20 and 24. Transect data off of Kaloko pond (Figure 20) are noteworthy for the very low salinities in nearshore samples and the correspondingly elevated concentrations of silica, nitrate and phosphate, indicative of large inputs of groundwater. The sudden drop in salinity in all transects at the nearshore site compared to offshore samples and the adjacent fishpond site suggests a persistent, strong plume of groundwater discharging from a point near the transect, but not from the fishpond itself. A strong 'stream' of cold, brackish groundwater has been observed discharging to nearshore waters from a site just south of Kaloko pond on several dates between 2002 and 2005 (Hoover pers. obs. 2005, Larry Basch pers. comm. 2005). Waters immediately offshore of the fishpond wall also are noticeably colder than adjacent coastal waters, and exhibit visible evidence of freshwater additions (i.e. the Schlieren effect), and reef morphology around the discharge suggests that it is a persistent feature (Hoover pers. obs. 2005). While the presence of significant groundwater in the nearshore samples causes large changes in water quality, most of the changes are due to simple mixing of groundwater and seawater, with very little due to biological or other chemical processes (Brock and Kam 1997). Water quality in samples from the two offshore sites generally is very similar and shows only slight evidence of freshwater inputs. These results are consistent with the rapid dilution expected in open coastal waters in Hawai'i.

Unlike the Kaloko transect data, data off of Aimakapa pond (Figure 24) do not show large along-transect gradients, indicating that despite the proximity of a large reservoir of low-salinity water in Aimakapa pond, discharges of pond water through the sand berm are slow relative to nearshore mixing rates. Some input of fresh water is evident in slight depressions in salinities and corresponding increases in silica and nutrients, particularly at the nearshore site, but freshwater discharging from sources other than Aimakapa pond could be as or more important than discharges from Aimakapa pond. Overall, water quality along the Aimakapa transect is rather similar to that seen at the offshore sites in the Kaloko transect. Water quality at both sites also shows some temporal variability on the timescale of sampling (2 – 14 months), even at the offshore sites that should be least affected by groundwater inputs.

Marine Research Consultants (2000) measured coastal water quality once in May-June 2000 along a transect off of Kaloko pond, but sampled at closer intervals (1, 3, 10, 25, 50, 100, and 150 m offshore) than Brock and Kam (1997). The Marine Research Consultants (2000) data are plotted with the Brock and Kam (1997) data in Figures 20 and 24 to facilitate comparison between the datasets. One striking difference in the 2000 Kaloko transect data is the very reduced groundwater signal in nearshore samples. One possible explanation is that groundwater discharge was reduced significantly, at least at the time of sampling, compared to 1994-96. This interpretation is consistent with salinity and silica data from Kaloko and Aimakapa ponds that suggest reduced groundwater inputs in 2000, but differences in transect locations might also be responsible (Figure 19), as the groundwater discharge noted by Hoover (pers. obs. 2005) was strongest in the area just south of the Brock and Kam (1997) transect. Most of the other differences in water quality in the 2000 data are consistent with reduced groundwater impacts in general in 2000, whether due to reduced discharge or transect location. Parameters that do not follow simple dilution trends, such as dissolved oxygen and pH, are controlled primarily by biological activity and commonly vary significantly on short timescales, particularly in estuarine systems.

The 2000 data from the transect off of Aimakapa pond show reduced salinities in nearshore samples very similar to those seen in the Kaloko transect, with the lowest value at the 25 m site. However, data from the 10m and 100m sites are quite similar to the 1994-96 data from Brock and Kam's 10m and 100m sites, so it is not possible to determine whether the 25 m feature also was present in 1994-96. The reduced salinities at nearshore sites could be due partially to discharges of Aimakapa pond water through the sand berm, but groundwater has been observed discharging from shallow springs on the reef platform seaward of the fishpond, and some contribution from groundwater seems likely based on the increased nitrate in nearshore samples compared to offshore and Aimakapa pond samples (Figure 24). Variations in most of the other water quality parameters can be explained largely by simple mixing between groundwater and seawater, although dissolved oxygen is elevated at most of the offshore sites in the 2000 transect and there is a small nearshore peak in the chlorophyll-*a* data, both of which suggest stimulation of algal growth by nutrients, likely from the groundwater. In fact, dissolved oxygen and chlorophyll-*a* trends are quite similar along both the Kaloko and Aimakapa transects, and both contain chlorophyll-*a* peaks at the 50 m sites, indicating that there was an extended nearshore zone where biological uptake was rapid enough to allow significant algal growth despite the rapid dilution of groundwater inputs in this region.

While the Brock and Kam (1997) and Marine Research Consultants (2000) data provide only a very limited view of water quality in KAHO coastal waters, the data are consistent with the expectation that groundwater has a significant effect on nearshore water quality, but that it is diluted rapidly so that water quality rapidly approaches more typical oceanic conditions with increasing distance from shore. Because of the rapid dilution and the presence of significant discharges of groundwater that already contains relatively high concentrations of nutrients, the increased nutrients observed in park groundwater probably have had no significant effects on KAHO's coastal waters.

Subtidal benthic resources

- Reef flats and reef communities

KAHO's reef communities are designated Class II by the State of Hawaiʻi and are subject to specific criteria relating to deposition of flood-borne sediment, within-sediment redox potential, and grain size. Narrative criteria also stipulate that "no action shall be undertaken which would substantially risk damage, impairment, or alteration of the biological characteristics of the areas named herein". As noted above for KAHO's rocky and sandy intertidal areas, sediment deposition is unlikely to be a significant issue in KAHO's coastal waters.

- Soft bottom communities

Soft bottom communities in KAHO’s coastal waters would be designated Class II by the State of Hawai‘i and would be subject to specific criteria for within-sediment redox potential. Only relatively small patches of primarily coarse sand sediment deposits have been identified in park coastal waters (Parrish et al. 1990), although observations of garden eels in sands at the base of the deep coral slope suggest that sands in that area may contain a significant quantity of fine-grained material (Larry Basch, pers. comm. 2005). However, the generally good quality of coastal waters and the very low inputs of sediment and organic material to coastal waters suggest that these and any other areas that might qualify as soft-bottom communities would be in good condition.

C.2.b. Ecosystem effects

C.2.b.i. Groundwater/anchialine pools

Although groundwater contains biological resources, no data are available on the relationships between groundwater ecosystems and groundwater quality. However, anchialine pools are surface expressions of groundwater, so anchialine ecosystems may provide insights into water quality effects on both anchialine and groundwater ecosystems.

Anchialine ecosystems and associated species still are poorly understood (Brock 1985). Anchialine and other mixohaline fauna generally seem to be tolerant of a fairly wide range in water quality, at least with respect to salinity and nutrients (Brock and Kam 1997). Tolerance to other contaminants is less well known. Oil and grease pollution in an anchialine pool near Honokohau Harbor resulted in the disappearance of endemic shrimp from the pool, but these pollutants likely would not be transported effectively through groundwater due to sorption of contaminants to solid surfaces.

The historical water quality data discussed above show that groundwater quality, and thus anchialine pool water quality, probably has changed significantly due to human activities upslope of the park. Brock and Kam (1997) and Nance (2000) argue that changes in salinity and nutrient concentrations like those occurring in park groundwater are unlikely to affect anchialine ecosystems because salinities and nutrient concentrations vary widely in natural anchialine systems, and because nutrients normally are present at relatively high concentrations and are not limiting to photosynthesis. However, mixing diagrams in Brock and Kam (1997) show significant nutrient depletion in many pools, with a few having very low nutrient concentrations. Nutrient additions to these pools might stimulate plant production and impact the pond ecosystem. Perhaps more importantly, the presence of anthropogenic nutrients in park groundwater shows that groundwater is affected by upslope contamination, which may include other contaminants such as pesticides, solvents, and pharmaceuticals. The effects of these types of contaminants on anchialine systems are not known, and while Brock and Kam (1997) argue that the apparently healthy fauna in many pools argues against significant contamination of any sort, the effects of chemical contaminants may be subtle and difficult to identify, particularly given our current poor understanding of these ecosystems.

While sediment inputs to anchialine pools in the park apparently are low, a number of anchialine ponds in KAHO have been degraded by sedimentation from sources in or adjacent to the pools. The primary cause seems to be accumulation of organic matter produced within the pond or from adjacent terrestrial (often alien) vegetation. Accelerated sedimentation in pools reduces water exchange and leads to premature pool senescence (Brock and Kam 1997).

C.2.b.ii. Ponds

Kaloko pond

Marine Research Consultants (2000) observed that the relatively small fraction of groundwater normally present in Kaloko Fishpond, and the free exchange of pond waters with offshore waters would tend to minimize any adverse effects that contaminated groundwater might have on this fishpond (Marine Research Consultants 2000). While this might be a reasonable argument if these conditions persisted in the pond, restoration of the fishpond wall probably has reduced exchange with offshore waters and increased the residence time of groundwater in the pond (Figures 20 and 21a), thus increasing the impacts of any contaminants reaching the system. As a result, the potential for groundwater contaminant impacts on the Kaloko pond ecosystem cannot be ignored.

Although groundwater is less important in Kaloko than in Aimakapa pond, groundwater inputs to Kaloko pond do stimulate pond productivity and thus play a significant role in structuring the pond ecosystem. Some changes in groundwater inputs probably already have occurred due to upslope withdrawals from wells and due to inputs in the form of domestic and industrial wastewater, including storm runoff from developed areas, and further changes are likely as development in the area continues. Oki et al. (1999) estimated that natural groundwater fluxes in the park prior to development (i.e. prior to groundwater withdrawals from the coastal and upslope aquifers) were on the order of 6.6 million gallons per day (Mgal/d). Their groundwater model showed that by 1978, withdrawals probably only reduced flow through the park by 0.07 Mgal/d, or 0.1% of the natural flow, but that by 1998, pumping could have reduced flows through the park by up to 47%. Actual reductions probably were less, as most wells were not being pumped at full capacity, but significant reductions probably did occur. Nance (2000) used Oki et al.'s (1999) results, their own estimates of enhanced recharge due to wastewater disposal and irrigation, and their own water quality data to estimate the changes in groundwater flow and quality that would be associated with the Phase III-IV development in the Kaloko Industrial Park development upslope of KAHO. For the worst-case scenario, groundwater flow was reduced by an additional 7%, groundwater salinity increased by 10%, and nitrogen concentrations increased by 45-50%. The impacts of these types of changes on the Kaloko pond ecosystem in general will depend on its sensitivity to groundwater supply and quality. The projected changes in groundwater salinity are within the range of natural variability observed in Kona coast anchialine systems, suggesting that the pond ecosystem may be relatively tolerant of the changes (Nance 2000), but the effects of changing groundwater flow and quality on a specific system are difficult to predict. Kaloko pond historically appears to have been nitrogen-limited, so increased nitrogen loading could well increase algal productivity, and potentially alter the structure of the algal community. For instance, macroalgae commonly require higher nitrogen subsidies than phytoplankton and other aquatic plants, and thus often respond preferentially to increased nitrogen loading. Kaloko pond has been the site of an invasion of the alien macroalga *Acanthophora spicifera* since at least 2000 (Marine Research Consultants 2000), but the effects of groundwater nitrogen on the success of this species are not known, and other factors may be equally or more important, such as palatability to grazers or reproductive factors. While the importance of groundwater nitrogen to the success of *A. spicifera* is not clear, this type of shift to macroalgal dominance will change the quantity and quality of food available to grazers, affecting the entire food web. Unfortunately, accurately predicting the impacts of increased nitrogen loading on higher trophic levels would require an understanding of pond ecosystem dynamics that is not now, and might never be, available. Other impacts associated with changing groundwater quality might also occur if contaminants such as pesticides, solvents, and pharmaceuticals reach pond waters. Given that one of the goals of the restoration of Kaloko pond is to restore ecological function and to maintain the pond in the traditional Hawaiʻian manner for fish production (Bond and Gmirkin 2003), preventing groundwater contamination upslope of the pond seems like a critical priority.

Aimakapa pond

Although Marine Research Consultants (2000) argued that fishpond floor sediments impede groundwater flow into KAHO's fishponds, protecting the ponds from groundwater contaminants, this argument clearly does not 'hold water'. Groundwater makes up a significant fraction of the water in both fishponds, and contaminants seem likely to be concentrated near the water table where flow into ponds is unimpeded by sediments. Aimakapa pond in particular consistently contains a very high proportion of groundwater (~83% during the Marine Research Consultant's 2000 sampling), so groundwater quality clearly will play a major role in determining pond water quality and ecosystem function. Marine Research Consultants (2000) also argued that the elevated nitrogen observed in park groundwater would have no significant impacts on the Aimakapa ecosystem, because the pond was a "nutrient saturated system". This conclusion is at best oversimplistic and appears to be deliberately optimistic – while productivity in the pond certainly is high, inorganic nitrogen was present in pond waters only at extremely low concentrations, so additional nitrogen almost certainly would fuel additional primary production. The additional production might or might not occur as a "significant" increment to existing production, but other effects might also result from the changing nutrient subsidy, such as changes in the types and relative abundances of phytoplankton, macroalgae and aquatic plants, with attendant impacts on the entire pond ecosystem. A significant concern in eutrophic systems frequently is dissolved oxygen depletion in bottom waters: Aimakapa pond has been the site of both an avian botulism outbreak in 1994 (Morin 1998), and a fish kill in 2003, both of which may have been related (directly or indirectly) to low oxygen levels (Bhambare 1996; Sallie Beavers, pers. comm. 2005). However, even if the additional nitrogen did not produce unacceptable impacts by itself, the presence of nutrient contamination clearly demonstrates that wastewater from upslope developments is reaching the pond, indicating that other contaminants could also be present. Very limited testing of park groundwaters has not identified extensive contamination by heavy metals or organochlorine pesticides, but groundwater flow in the park is likely to be complex (see *Groundwater*), so contaminated water may not have been sampled, and many contaminants have not been tested for. Thus, the impacts of upslope alterations of groundwater quantity and quality are not known but could have significant effects on the pond ecosystem. Aimakapa pond contains unique habitat and fauna, including endangered Hawaiʻian birds that may be particularly vulnerable to contaminants reaching the pond. As for Kaloko pond, maintaining the viability of the pond ecosystem requires maintaining the quality of groundwater in upslope areas to avoid potentially irreversible damage to the pond ecosystem.

Aiopio pond

As noted previously, there are almost no data on water quality in Aiopio pond, or on biota in the pond. Thus no specific conclusions can be reached on the vulnerability of the pond ecosystem to changes in water quality. However, the small size of the pond and the apparently rapid flushing due to groundwater inputs and tidal cycling suggest that susceptibility to contaminant inputs will be relatively low.

C.2.b.iii. Wetlands

No chemical water quality data are available for wetland areas, and there are no data on aquatic ecosystems in wetland areas except for plants (e.g., Canfield 1990, Pratt 1998). Available data show that salinity is highly variable, as would be expected due to localized groundwater inputs from seeps and springs. Because wetlands commonly are highly productive, and productivity probably is maintained to a significant degree by nutrients derived from groundwater, wetlands may be particularly susceptible to adverse impacts of contaminated groundwater. Wetlands provide significant foraging habitat for resident and transient waterbirds in the park, so contaminants in wetlands may also affect birds, including endangered Hawaiʻian coots and stilts.

C.2.b.iv. Rocky and sandy intertidal

No chemical water quality data are available for rocky and sandy intertidal areas. Observations of intertidal ecosystems by Parrish et al. (1990) suggest that there were no obvious indications of ecosystem degradation related to water quality. The most likely source of contaminants in intertidal areas would be groundwater discharging to tidepools or through rocky or sandy substrates. Sessile flora and fauna might accumulate pollutants if these were present in groundwater, resulting in pollutant transfer to higher trophic levels, such as endangered waterbirds and green sea turtles. However, no testing has been conducted in these areas, and in general, rocky and sandy intertidal areas should be relatively insensitive to contaminant inputs due to the short residence time of groundwater and seawater in these areas.

C.2.b.v. Coastal waters

Planktonic and pelagic

The response of planktonic and pelagic organisms to aquatic pollutants depends heavily on pollutant concentration and duration of exposure. Because the biggest potential source of contaminants to coastal waters probably is groundwater, ecosystem impacts probably will depend primarily on the balance between groundwater supply and mixing in receiving waters. Groundwater is less dense than seawater, and in the absence of mixing by wind and waves, groundwater will float on underlying seawater, forming laterally extensive but relatively thin layers. If calm conditions allow these layers to persist, gradual mixing between the surface layer and underlying seawater can result in a mixture of intermediate salinity that is suitable for the growth of marine phytoplankton, which then may grow rapidly in response to the nutrients contributed by groundwater. The presence of toxic contaminants under these conditions also could result in significant effects on phytoplankton populations due to increased concentrations and exposure times, and additional bottom-up effects on higher trophic levels. While these conditions occasionally may be found in enclosed bays or harbors (and in fishponds and anchialine pools), they are extremely rare in open coastal settings in Hawaiʻi. As a result, although groundwater additions clearly alter coastal water quality in the immediate area of discharges, there probably is relatively little biological impact under most conditions (Dollar and Atkinson 1992; Dollar and Andrews 1997).

Subtidal benthic

As noted previously, the most significant pathway for contaminants reaching KAHO coastal waters probably is through groundwater discharge. Most of the groundwater discharge in the park probably occurs near the coastline, and because groundwater is more buoyant than seawater, groundwater floats to the surface and likely has little effect on subtidal benthos. Some groundwater does discharge subtidally through rocky and sandy substrates, so flora and fauna in these areas may be affected by groundwater quality, but no quantitative surveys have been performed to locate subtidal discharges or to assess possible impacts on benthic resources. Previous surveys of benthic resources generally concluded that benthic resources appeared healthy and typical of other West Hawaiʻi coastal areas (Parrish et al. 1990; Marine Research Consultants 2000). One exception is the observation of an invasive macroalga, *Acanthophora spicifera*, at a shallow water site that appears to be near Honokohau Harbor (site *A.s.* in Figure 9) (HCRI 2000). Macroalgae often are observed to thrive at intertidal and subtidal sites where ground or surface water discharges occur, due primarily to elevated nitrogen concentrations in these waters. Groundwater in the Honokohau Harbor area is enriched in nitrogen (Bienfang and Johnson 1980), and may be further enriched by the presence of sewage effluent that recharges groundwater at an infiltration site upslope of the harbor (Parsons et al. 2005).

C.2.c. Human health effects

Human health effects associated with water quality could result either from disease associated with water-borne pathogens, or from assimilation of toxic substances via consumption of contaminated aquatic organisms.

C.2.c.i. Groundwater

Groundwater in the park is not used for human consumption or for other purposes that might result in human contact, so groundwater does not pose a direct threat to human health. Groundwater does make up a significant portion of the water in the park's anchialine pools and in Aimakapa fishpond, and is present in Kaloko and Aiopio ponds and in portions of the park's coastal waters. Potential human health effects in each of these areas are discussed briefly below.

C.2.c.ii. Anchialine pools

Anchialine pools have been used for a variety of purposes that may have human health implications. Bathing in pools may expose humans to bacteria in contaminated groundwater, and may increase the risk of disease transmission between users via bacteria left in the pool (Brock and Kam 1997). Some of the larger anchialine pools were used as recently as 1972 for aquaculture, and harvesting of cultivated or natural pool resources [e.g. shellfish (hihiwai)] (Brock and Kam 1997) carries a risk of ingestion of toxins accumulated by the organisms. There have been no analyses of water quality in pools or of organism tissues that would allow assessment of this risk, but the generally good water quality likely in these areas suggests that the risk is low.

C.2.c.iii. Ponds

Kaloko and Aimakapa fishponds are relatively unattractive for contact recreation due to the relatively murky, smelly water in Aimakapa pond and to hazards in Kaloko pond, including often silty low visibility water, sharp oyster shells and stinging fire worms (Morin 1998). As a result, exposure likely is rare and the potential for human health problems due to water-borne pathogens probably is minimal. No data are available on fishing or other harvesting from Aimakapa pond, but some fishing apparently does occur in Kaloko pond based on the presence of fishing line in the pond (Morin 1998), so there is potential for health effects if contaminated organisms are harvested. To date, very limited analyses of park groundwaters, sediments in Kaloko and Aimakapa ponds, and organism tissues in Kaloko and Aimakapa have not identified any significant contamination that would represent a human health threat (Tribble 2003, Wolff unpubl.).

No data are available on fishing or other harvesting from Aiopio pond, but visitor use of the pond (wading, swimming, and snorkeling) and of the adjacent beach has increased dramatically since the park visitor contact station opened (Sallie Beavers pers. comm. 2005). Aiopio pond is located within an area that potentially could be affected by groundwater contaminated by upslope sewage effluent disposal, and there appear to be significant groundwater discharge into the pond (Kikuchi and Belshe 1971), so there may be associated environmental impact and human health issues at this site.

C.2.c.iv. Wetlands

There are no data on the frequency with which visitors or park personnel utilize wetlands in ways that might promote pathogen transfer, but this type of activity seems likely to be rare and human health risks very small. Similarly, while some wetland organisms might accumulate toxic contaminants, there is no evidence to date of significant contamination, and it seems highly unlikely that there is any significant consumption of wetland organisms. Thus, the risk of human health issues related to wetland water quality seems small.

C.2.c.v. Rocky and sandy intertidal

Bacterial contamination might occur in tidepools, but the residence time of water in pools usually is relatively low, so the risk of human health effects seems small. Health effects related to consumption of contaminated organisms also are possible, but probably are negligible. The most likely pathway for consumption of contaminated organisms probably is through shellfish, particularly native limpets, or opihi. However, there is no significant evidence of contamination by toxics in the park in general, and opihi generally occur at low densities due to heavy harvesting pressure and thus probably do not represent a significant food resource in the park at the present time.

C.2.c.vi. Coastal waters

Planktonic and pelagic

Bacterial contamination of coastal waters may occur in association with discharges of contaminated groundwater, or due to discharges of waste from boats or from Honokohau Harbor. Groundwater discharging into Honokohau Harbor probably is contaminated by sewage effluent, and boats inside the harbor have been observed to discharge wastes into harbor waters (Bienfang 1983). However, bacterial contamination inside the harbor was relatively low after initial construction (Bienfang and Johnson 1980), and in the past water quality was shown to improve rapidly as affected water exited the harbor and was diluted by uncontaminated offshore water. Because dilution reduces pathogen concentrations quickly and most pathogens do not persist in salt water, the risk of human health issues probably is low. The risk may be further reduced by the fact that immediately adjacent to the harbor mouth, where pathogen concentrations might be expected to be highest, boat traffic probably discourages swimming. However, there is significant use of the beaches and waters immediately adjacent to either side of the harbor mouth by fishers, swimmers and snorkelers (Larry Basch pers. comm. 2005), and mooring buoys used by SCUBA divers are nearby. In addition, while there are no quantitative data on circulation in the area, the configuration of the coastline around the harbor mouth suggests that water in the area may have a longer residence time, and be diluted less efficiently, than at more offshore sites. Thus, there may be some associated risk of human health issues in this area.

Fishing in coastal waters is allowed, and carries some risk of consumption of contaminated organisms. However, rapid mixing in KAHO's coastal waters minimizes the residence time and adverse effects of contaminants in the water column, so fish and other pelagic organisms seem unlikely to be contaminated significantly within park waters. One possible pathway for transfer of contaminants to humans through fish caught in KAHO coastal waters would be if the fish acquired the contaminants outside of park waters, such as in Honokohau Harbor. The risk associated with this pathway is not known, but some contaminants common in boat harbors (e.g. heavy metals) can bioaccumulate and might result in a human health risk.

Subtidal benthic

Some of the subtidal benthic resources in KAHO probably are harvested for consumption (e.g., octopus, sea urchins and snails are heavily fished in many areas in Hawai‘i). There are no data on contaminants in subtidal benthic resources in KAHO, but the generally good water quality in the park suggests that human health risk is low. As for pelagic resources, the most credible threat probably would be if harbor contaminants are accumulating in benthic organisms outside the harbor, but the magnitude of this threat is not known at this time.

C.3. List of impairments

None of KAHO's coastal water resources are listed on the State of Hawai'i's most recent 303(d) list of impaired waters (Koch et al. 2004).

C.4. List of water bodies with undocumented conditions/status

Although there are limited data for virtually all of the water bodies in the park, at present none of KAHO's waterbodies are monitored sufficiently to establish compliance with water quality standards or to assess confidently the condition of waters relative to ecosystem function. Current studies (e.g., Bienfang unpubl.; Weijerman unpubl.) are collecting valuable data in Kaloko and Aimakapa ponds and in anchialine pools in the park, but these data still likely will not be sufficient to characterize water quality adequately, and they probably will only begin to resolve relationships between water quality and ecosystem function. From a practical point of view, available data and the effectiveness of natural dilution processes suggest that coastal waters and associated resources probably are in relatively good condition and not in need of exhaustive monitoring, although some characterization of groundwater inputs and effects would be useful. Kaloko pond probably also is in reasonably good condition, but conditions appear to be changing significantly as the fishpond wall is restored, and Aiopio pond is effectively uncharacterized. Anchialine pools may be tolerant of variations in water chemistry, so barring the addition of toxic chemicals, they probably do not warrant rigorous monitoring, other than to document status and trends of endemic or endangered species. In addition, because conditions probably are variable due to the short residence time of water in the ponds, they would be very difficult to sample sufficiently to characterize long-term trends. Aimakapa pond, however, is both critical habitat for endangered birds, and is associated with extensive marsh lands. In addition, the long residence time of water in this pond means that changes in water quality very likely would result in responses in the pond ecosystem. Because groundwater plays a critical role in all of the parks aquatic ecosystems, groundwater monitoring seems essential and probably should be expanded. Monitoring in Aimakapa also would be useful, as the long residence time of groundwater probably represents the worst-case scenario in the park with respect to possible impacts on pond ecosystems, and the ecosystem itself is unique and critical for the survival of endangered species. Kaloko pond monitoring may be a lower priority, although re-establishing aquaculture in the pond will require an improved understanding of pond ecosystem response to upland loading, and toxic contaminants clearly would be unacceptable in fish raised for consumption. Some monitoring in and around Aiopio would be useful, as no baseline data are available, and because the area is used heavily for recreation. In particular, the possibility that sewage effluent is discharging in groundwater in the area suggests that nutrient and bacterial monitoring would be useful.

D. ISSUES AND THREATS TO COASTAL RESOURCES

D.1. Coastal development trends

D.1.a. Population & Land use

Population growth and coastal development are major issues in West Hawai‘i and pose potentially significant threats to KAHO’s coastal resources. The area around KAHO has experienced steady population increases over the last 30 years: from 1990 to 2000, population in the State grew by 9%, while the population of North and South Kona grew by about 24% (http://www.hawaii-county.com/planning/konaroads.htm), and more recent data show that from July 1, 2003 to July 1, 2004, Hawai‘i county had the highest growth rate in the State (Gima 2005) (Table 10). Growth-driven changes in land use are increasing urban areas at the expense of conservation and agricultural lands (Figure 27). Rezoned lands around KAHO are being developed for a variety of purposes, including a light industrial complex immediately upslope from KAHO and the Kohanaiki resort/residential development along the coast immediately north of the park. Upslope developments may contaminate groundwater that subsequently flows downslope to the park, and coastal developments also may impact nearby KAHO resources via increases in sediment, nutrient, and other chemical pollutants, introduction of alien species, and through increased visitor use and associated impacts.

Table 10. Population change by county in the State of Hawai‘i (Gima 2005)

	1-Jul-04	1-Jul-03	% Change
Hawaii County	162971	158735	2.7
Honolulu County	899593	893358	0.7
Kalawao County (Kalaupapa)	126	130	-3.1
Kauai County	61929	60736	2.0
Maui County	138221	135796	1.8
State of Hawaii (total)	1262840	1248755	1.1

In addition to general effects associated with new development, population growth will increase impacts of existing developments. For instance, increasing urbanization is likely to result in increased demand on Honokohau Harbor, with attendant increases in visitor and boat traffic, and possibly expansion of the harbor. For instance, a recent development proposal that was provisionally approved by the State would increase the size of the harbor by 300% (Lisa Marrack pers. comm. 2005). Harbor expansion could have a number of direct impacts associated with construction, while increased usage likely would increase impacts in a number of areas, including nutrient and chemical pollutant loading to park waters, marine debris, boat groundings and turtle strikes, underwater noise, introduction of alien algae and invertebrates, and recreational impacts associated with increased fishing, SCUBA and snorkel diving, and use of park moorings.

Increased resident and visitor populations also will result in increased park visitation, with attendant impacts on park coastal water resources. As noted above, visitation is associated with impacts like increased garbage and animal waste and direct inputs of contaminants to park waters. Visitors also may alter the physical structure of anchialine pools and may take items from tidepools and ponds. For instance, because corals in the intertidal zone are conspicuous and can be taken easily without swimming, they are subject to collection as ornamental curios by visitors (Parrish et al. 1990). Native edible limpets are heavily harvested from intertidal areas, and cowries and other large shelled and unshelled (octopus) mollusks also may be collected for food

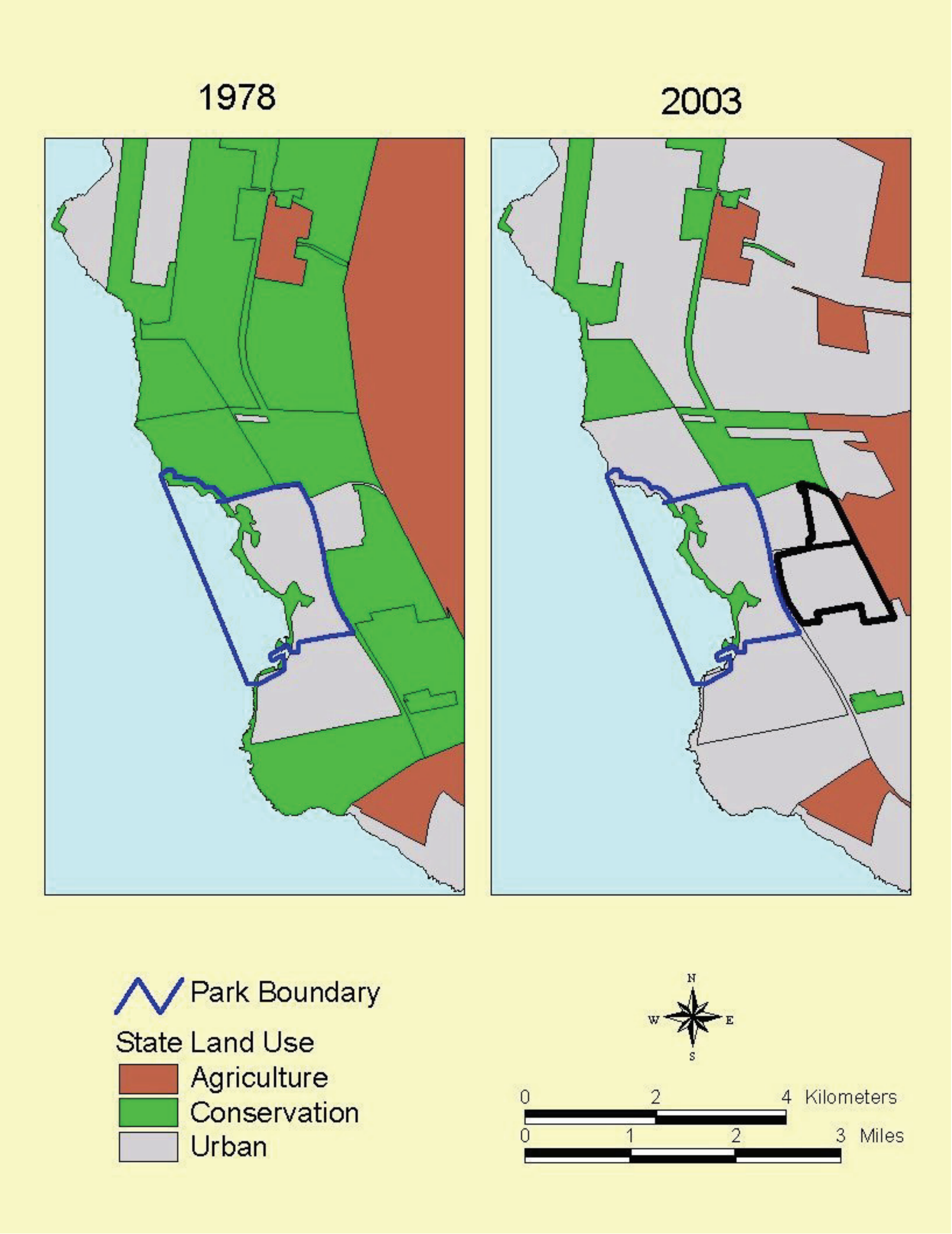


Figure 27. Land use change around KAHO from 1978-2003. Boundaries of industrial park upslope of KAHO are shown by heavy black lines in right panel (NPS unpubl.).

or decorative purposes. The presence of visitors around nearshore habitats may stress turtles, fish, and invertebrates in shallow pools, ponds, and on beaches, and visitor activity around bird habitats in the park can stress or even kill endangered waterbirds (Morin 1998). Recreational fishing in park coastal waters may be impacting KAHO's fish populations, and impacts likely will increase in the future, but neither the park nor the State of Hawai'i collects recreational catch or effort data suitable for assessing the effects of recreational fishing on park resources.

D.1.b. Surface and groundwater withdrawals and additions

Developments adjacent to and upslope of the park affect groundwater flow and quality via groundwater pumping and wastewater disposal, and via increases in impervious surfaces that enhance surface water runoff and infiltration. Oki et al. (1999) modeled groundwater flow in the park and showed that while withdrawals had a negligible effect on flow through the park in 1978, by 1997 there was sufficient pumping capacity to reduce groundwater flow through the park by 47%. Actual reductions probably were considerably lower, as most of the wells in the area were not operating at full capacity, but significant reductions probably did occur, and pumping probably will increase in parallel with population growth and development. Development impacts on recharge probably already are significant, as increases in impervious surfaces and storm runoff collection systems enhance and concentrate contaminated runoff into designated infiltration areas, and wastewater disposal at present primarily is through cesspools and septic systems that result in localized inputs of contaminated water at multiple sites in the watershed. These changes could have potentially major impacts on KAHO's coastal water resources, particularly its anchialine pools and fishponds.

D.2. Nuisance species

Invasive species are a major concern in Hawai'i due to the unusual vulnerability of Hawai'ian ecosystems to alien introductions, particularly in terrestrial ecosystems. Hawai'ian marine ecosystems have been thought to be somewhat more resistant to alien introductions than terrestrial systems due to their lower degree of endemism (Eldredge and Carlton 2002), but most areas have not been surveyed extensively for invasives and the vulnerability of specific ecosystems probably varies. Because KAHO's coastal water resources include both offshore marine waters and brackish inland waters, both terrestrial and marine invasive species potentially can impact coastal water resources. Organisms other than plants or animals that can seriously affect biological resources include microbes and fungi. Viruses are linked to the occurrence of fibropapilloma tumors on green sea turtles (Herbst and Klein 1995); the occurrence and extent of tumors may be related to water quality in certain areas of the main Hawai'ian Islands (Larry Basch pers. comm. 2005). Coral diseases also recently have been documented in Hawai'i, including on Kona reefs, and are believed to be caused by pathogenic microbes or fungi (Larry Basch. pers. comm. 2005).

D.2.a. Terrestrial animals and plants

Mongooses, rats, goats, feral cats, feral dogs, and wild pigs all have been seen in the park (Morin 1998; DeVerse and DiDonato 2005). Herbivores can impact native plants in KAHO's wetland, anchialine pool, fishpond, and coastal strand communities. Predators prey on herbivores, represent a significant hazard to nesting birds, and may harass native animals, such as turtles and monk seals. Traps and eradication measures have been used to try to control populations of some of the animals (Morin 1998).

Alien plants are a significant problem in KAHO, as they are in most developed coastal areas in Hawaiʻi (Pratt and Abbott 1996, DeVerse and DiDonato 2005) (Table 11). Surveys have documented a number of alien species of particular concern in the park (Canfield 1990, Pratt and Abbott 1996b). The ivy gourd (*Coccinia grandis*) is considered to be the greatest threat since it is extremely invasive and disruptive (Pratt 1998). The red mangrove (*Rhizophora mangle*) also is a major threat to coastal resources and has been the subject of extensive removal efforts, particularly around Kaloko pond (Bond and Gmirkin 2003). Unfortunately, an existing mangrove stand north of the park provides a steady supply of propagules that can be transported into Kaloko pond and (less frequently) into nearshore anchialine pools and Aimakapa pond (Allen 1998), resulting in a need for continued monitoring and control (Morin 1998; Sallie Beavers pers. comm. 2005). Anchialine pools can be degraded rapidly by mangrove colonization - trees can completely fill in shallow pools, and shading and deposition of leaf litter greatly increase the rate of organic matter accumulation, reducing dissolved oxygen levels and leading to premature pool senescence (Allen 1998). Mangrove roots and leaf litter also can reduce tidal flushing of anchialine pools and fishponds by blocking natural channels and artificial water control structures (Allen 1998), and mangrove detritus may have significantly increased organic loading to sediments in Kaloko pond prior to their removal in 1992. Direct impacts of mangroves on native species in anchialine pools have not been documented, but also may be important.

Table 11. Invasive alien plants found in KAHO (Pratt 1998).

Scientific name	Common name	Abundance (1998)
Acacia farnesiana	*Klu*	Common in shrublands
Batis maritima	Pickleweed	Common near ponds and on coast
Coccinia grandis	Ivy gourd	Rare in kiawe forest and open disturbed sites
Leucaena leucocephala	*Ekoa, koa haole*	Abundant in shrublands
Opuntia ficus-indica	Prickly pear cactus	Uncommon, potentially invasive
Panicum maximum	Guinea grass	Common near Aimakapa Pond
Pennisetum setaceum	Fountain grass	Abundant throughout park
Pithecellobium dulce	*Opiuma*	Common in shrublands
Pluchea symphytifolia	Sourbrush	Common near pools
Prosopis pallida	*Kiawe*	Abundant near ponds
Rhizophora mangle	American mangrove	Controlled in wetlands
Schinus terebinthifolius	Christmas berry	Common
Tribulus terrestris	Puncture vine	Rare on roads/trails

D.2.b. Algae

Alien and invasive algae are considered a major threat to coral reef ecosystems in Hawai‘i (Davidson et al. 2003). Invasive algae have had significant impacts on reef ecosystems on Oahu, but appear to be less established on the other islands. In a 2000 survey of State coastal waters, one invasive species (*Acanthophora spicifera*) was found covering roughly 10% of the substrate at a nearshore survey site close to Honokohau Harbor (Figure 9, site *A.s.*) (http://www.hawaii.edu/ssri/hcri/rbi/hawaii/honokohau_bay.htm; Smith et al. 2002). The same species also was found to be abundant inside Kaloko pond in 2000 (Marine Research Consultants 2000), and is the subject of ongoing management/eradication efforts by park staff under PMIS project 91680 (Mariska Weijerman pers. comm. 2005).

D.2.c. Fish and invertebrates

Introduced fish and invertebrates can have significant impacts on KAHO’s brackish and marine ecosystems. Invasive fish already are a serious threat to endemic species and habitat in many of KAHO’s anchialine pools and possibly in KAHO’s fishponds. The presence of alien fish in anchialine pools commonly leads to a reduction in grazing and detrital processing by endemic shrimp, resulting in increased algal growth, debris accumulation, and accelerated senescence of the ponds. Brock and Kam (1997) found a dramatic increase in the proportion of anchialine pools in the park that contained alien fish compared to previous studies, with a corresponding decrease in the abundance of native fauna and undisturbed habitat. Introduced shrimp and prawns also may compete with or prey on native shrimp, altering the ecological balance in anchialine pools. The extent of alien fish introductions into KAHO’s fishponds is not known, but it seems likely that introductions have occurred, and ponds provide excellent habitat for nuisance species. In particular, the brackish waters in Aimakapa pond would provide excellent habitat for tilapia, which have come to dominate many estuarine regions in Hawai‘i.

Alien fish and invertebrates also could have significant impacts on KAHO’s coastal ecosystems. A few alien invertebrates currently are known to occur in KAHO waters (e.g. they hydroid *Pennaria disticha*), and several introduced fish are present in KAHO’s coastal waters, including the peacock grouper or roi (*Cephalopholis argus*), black tail snapper (to‘au-*Lutjanus fulvus*), and blue-striped snapper (ta‘ape-*Lutjanus kasmira*) (Parrish et al. 1990). Parrish et al. (1990) suggested that roi and to‘au might have relatively insignificant effects on the natural community structure, but that ta‘ape might produce significant impacts due to their “piscivorous habits and extreme abundance achieved over a short time in many areas”. These and other fishes are the subject of recent and current studies in KAHO, and will be part of long-term community monitoring efforts by NPS Pacific Islands Coral Reef Program staff in future studies (Larry Basch pers. comm. 2005).

D.3. Physical impacts

Physical impacts to KAHO’s coastal resources could occur due to visitor modifications to anchialine pools and fishpond walls, and impacts to benthic resources might occur in association with diving, fishing, and boating in park coastal waters. Modifications to anchialine pools probably are minor and likely occur mostly in the few pools deep enough to accommodate bathing, such as the Queen's Bath pool. Visitors walking on fishpond walls might damage walls, but these effects probably are minor in Kaloko and Aimakapa because access to vulnerable interior walls is poor, while the easily accessible main wall of Kaloko fishpond is wide and stable enough to support foot and even vehicle traffic. Impacts to walls and associated structures around Aiopio pond may be more significant due to the high visitor use of the area and the easy access to pond walls. Fishing and diving may have some minor impacts on benthic substrates, but a study at a popular nearby diving site showed no significant physical effects due to diving activity (Tissot and Hallacher 2000), nor were significant impacts observed in an area frequented by aquarium fishermen in the park (Tissot and Hallacher 2003). Boating may have significant local impacts where boat groundings occur; at least two groundings have occurred in a nearshore area just north of Aimakapa beach, and wreckage from at least one of the groundings still is present at the site (Sallie Beavers pers. comm. 2005). However, benthic substrate in shallow coastal waters in the park mostly is sparsely colonized basalt, so groundings in shallow waters probably have minimal direct physical impacts on benthic biota.

D.4. Global change

Global change is a potentially significant issue for KAHO's coastal water resources. There are a number of aspects of global change that may impact park resources, including sea level rise, climate change, and the biogeochemical effects of increasing atmospheric CO_2.

D.4.a. Sea level rise

Tide gage data show that from 1946 to 2002, sea level at Hilo rose an average of 0.34 cm per year (0.13 in/y), likely due both to a combination of global sea level rise and local subsidence of the island (Hapke et al. 2005). Global sea level probably will continue to rise due to global warming, and the island of Hawai'i will continue to sink as the mass of the growing volcanoes depresses the underlying oceanic crust. As a result, KAHO's beaches and other intertidal resources will continue to slowly be inundated, with the intertidal zone moving further inshore (Pendleton et al. in press 2005). One result will be that some nearshore mixohaline resources, such as tidepools and anchialine pools, will become more saline, and some previously intertidal resources will become permanently subtidal, but these changes will take place relatively slowly and probably will not affect the overall condition of these resources significantly. Kaloko and Aimakapa fishponds and Aiopio fishtrap will be affected both by the direct effects of increasing sea level on pond/fishtrap water levels and mixing between seawater and brackish ground water, and by the indirect effects of higher sea level on the effectiveness of the existing barriers between the ponds and offshore waters. However, because coastal groundwater floats on underlying seawater, groundwater levels will rise concurrently with sea level, and changes in groundwater/seawater mixing likely will be controlled mostly by changes in the physical relationships between sea level and features that control mixing (e.g. fishpond walls). Higher sea levels seem likely to allow more wave energy to reach the Kaloko and Aiopio pond walls and the Aimakapa sand berm, which might result in greater damage to these structures during storms. Changing sea level might also alter coastal circulation, increasing or decreasing sand supply to the Aimakapa berm.

D.4.b. Climate change

Global climate change may impact KAHO coastal water resources through the effects of increasing air and sea temperatures, and through the effects of changes in the frequency and intensity of storms. The impacts of these changes on coastal water quality and associated flora and fauna are difficult to predict, but might be significant, for instance if changing climate alters groundwater recharge, affecting groundwater flow through the park. Changes in the frequency and intensity of storms also could affect the direction and intensity of wave energy reaching KAHO's shoreline, affecting the distribution of sand along the coast, potentially adding to or eroding the Aimakapa berm, and likely altering the distribution, abundance, and diversity of organisms in nearshore areas subject to storm disturbance. Increased temperatures also correlate with increased coral bleaching and the susceptibility of corals to disease.

D.4.c. Increasing atmospheric carbon dioxide

In addition to its greenhouse-gas role in altering global temperatures and climate, atmospheric carbon dioxide (CO_2) plays important roles in both aquatic photosynthesis and in carbonate biogeochemistry. Increasing atmospheric CO_2 results in higher levels of dissolved CO_2 in coastal waters, increasing the availability of CO_2 for photosynthesis and changing the concentrations of the carbonate ions that buffer ocean pH, or acid-base balance, ultimately increasing seawater acidity. Increases in dissolved CO_2 probably will not enhance aquatic photosynthesis significantly in the park, because other nutrients (usually nitrogen or phosphorus) usually are more limiting and CO_2 should always be present at concentrations well in excess of plant needs. However, the addition of atmospheric CO_2 to ocean waters is increasing seawater acidity, which may lead to increased dissolution of carbonate minerals (the biominerals secreted by many marine organisms, including corals and calcifying marine algae), and may also inhibit organisms' ability to secrete carbonate minerals in the first place. Increasing CO_2 thus may affect KAHO's aquatic communities in fishponds, which are areas of very active photosynthesis and carbonate synthesis, and in intertidal and coastal waters where the growth of corals and a number of other marine organisms depends on calcification, and where reef accretion depends on coral growth and the ability of calcifying marine algae to cement reef rubble into solid substrate. Increasing CO_2 also may affect the health of hermatypic zooxanthellate corals indirectly by altering the competitive balance between calcification and primary production by symbiotic zooxanthellae (Langdon and Atkinson 2005).

D.5. Fisheries

Fishing in KAHO occurs both from shore and by boat, but there are no data available on catch or effort, and no significant enforcement of existing regulations (Daniel and Minton 2004). In 1999, KAHO's coastal waters were designated as an aquarium Fish Replenishment Area (FRA), and aquarium fish collecting was prohibited. Monitoring prior to and following the ban showed significant increases in species targeted by aquarium fishers in several West Hawai'i FRAs, but no significant increases were observed in KAHO, possibly due to the small size of the KAHO FRA and the apparently poorer fish habitat compared to other FRAs (Tissot et al. 2003; Tissot and Hallacher 2003; Division of Aquatic Resources 2004). Other fishing activities are allowed subject to size and season limits applicable to all State waters, but KAHO and NPS management are considering limiting fishing to use of traditional Hawai‘ian methods within park waters (Larry Basch pers. comm. 2005).

D.6. SCUBA/Snorkeling

Diverse underwater topography, rich benthic and fish communities, and abundant turtles make KAHO’s coastal waters attractive to recreational divers and commercial tour operators. Parrish et al. (1990) observed commercial SCUBA charter boats anchored next to an underwater cliff within park waters several times during their study, and noted that there were no quantitative studies on impacts of SCUBA operators and divers on coastal resources. However, a recent study of diver impacts on benthic resources at another popular diving site in West Hawai‘i (Kealakekua Bay), showed no significant impacts (Tissot and Hallacher 2000), and the extensive mooring buoy system in and around KAHO waters (Figure 28) minimizes anchoring impacts on park reefs. The non-consumptive nature of recreational SCUBA diving appears to promote marine environmental and conservation awareness among divers and tour operators, with operators educating diving clients about minimizing contact with the benthos (Larry Basch pers. comm. 2005), and operators generally seem willing to comply with limitations that preserve the resource for future use (Sallie Beavers pers. comm. 2005). KAHO’s coastal waters are not a prime destination for visiting snorkelers, possibly due to the relatively scarcity of good entry and exit points and to the frequently cold, turbid, conditions found in nearshore areas where groundwater discharges occur, but park waters often are used by local snorkelers accustomed to these conditions (Larry Basch pers. comm. 2005).

Figure 28. Mooring buoys off KAHO (NPS unpubl.).

E. SUMMARY AND RECOMMENDATIONS FOR ADDRESSING EXISTING IMPAIRMENTS, POTENTIAL IMPACTS, AND INFORMATION GAPS

E.1. Summary

Table 12 summarizes existing impairments and the potential for impairment of KAHO's coastal water resources based on available data and our best professional judgement. Brief rationales for the classifications listed in Table 12 are provided below.

E.1.a. Groundwater

Only very limited groundwater data are available, but direct threats to groundwater probably are limited to effects of toxic contaminants on hypogeal fauna. Invasive species are not currently known from park groundwater, but colonization of groundwater by invasive species could impact a variety of coastal water resources linked by groundwater (e.g. anchialine pools and fishponds).

E.1.b. Anchialine pools

Brock and Kam (1997) have argued that the biggest threat to KAHO's anchialine ecosystems is alien fish, which historically have spread rapidly throughout many of the park's anchialine pools. Anchialine ecosystems also may be vulnerable to toxic contaminants and nutrients in groundwater reaching the pools. Anchialine systems occur over a wide range of salinities, but salinities in individual pools vary over smaller ranges, so significant changes in groundwater supply or in seawater inputs due to sea level rise might impact individual pool ecosystems. Anchialine systems are vulnerable to overharvesting of fish and shellfish, some of which may be rare and uniquely adapted to these systems, and anchialine ecosystems may be vulnerable to light pollution, as many organisms emerge at night to feed when they are less vulnerable to predation (Chai unpubl.).

E.1.c. Kaloko pond

Kaloko pond currently is the site of a significant infestation of the alien alga *Acanthophora spicifera*, which is the subject of ongoing study and eradication efforts (PMIS project 91680). Mudflats around the pond also are overgrown by the alien pickleweed *Batis maritima*, which is an ongoing management concern. Pond ecosystem function likely depends on the balance between the supply of new nutrients in groundwater and dilution by seawater, which currently appears to be changing as restoration of the fishpond wall reduces exchange between the pond and coastal waters. Thus, the pond's sensitivity to changes in groundwater quantity and quality, including possible toxic contaminants from upslope developments, likely is increasing.

E.1.d. Aimakapa pond

Aimakapa pond provides some of the best habitat for feeding, resting and nesting of endangered waterbirds in West Hawaiʻi, so maintaining ecosystem function is critical. Seawater inputs to

Table 12. Existing and potential impairment in KAHO coastal water resources.

Stressor	Ground-water	Anchialine Pools	Kaloko Pond	Aimakapa Pond	Aiopio Pond	Wetlands	Intertidal	Coastal Waters
Water Quality								
Nutrients	OK	PP	PP	PP	PP	OK	OK	OK
Fecal bacteria	OK	OK	OK	OK	PP	OK	OK	OK
Dissolved oxygen	OK	OK	OK	PP	OK	OK	OK	OK
Metals	OK	OK	OK	OK	OK	OK	OK	PP
Toxic compounds	PP	PP	PP	PP	OK	PP	OK	OK
Increased temperature	OK	OK	OK	OK	OK	OK	OK	PP
Water Quantity								
Reduced GW flux	OK	PP	PP	PP	OK	PP	OK	OK
Population Effects								
Fish/shellfish harvest	na	PP	OK	OK	OK	OK	PP	OK
Invasive species	PP	EP	EP	PP	PP	EP	PP	PP
Physical impacts	na	OK	OK	OK	PP	OK	OK	OK
Behavioral impacts	na	OK	OK	OK	PP	PP	PP	PP
Habitat Disruption								
Sea level rise	OK	PP	OK	OK	PP	OK	PP	OK
Sound pollution	na	OK	OK	PP	OK	PP	PP	PP
Light pollution	na	PP	OK	OK	PP	OK	OK	PP

EP - existing problem, PP - potential problem, OK - not currently or expected to be a problem, shaded - limited data, na - not applicable.

Aimakapa are restricted compared to Kaloko and Aiopio, so the pond contains a very high proportion of groundwater and thus may be particularly vulnerable to changes in groundwater quantity and quality. The lack of exchange with coastal waters also results in greater potential for oxygen depletion in bottom waters, which may lead to fish kills and avian botulism outbreaks.

Invasive species are not known to be a significant issue in the pond at this time, but successful invasions could alter ecosystem function and suitability for endangered birds, and invasive plants are found in wetland areas around the pond. Noise pollution might also affect the suitability of the pond as habitat for endangered birds.

E.1.e. Aiopio pond

Aiopio pond is essentially uncharacterized with respect to water quality and ecosystem status, but groundwater inputs to the pond likely are significant. Groundwater in this area may be affected by upslope sewage disposal, and thus seems likely to contain elevated concentrations of nutrients and possibly bacteria that may affect the pond ecosystem and park visitors wading or swimming in the pond. The pond's proximity to Honokohau Harbor makes it relatively susceptible to colonization by alien species brought to the harbor on boats, and the pond walls may be vulnerable to physical impacts by visitors and to sea level rise. The pond's location also makes it more likely to be exposed to light pollution from development around the harbor, and increased visitor use may be affecting turtle use of the area (Sallie Beavers pers. comm. 2005).

E.1.f. Wetlands

Wetlands in the park provide critical habitat for endangered waterbirds and for other potentially rare species. Wetlands in the park mostly are inland and thus should not be affected greatly by sea level rise, but may be affected by changing groundwater flows, and toxic contamination of groundwater could result in contaminant accumulation in wetlands, where endangered waterbirds feed. Invasive species, particularly plants such as the mangrove *Rhizophora mangle* and the alien pickleweed *Batis maritima*, alter the structure and suitability of wetlands for birds and other organisms. Both *R. mangle* and *B. maritima* are subjects of ongoing eradication and control efforts in wetlands in the park. Endangered waterbirds using wetlands may be impacted by sound pollution, and their behavior may be altered by the activities of visitors and pets (Morin 1998).

E.1.g. Intertidal

Sandy and rocky intertidal areas in the park mostly are subject to regular flushing by offshore seawater and thus should be relatively insensitive to contaminant inputs and oxygen depletion. Intertidal areas are, however, affected significantly by sea level rise and may be impacted by harvesting of fish, shellfish, and other resources such as corals. Intertidal areas also are vulnerable to invasion by alien species, and are utilized by some endangered waterbirds. Sound pollution and visitor activity in these areas may adversely impact bird behavior and fitness. Intertidal areas also are utilized by endangered green sea turtles for grazing and access to resting areas on park beaches.

E.1.h. Coastal Waters

Coastal waters are subject to rapid mixing and frequent exchange with offshore waters, making them relatively tolerant of inputs of dissolved contaminants. However, particle-bound contaminants may reach park waters from adjacent developments, such as Honokohau Harbor, impacting benthic biota and fish and other organisms that feed on them, and increasing temperatures due to global change may result in greater probability of coral bleaching. Invasive species also are a potential issue in all coastal areas in Hawaiʻi, especially in areas near boat harbors which often serve as points of introduction for alien species. Invasive species of concern can include both species that compete directly with existing species, and pathogens such as viruses and fungi that result in disease. Light and sound pollution in coastal waters may affect resident and transient fauna, such as plankton, manta rays, dolphins and whales, and human activities may alter organism behavior, either directly, such as by harassment of turtles and dolphins, or by indirect effects, such as observations of increased shark activity around Honokohau Harbor that have been attributed to improper disposal of fish waste inside the harbor (Honebrink and Ward 2001; Thompson 2005).

E.2. Recommendations

Although KAHO's coastal resources mostly appear to be in relatively good condition, there are known impairments in some areas and potential impairments in others (Table 12). However, even areas with known impairments generally lack sufficient data to document existing conditions adequately and to determine the degree to which park resources are impacted, and many areas where impairments are likely have no data at all. As a result, there are significant and fundamental information needs for the park related to most of the known and potential impairments in Table 12. These are listed below, followed by recommended courses of action for other known impacts and issues. It should be noted that for all of the recommended water quality studies, the potential for vertical stratification and water quality gradients due to the presence of groundwater mixing with underlying seawater makes it extremely important that sampling be performed using protocols that control and document the depth at which samples are collected, preferably with parallel data on associated depth variations in salinity.

E.2.a. Information Needs

E.2.a.i. Water quality

Groundwater supply and quality

1. Obtain a quantitative assessment of groundwater dynamics in the park, including variability in total groundwater flux, and partitioning between major discharge areas, including separate quantification of groundwater inputs into Kaloko, Aimakapa, and Aiopio ponds, as well as a more precise estimate of the current effect of upslope withdrawals (well pumping) and additions (domestic and other wastewater disposal) on groundwater flows in the park. Determining the time required for groundwater from the upslope industrial area to reach park resources would provide an estimate of the response time available for preventative or remediative action if a significant contamination event occurs. Quantification of flow directions in key areas (i.e. near contaminant sources) and of rates of lateral and vertical contaminant spread via mixing and diffusion would allow better characterization of the threat and extent of contamination by sources in the upslope industrial park and by potential sources adjacent to the park, such as the sewage leach pit upslope of Honokohau Harbor and new sources associated with the Kohanaiki development north of the park.

2. Conduct regular monitoring of groundwater flows and quality in the park. Additional monitoring wells would improve the likelihood of detecting contaminant plumes, but may not be cost effective as a means of obtaining the comprehensive coverage needed to ensure that contaminated plumes are intercepted. A more cost effective and ecologically relevant approach could be to monitor water quality in Kaloko, Aimakapa, and Aiopio ponds, and in anchialine pools as an indicator of groundwater quality, but this approach carries the risk of damaging receiving ecosystems before contamination is detected. The choice and scope of monitoring approach should consider the costs, risks, and benefits of each approach, and might include a mix of various approaches. Regular monitoring should focus on identified pollutants and basic water quality parameters, but less frequent monitoring also should be conducted for more 'exotic' contaminants, such as pesticides, solvents, heavy metals, and pharmaceuticals. The frequency of sampling and the analytes selected should be based on an assessment of cost, probability of detection, and risk to park resources.

3. Consider targeted monitoring of upslope and adjacent pollutant sources based on potential for significant/catastrophic contamination.

4. Analyze municipal water supplying the upslope industrial park to determine whether it has a chemical 'signature' suitable for identifying municipal wastewater contributions to park groundwater. One possible candidate is silica, which can have significantly different concentrations in different aquifers.

Water quality in anchialine pools

1. Establish regular water quality monitoring in selected anchialine pools. While Brock and Kam (1997) argue that anchialine pool ecosystems in general are relatively insensitive to changes in water quality, there are few long-term data available to test this hypothesis. Because anchialine pools in the park are protected, they provide an excellent opportunity to test the hypothesis. In addition, because anchialine pools are subaerial exposures of groundwater, water quality in anchialine pools likely can be used to infer groundwater quality at greater spatial resolution than is possible with monitoring wells. Monitoring probably could be limited to basic water quality parameters, although additional parameters could be analyzed if appropriate. Ponds should be selected to meet several criteria: maximizing spatial coverage in the park, including ponds containing critical biological resources, and including ponds with existing long-term water quality datasets (e.g. Queen's Bath).

Water quality in Kaloko pond

1. Conduct regular water quality monitoring in Kaloko pond with the goal of characterizing both the baseline ecosystem response to nutrient loading and the probable response to pollutants detected or anticipated in park groundwater based on upslope pollutant sources. Based on existing data, the initial focus should be on nitrogen as a key forcing factor, but monitoring should include the full suite of basic water quality parameters (e.g.,

T, S, DO, all inorganic species of nitrogen and phosphorus, silica, chlorophyll-*a*). Water sampling can be focused primarily on surface waters, but high resolution (cm-scale) depth profiles of temperature, salinity, and dissolved oxygen should be collected simultaneously with water samples to characterize stratification and bottom-water oxygen levels. Dissolved organic nitrogen and phosphorus probably can be omitted as these parameters are difficult and expensive to measure and probably would not provide significant insight into pond ecosystem function. Other useful data could include rates of primary production, accessory pigments as an indication of phytoplankton community structure, and nutrient and oxygen fluxes between pond sediments and overlying pond waters. The specific approach should be developed after consultation with experts in estuarine and wetland ecology and biogeochemistry, and should be coordinated with ongoing efforts to eradicate/control the invasive alga *A. spicifera* in the pond and, if appropriate, with the stated objective of operating the pond in the traditional manner for aquaculture. The latter may require testing for additional contaminants if fish raised in the pond are to be consumed.

2. Characterize water circulation and mixing in the pond. Completion of restoration activities on the fishpond wall and makahas should produce a relatively stable flow system compared to recent historical conditions, allowing for a reasonably robust characterization of pond hydrodynamics. Hydrodynamic data will assist in determining the impacts of changes in groundwater flux and quality on water quality and ecosystem function in the pond. Data currently being collected by PMIS project 91680 show lateral and vertical variations in salinity that provide some insight into freshwater inputs and fate (Figure 21a-d), but measurements with greater depth and temporal resolution will be needed to adequately describe both the general circulation and temporal (tidal, diel, seasonal), spatial, and depth variations.

Water quality in Aimakapa pond

1. Conduct regular water quality monitoring in Aimakapa pond with the goal of characterizing both the baseline ecosystem response to nutrient loading and the probable response to pollutants detected or anticipated in park groundwater based on upslope pollutant sources. Based on existing data, the initial focus should be on nitrogen as a key forcing factor, but monitoring should include the full suite of basic water quality parameters (e.g., T, S, DO, all inorganic species of nitrogen and phosphorus, silica, chlorophyll-*a*). Water sampling can be focused primarily on surface waters, but high resolution (cm-scale) depth profiles of temperature, salinity, and dissolved oxygen should be collected simultaneously with water samples to characterize stratification and bottom-water oxygen levels. Dissolved organic nitrogen and phosphorus probably can be omitted as these parameters are difficult and expensive to measure and probably would not provide significant insight into pond ecosystem function. Other useful data could include rates of primary production, accessory pigments as an indication of phytoplankton community structure, and nutrient and oxygen fluxes between pond sediments and overlying pond waters. The specific approach should be developed after consultation with experts in estuarine and wetland ecology and biogeochemistry.

2. Characterize water circulation and mixing in the pond. Existing data suggest that the pond is relatively well-mixed with respect to groundwater inputs, but that significant depth gradients probably exist in parameters affected primarily by biological processes. Quantifying physical circulation and mixing would provide insight into the rates of these processes, particularly oxygen production in the water column and respiration in the water column and in pond sediments, which determine the potential for bottom-water hypoxia and possible associated impacts such as fish kills and avian botulism outbreaks.

Water quality in Aiopio pond

1. Conduct a preliminary study of water quality in Aiopio pond with the goal of characterizing groundwater inputs and quality and its potential impact on the ecosystem in and adjacent to the pond, and on visitors using the pond for recreation. Initial measurements should include the full suite of basic water quality parameters (e.g., T, S, DO, inorganic species of nitrogen and phosphorus, silica, chlorophyll-*a*), plus bacterial indicators. Water sampling can be focused primarily on surface waters, but where practical high resolution (cm-scale) depth profiles of temperature, salinity, and dissolved oxygen should be collected simultaneously with water samples to characterize stratification and bottom-water oxygen levels. Dissolved organic nitrogen and phosphorus probably can be omitted as these parameters are difficult and expensive to measure and probably would not provide significant insight into pond ecosystem function. Other parameters also may be useful to assess the possible presence of sewage effluent in groundwater entering the pond (e.g. caffeine). Measurements to be used to characterize ‘typical’ conditions and long-term (>months) trends should be conducted at similar tidal conditions, as water quality probably varies significantly with tide height. At least one set of high-frequency measurements (e.g. hourly sampling for 12 – 24 hours) should be made to characterize tidal effects on water quality.

2. Characterize water circulation and mixing in the pond. The small size of the pond and its proximity to coastal waters suggest that the residence time of water in the pond is short, but a quantitative estimate of residence time would assist in determining the probable impacts of contaminants on water quality in the pond and on pond users.

Water quality in coastal waters

1. Characterize the spatial distribution and intensity of groundwater discharges to KAHO coastal waters. Conduct surveys of onshore-offshore gradients in surface salinity and obtain vertical profiles of salinity and temperature at regular intervals to characterize mixing dynamics. Combining these data with groundwater quality data will allow a general estimation of the quantity of groundwater contaminants reaching KAHO’s coastal waters and the rate at which physical mixing processes dilute them.

2. Conduct hydrographic/water quality surveys to characterize water quality and dilution in KAHO coastal waters adjacent to the entrance to Honokohau Harbor. These data could be obtained in conjunction with (1) above, but should be focused in the area around the harbor mouth. Sampling sites should include those sampled by Bienfang (1983) and

Parsons et al. (2005) (Figure 9) to facilitate comparison to historical data. Bacterial assays should be included to evaluate the potential for human health risks at recreational sites near the harbor entrance (i.e. the beaches north and south of the harbor and the mooring buoys near the harbor entrance). Sampling should be designed to provide data suitable for both characterization of current conditions over a range of tidal and weather conditions, and for use as baseline data for comparison to future data if the planned harbor expansion is implemented.

3. Collect sediment samples, fish and benthic organisms from the harbor and from KAHO coastal waters adjacent to the harbor and analyze for contaminants that could represent human health issues if consumed.

4. Work with the State of Hawaiʻi to mitigate potential contaminant sources in Honokohau Harbor, to encourage use of Best Management Practices (BMP's) in the harbor, and to establish a certification program similar to mainland 'Clean Marina' programs (cf., http://cleanmarinas.noaa.gov/).

E.2.a.ii. Biological resources

Anchialine pools

1. Survey biological resources in anchialine pools throughout the park to determine their current status and the current extent of alien fish invasions. There have been no comprehensive surveys of biological resources in the park's anchialine pools since the Brock and Kam (1997) survey (although data from recent invertebrate surveys should be published soon, e.g. Cooper et al. submitted 2005; Foote et al. submitted 2005a; Foote et al. submitted 2005b), and their data showed a marked decline in the number of pristine pools relative to earlier studies, largely due to impacts of alien fish. Consider collecting common anchialine fauna that are found throughout the park's anchialine resources and conducting genetic analyses to determine whether groundwater provides significant connectivity between populations in individual ponds and regions of the park.

2. Establish regular ecosystem monitoring, including rare and endangered species, in selected anchialine pools. While Brock and Kam (1997) argue that anchialine pool ecosystems in general are relatively insensitive to changes in water quality, there are few long-term data available to test this hypothesis. Because anchialine pools in the park are protected, they provide an excellent opportunity to test the hypothesis and simultaneously to monitor ecosystem conditions.

Kaloko pond

1. Obtain baseline data on the food web in Kaloko pond, including phytoplankton and zooplankton composition, biomass, and production, and the abundance and size distributions of common herbivores and carnivores in higher trophic levels. These data can be utilized with data from pond water quality studies to begin to assess ecosystem function and probable response to natural and anthropogenic perturbations. Include

assessment of alien species to provide baseline data and to determine need for further action. Use data on large carnivores to assess their potential role as predators on chicks of endangered waterbirds as suggested by Morin (1998).

Aimakapa pond

1. Obtain baseline data on the food web in Aimakapa pond, including phytoplankton and zooplankton composition, biomass, and production, and the abundance and size distributions of common herbivores and carnivores in higher trophic levels. These data can be utilized with data from pond water quality studies to begin to assess ecosystem function and probable response to natural and anthropogenic (contaminant) perturbations. Include assessment of alien species to provide baseline data and to determine need for further action. Use data on large carnivores to assess their potential role as predators on chicks of endangered waterbirds as suggested by (Morin 1998).

Aiopio pond

1. Perform a preliminary survey of biological resources in Aimakapa pond, including both water column and benthic resources. These data can be utilized with data from pond water quality studies to begin to assess ecosystem function and probable response to natural and anthropogenic (contaminant) perturbations. Include assessment of alien species to provide baseline data and to determine need for further action.

Intertidal areas

1. Perform quantitative surveys of biological resources in rocky intertidal areas in the park and in the intertidal area north of the park (the area within the legislated boundary that currently is slated for development) to provide baseline data for assessment of possible future impacts associated with increased visitation to the park overall, and to northern portions of the park in particular (due to improved access via the Kohanaiki development). Some of these data may already be being collected as part of the monitoring being conducted in conjunction with the Kohanaiki development (cf. (Eadie 2005), and additional data should be forthcoming from intertidal habitat and resource characterization to be conducted by PICRP in 2007. (Larry Basch pers. comm. 2005).

Coastal waters

1. Perform quantitative surveys of reef fish populations for comparison to semi-quantitative historical data (e.g. Parrish et al. 1990) and to provide baseline data for future studies. Surveys should be designed to complement recent surveys focused on aquarium fish (Tissot and Hallacher 2003; Tissot et al. 2004). Include monitoring of alien fish for assesment of population trends in known (e.g. roi, toʻau, taʻape) and new aliens. Much of these data may be available from recent surveys conducted in 2005 (Beets and Friedlander in prep 2005; Larry Basch pers. comm. 2005).

2. Repeat quantitative benthic community surveys along transect established by (Tissot and Hallacher 2003). Monitor benthic community for overall condition, including coral bleaching and diseases and invasive species.

E.2.a.iii. Recreational and development impacts

1. Obtain quantitative or at least-semi-quantitative data on park fisheries catch and effort, including fishing method and type and size distributions of harvested organisms.

2. Obtain quantitative data on SCUBA diving activities in the park, including location and number of dives. Consider monitoring of selected sites for physical damage due to diving.

3. Perform a preliminary assessment of artificial light pollution in the park and the potential for impacts on park resources.

4. Assess the potential for underwater noise pollution impacts on biological resources in coastal waters. Data recently obtained and currently being analyzed by Cornell University researchers may be suitable for a preliminary assessment.

E.2.b. Recommendations for existing/potential impairments

1. Continue efforts to eradicate or control A. spicifera in Kaloko pond (ongoing PMIS project 91680), including monitoring of adjacent coastal waters to document potential spread.

2. Continue research on eradication and control of alien pickleweed (*Batis maritima*) around Kaloko pond.

3. Consider prohibiting harvesting of endemic Hawai‘ian limpets (‘opihi’) from park waters.

4. Enforce existing fishing regulations in park waters.

5. Consider an aggressive campaign to make the State accountable for impacts of current and future harbor operations on water quality in KAHO coastal waters. At a minimum, it seems reasonable that the State should fund long-term water quality monitoring at a site near the harbor entrance and possibly at an appropriate control site.

6. Support ongoing WHAP monitoring of aquarium and other fish species at established transects in park coastal waters.

7. Use recent data on abundance of fish in coastal waters (Beets and Friedlander in prep. 2005) to assess status of alien fish (ta’ape, to’au, roi, others as appropriate) and need for control.

BIBLIOGRAPHY

Anonymous (1978). National Parks and Recreation Act of 1978**:** 3491-3500.

Adams, W. (1969). A hydrogeophysical survey from Kawaihae to Kailua-Kona, Hawaii. Honolulu, University of Hawaii Water Resources Research Center**:** 156 pp.

Allen, J. A. (1998). "Mangroves as alien species: the case of Hawaii." Global Ecology and Biogeography Letters **7**(61-71).

Apple, R. A. and G. A. Macdonald (1966). "The rise of sea level in contemporary times at Honaunau, Kona, Hawaii." Pacific Science **20**: 125-136.

Beavers, S. C. and L. Marrack (in prep 2005a). Green sea turtle (*Chelonia mydas*) health, abundance, and habitat use within Kaloko-Honokohau National Historical Park: 1999 to 2002. Kailua-Kona, PCSU**:** 30pp. Draft report

Beavers, S. C. and L. Marrack (in prep 2005b). Green sea turtle (*Chelonia mydas*) health, abundance, and habitat use within Kaloko-Honokohau National Historical Park: 2003. Kailua-Kona, PCSU**:** 32 pp. Draft report

Beavers, S. C. and L. Marrack (in prep 2005c). Green sea turtle (*Chelonia mydas*) health, abundance, and habitat use within Kaloko-Honokohau National Historical Park: 2004. Kailua-Kona, PCSU. Draft report

Bhambare, D. N. (1996). Design and development of a remotely controlled mobile data acquisition system for continuous and long-term monitoring of water quality in Hawai`ian anchialine ponds : Water quality characteristics of Kaloko Pond, a small case study, University of Hawai`i at Manoa, Civil Engineering Department.

Bidigare, R. R., C. Benitez-Nelson, C. L. Leonard, et al. (2003). "Influence of a cyclonic eddy on microheterotroph biomass and carbon export in the lee of Hawaii." Geophysical Research Letters **30**(6): 51-1 to 51-4.

Bienfang, P. (1980). "Water quality characteristics of Honokohau Harbor: a subtropical embayment affected by groundwater intrusion." Pacific Science **34**: 279-291.

Bienfang, P. and W. Johnson (1980). "Planktonic properties of Honokohau Harbor: a nutrient enriched subtropical embayment." Pacific Science **34**: 293-300.

Bienfang, P. K. (1983). The status of water quality, water circulation and plankton populations in Honokohau small boat harbor, 1982. A decade of ecological studies following construction of Honokohau small boat harbor, Kona, Hawaii. Honolulu, US Army Corps of Engineers**:** 11-31.

Bond, S. C. J. and R. Gmirkin (2003). "Restoring a part of Hawai'is past: Kaloko Fishpond restoration." Ecological Restoration **21**(4): 284-289.

Brasher, A. M. (1999). Development of a monitoring program to assess physical, chemical and biological components of Kaloko Fishpond at Kaloko-Honokohau National Historical Park on the Island of Hawaii. NPS Report.

Brock, R. E. (1985). An assessment of the conditions and future of the anchialine pond resources of the Hawaiian Islands. Honolulu, Prepared for Transcontinental Development Co.

Brock, R. E. and A. K. H. Kam (1997). Biological and water quality characteristics of anchialine resources in Kaloko-Honokohau National Historical Park. Honolulu, University of Hawaii at Manoa**:** 115 pp.

Brock, R. E., J. E. Norris, D. A. Ziemann, et al. (1987). "Characteristics of water quality in anchialine ponds of the Kona, Hawai`i, USA coast." Pacific Science **41**(1-4): 200-208.

Canfield, J. E. (1990). Description and map of the plant communities of Kaloko-Honokohau National Cultural Park. Honolulu, University of Hawaii at Manoa**:** 30 pp.

Chavanne, C., P. Flament, R. Lumpkin, et al. (2002). "Scatterometer observations of wind variations induced by oceanic islands: Implications for wind-driven ocean circulation." Canadian Journal of Remote Sensing **28**(3): 466-474.

Cooper, I. A., L. K. Tango and D. Foote (submitted 2005). Inventory of native and non-native damselflies in National Parks of Hawaii, Maui, and Molokai. Hawaii Volcanoes National Park, HI, USDI National Park Service, Inventory and Monitoring Program, Pacific Island Network. 19 pp.

Cordy, R., R. Tainter, R. Renger, et al. (1991). An Ahupua'a study: The 1971 archaeological work at Kaloko Ahupua'a, North Kona, Hawai'i, National Park Service United States Department of the Interior.

Cuddihy, L. W. and C. P. Stone (1990). Alteration of native Hawaiian vegetation: Effects of humans, their activities and introductions. Honolulu, University of Hawaii Cooperative National Park Resources Studies Unit.

Daniel, R. and D. Minton (2004). Marine Report**:** 127 pp. National Park Service Inventory & Monitoring Program - Pacific Island Network Monitoring Plan Appendix A

Department of Health (2004). Water quality standards. Hawaii Administrative Rules, Title 11, Chapter 54.

DeVerse, K. and E. DiDonato (2005). Water Quality Report**:** 104 pp. National Park Service Inventory and Monitoring Program Pacific Island Network Monitoring Plan Appendix A

Division of Aquatic Resources (2004). A report on the findings and recommendations of effectiveness of the West Hawai'i Regional Fishery Management Area, State of Hawai'i, Department of Land and Natural Resources.

Dollar, S. and C. Andrews (1997). Algal blooms off West Maui: Assessing causal linkages between land and the coast ocean. Honolulu**:** 101 pp.

Dollar, S. J. and M. J. Atkinson (1992). "Effects of nutrient subsidies from groundwater to nearshore marine ecosystems off the island of Hawaii." Estuarine, Coastal and Shelf Science **35**: 409-424.

Duarte, K. and J. Kauahikaua (1999). Use of magnetic methods in the investigation of an ancient Hawaiian fishpond: 'Aimakapa'a Fishpond, Hawai'i. Hawai'i National Park, USGS**:** 11pp.

Eadie, D. (2005). Re: Special Management Area Use Permit (No.439), Use Permit nos. 197 and 198, Shores at Kohanaiki, TMK: 7-3; 3 and 16. G. Bell. Kailua-Kona. Letter regarding status of water quality and ecological monitoring.

Eldredge, L. G. and J. T. Carlton (2002). "Hawaiian marine bioinvasions: A preliminary assessment." Pacific Science **56**: 211-212.

Else, P. (2004). Puuhonua o Honaunau National Historical Park Resource Overview**:** 15 pp. National Park Service Inventory & Monitoring Program - Pacific Island Network

Fischer, W. (1966). Fresh-water springs of Hawaii from infrared images. Washington D.C., U.S. Geological Survey.

Foote, D., M. F. Acly, C. King, et al. (submitted 2005a). Biological inventory of anchialine pools in Kaloko-Honokohau National Historical Park and Hawaii Volcanoes National Park. Hawaii Volcanoes National Park, HI, USDI National Park Service, Inventory and Monitoring Program, Pacific Island Network. 46 pp.

Foote, D., I. A. Cooper, L. Tango, et al. (submitted 2005b). Anchialine pool survey at Kohanaiki, Hawaii: documenting damselflies. Hawaii Volcanoes National Park, HI, USDI National Park Service, Inventory and Monitoring Program, Pacific Island Network. 16 pp.

Gibbs, A., E. Grossman, J. Logan, et al. (2004). Seafloor habitat mapping and oceanographic studies in the Kona Coast National Parks. Annual Meeting, Denver, Geological Society of America.

Gima, C. (2005). Big Isle leads state in populace growth. Honolulu Star Bulletin. Honolulu**:** 2.

Greene, L. W. (1993). A cultural history of three traditional Hawaiian sites on the west coast of Hawaii island. Denver, National Park Service.

Grovhoug, J. G. (1992). Evaluation of sediment contamination in Pearl Harbor. San Diego, Naval Command, Control and Ocean Surveillance Center, RDT&E Division.

Halliday, W. R. (2003). "Raw sewage and solid waste dumps in lava tube caves of Hawaii Island." Journal of Cave and Karst Studies **65**(1): 68-75.

Hapke, C. J., R. Gmirkin and B. M. Richmond (2005). Coastal Change Rates and Patterns: Kaloko-Honokohau NHP, Kona Coast, Hawaii, USGS open file report 2005-1069**:** 24 pp.

HCRI (2000). Honokohau Bay HCRI Results. http://www.hawaii.edu/ssri/hcri/rbi/hawaii/honokohau_bay.htm

Herbst, L. H. and L. H. Klein (1995). "Green turtle fibropapillomatosis: Challenges to assessing the role of environmental cofactors." Environmental Health Perspectives **103**(S4): 27-30.

Honebrink, R. and D. Ward (2001). DLNR urges water users near Kona's Honokohau Harbor to watch out for sharks. Honolulu, DLNR**:** 1.

Juvik, S. P. and J. O. Juvik, Eds. (1998). Atlas of Hawaii. Honolulu, University of Hawaii Press.

Kelly, M. (1983). Gardens of Kona: A history of land use in Kona, Hawaii. Honolulu, Department of Anthropology, Bernice Pauahi Bishop Museum.

Kikuchi, W. and J. Belshe (1971). Examination and evaluation of fishponds on the leeward coast of the island of Hawaii. Hawai'i County Planning Commission Report, Hilo, HI.

Koch, L., J. Harrigan-Lum and K. Henderson (2004). Final 2004 list of impaired waters in Hawaii. Honolulu, Hawaii State Department of Health Environmental Planning Office.

Langdon, C. and M. J. Atkinson (2005). "Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment." Journal of Geophysical Research **110**(C09S07).

Maciolek, J. A. and R. E. Brock (1974). Aquatic survey of the Kona coast ponds of Hawaii Island, University of Hawaii Sea Grant College Program.

Marine Research Consultants (2000). An assessment of potential effects to the marine and pond environments in the vicinity of the Kaloko Industrial Park, phases II and IV, North Kona, Hawaii. Honolulu. Prepared for Wilson Okamoto & Associates, for Kaloko Industrial Park, Phases III-IV, marine and pond environmental assessment (Appendix B)

McCoy, E. J. A. and L. T. Johnson (1995). Boating pollution economics and impacts, University of California Cooperative Extension, Sea Grant Program**:** http://seagrant.ucdavis.edu/Bpecon.htm

Morin, M. P. (1996). Birds of Kaloko-Honokohau National Historical Park. Honolulu, University of Hawaii, Manoa**:** 28 pp.

Morin, M. P. (1998). Endangered waterbird and wetland status, Kaloko-Honokohau National Historical Park, Hawai'i Island. Honolulu, University of Hawaii, Manoa**:** 43 pp.

Nance, T. (2000). Potential impact of water resources of Phases III and IV of the Kaloko Industrial Park in North Kona, Hawaii, Water Resources Engineering. Prepared for

Wilson Okamoto & Associates, for Kaloko Industrial Park, Phases III-IV, marine and pond environmental assessment (Appendix A)

National Park Service (2000). Baseline water quality data inventory and analysis: Kaloko-Honokohau National Historical Park, United States Department of the Interior, National Park Service, Water Resources Division.

Oceanic Foundation (1975). A three-year environmental study of Honokohau Harbor, Hawaii. Waimanalo, US Army Engineer District**:** 101.Oceanic Foundation, Environmental Analysis and Planning Division

Oki, D. S., G. W. Tribble, W. R. Souza, et al. (1999). Ground-water resources in Kaloko-Honokohau National Historical Park, Island of Hawaii, and numerical simulation of the effects of ground-water withdrawals, U.S. Geological Survey.

Östman-Lind, J., A. D. Driscoll-Lind and S. H. Rickards (2004). Delphinid abundance, distribution and habitat use off the western coast of the island of Hawai'i. Seattle, WA, National Oceanic and Atmospheric Administration. Final report for contract # AB133F-02-CN-0123

Parrish, J. D., G. C. Smith and J. E. Norris (1990). Resources of the marine waters of Kaloko-Honokohau National Historical Park. Honolulu, University of Hawaii at Manoa**:** 119 pp.

Parsons, M., W. Walsh, J. Michaud, et al. (2005). Assessment of anthropogenic impacts on two coral reef sites on the Big Island of Hawai'i: Honokohau Bay and Kealakekua Bay. http://www.hawaii.edu/ssri/hcri/files/parsons_2005_qtr_1.pdf

Pendleton, E. A., E. R. Thieler and S. J. Williams (in press 2005). Relative coastal vulnerability assessment of Kaloko-Honokohau National Historical Park (KAHO) to sea-level rise, USGS.

Pratt, L. W. (1998). Vegetation management strategies for three National Historical Parks on Hawai'i Island. Honolulu, University of Hawai'i at Manoa**:** 214 pp.

Pratt, L. W. and L. L. Abbott (1996). Distribution and abundance of alien and native plant species in Kaloko-Honokohau National Historical Park. Honolulu, University of Hawaii-Manoa**:** 96 pp.

Raine, L. M., B. Z. Siegel and G. M. McMurtry (1995). "Mercury accumulation in sediments of the Ala Wai Canal and in soils and stream sediments of the central Honolulu watershed." Pacific Science **49**(4): 511-525.

Ryan, S. (2003). The "clean air" layer at sea level along the Kona Coast, Mauna Loa Observatory. http://www.vognet.hpa.edu/CleanAirLayer.pdf

Seki, M. P., R. Lumpkin and P. Flament (2002). "Hawaii cyclonic eddies and blue marlin catches: the case study of the 1995 Hawaiian International Billfish Tournament." Journal of Oceanography **58**: 739-745.

Sparks, A. K. (1963). Survey of the oyster potential of Hawaii. Honolulu, Division of Fish and Game.

Storlazzi, C. and M. K. Presto (2005). Coastal circulation and water column properties along Kaloko-Honokohau National Historical park, Hawaii. Part I: Measurements of waves, currents, temperature, salinity and turbidity: April-October 2004, US Geological Survey Open File Report 2005-1161.

Thompson, R. (2005). Kona officials fear shark being lured to harbor. Star Bulletin. Honolulu**:** 2.

Tissot, B. (2000). Honokohau benthic habitat summary. Hawaii Coral Reef Initiative. http://www.hawaii.edu/ssri/hcri/rbi/hawaii/honokohau_bay.htm

Tissot, B. and L. Hallacher (2000). Diver impacts on coral reefs at Kealakekua Bay, Hawai'i. http://www.coralreefnetwork.com/research/kbay/default.htm

Tissot, B., J. J. Walsh and L. Hallacher (2003). Evaluating the effectiveness of a marine reserve network in West Hawaii to improve management of the aquarium fishery. Silver Springs, MD, HCRI and National Ocean Service, NOAA**:** 20 pp.

Tissot, B. N. and L. E. Hallacher (2003). "Effects of aquarium collectors on coral reef fishes in Kona, Hawaii." Conservation Biology **17**: 1759-1768.

Tissot, B. N., W. J. Walsh and L. E. Hallacher (2004). "Evaluating effectiveness of a Marine Protected Area Network in West Hawai`i to increase productivity of an aquarium fishery." Pacific Science **58**(2): 175-188.

Tribble, G. W. (2003). Results of August, 2002 water, fish, and sediment sampling in Kaloko-Honokohau National Historical Park, USGS**:** 2 pp. Letter.

US Army Corps of Engineers (1983). A decade of ecological studies following construction of Honokohau small boat harbor, Kona, Hawaii. Honolulu, Hawaii, US Army Corps of Engineers.

Van Dyke, P. (2001). Growing *Makaloa (Cyperus laevigatus)* in constructed wetlands for weaving and treating wastewater. Honolulu, Bishop Museum**:** 15pp.

Wilson Okamoto & Associates, I. (2000). Draft EIS Kaloko Industrial Park, Phases III and IV. Honolulu.

Wolff, R. (unpubl. 2005). Pacific Islands Network (PACN) Water Quality Database. Honolulu, USGS.

APPENDIX A. ADDITIONAL REFERENCES

Anderson, D. M. (2004). The growing problem of harmful algae. Oceanus Magazine. **43:** 1-5.

Bond, S. C. J., S. C. Beavers, N. Walthall, et al. Using State laws and regulations to protect parks from adjacent development impacts: a case study from Hawaii**:** 4.

Brock, J. H. and R. E. Brock (1974). The marine fauna of the coast of northern Kona, Hawaii, The University of Hawaii Sea Grant Program**:** 30.

Brock, R. E. (1975). "Fishes of the mixohaline lava ponds of the Kona, Hawaii coast." Transactions of the American Fisheries Society.

Brock, R. E. (1980). "Colonization of marine fishes in a newly created harbor, Honokohau, Hawaii." Pacific Science **34**: 313-325.

Brock, R. E. (1983). An eleven year study of the structure and stability of the coral reef fish community in Honokohau Harbor, Kona Hawaii. In: A decade of ecological studies following construction of Honokohau small boat harbor, Kona, Hawaii. Honolulu, Hawaii, US Army Corps of Engineers.

Brock, R. E. (1986). Status of the anchialine pond system of the Kona Hawai`i coast. Second International Symposium on Indo-Pacific Marine Biology, Western Society of Naturalists, University of Guam, 23-28 June 1986, Bulletin of marine science.

Brock, R. E. (2003). Preliminary inventory of the anchialine resources at Kohanaiki, North Kona, Hawaii, Prepared for Rutter Development Corp., 18012 Cowan, Suite 200, Irvine, California, 92614. EAC (Environmental Assessment Co) Report. No. 2003-14.

Brock, R. E. and A. K. H. Kam (1990). The Waikoloa anchialine pond program third annual report. Honolulu, University of Hawai`i, Hawai`i Institute of Marine Biology**:** 64 pp plus appendices.

Brock, R. E. and A. K. H. Kam (1994). The Waikoloa anchialine pond program fifth status report. Honolulu, University of Hawaii Sea Grant College Program**:** 78.

Brock, R. E. and J. E. Norris (1988). The Waikoloa anchialine pond program: second status report**:** 65pp.

Chang, D. L. (1994). Description of anchialine ponds.

Command, B. (2003). Development plans and proposals. West Hawaii Today**:** 1.

Davis, D. A. and G. Yamanaga (1968). Preliminary Report on the Water Resources of the Kona Area, Hawaii. Honolulu, USGS and DLNR**:** 22.

Dollar, S. J. (1975). Zonation of reef corals off the Kona Coast of Hawaii, Department of Oceanography, University of Hawaii.

Dollar, S. J., R. E. Brock and S. V. Smith (1995). Implementation of a water quality monitoring program on the west coast of the island of Hawaii in support of a proposed amendment to state water quality standards. Honolulu, State of Hawaii Department of Health, Environmental Planning Office**:** 54p.

Frankel, S. (2004). Students in Hawaii Define Anchialine Ponds, MIT Department of Civil and Environmental Engineering.

Kauahikaua, J., K. Takasaki and D. B. Jackson (1985). An evaluation of ground water resources in Kailua-Kona, Hawaii using electric geophysical measurements, U S Geological Survey.

Kay, E. A. and R. Kawamoto (1983). The mollusks and echinoids of Honokohau small boat harbor 1971-1982. A decade of ecological studies following construction of Honokohau small boat harbor, Kona, Hawaii. Honolulu, Hawaii, US Army Corps of Engineers**:** 60-73.

Kay, E. A., L. S. Lau, E. D. Stroup, et al. (1977). Hydrologic and ecologic inventories of the coastal waters of west Hawaii. Honolulu, University of Hawaii, Water Resources Research Center.

Kikuchi, W. F. (1976). "Prehistoric Hawaiian fishponds." Science **193**(4250): 295-299.

Kimura International (1996). Kaloko Town Center, North Kona, Hawai`i : final environmental impact statement, Kaloko International Inc.

Loomis, H. G. (1975). Normal modes of oscillation in Honokohau Harbor, Hawai`i, Hawaii Institute of Geophysics.

Maciolek, J. A. (1984). Exotic fishes in Hawaii and other islands of Oceania. Distribution, Biology and Management of Exotic Fishes. C. W.R. and J. R. Stauffer Jr. Baltimore, Johns Hopkins University Press**:** 131-161.

Maragos, J. (1991). Two decades of coral monitoring surveys following construction of Honokohau Harbor, Hawaii. Studies of water quality, ecology and mixing processes at Honokohau and Kawaihae Harbors on the island of Hawaii. Makapuu Point, Waimanalo, Hawaii, OI Consultants, Inc.**:** 28.

Maragos, J. E. (1983). The status of reef coral populations in Honokohau small boat harbor 1971-1981. A decade of ecological studies following construction of Honokohau small boat harbor, Kona, Hawaii. Honolulu, Hawaii, US Army Corps of Engineers**:** 32-59.

Rosenlieb, G. W., B. A. Long, L. Martin, et al. (1998). Potential influences of wastewater discharges on Aimakapa Pond and nearby anchialine pools, Kaloko-Honokohau National Historic Park, U.S. National Park Service, Water Resources Division.

Stromquist, C. D. (1996). Untitled: Monitoring well completion reports, Honokohau-NPS.

Wyban, C. A. (1996). Feasibility study for Kaloko fishpond - Kaloko-Honokohau National Historical Park, Island of Hawai`i.

APPENDIX B. STATE OF HAWAIʻI WATER QUALITY STANDARDS

Water body classification and water quality standards for the State of Hawaiʻi are promulgated through Chapter 11-54 of the Hawaiʻi Administrative Rules (DOH 2004). Sections relevant to coastal water resources in KAHO are excerpted/summarized below.

§11-54-1.1 General policy of water quality antidegradation.

(a) Existing uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

(b) Where the quality of the waters exceed levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the director finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the director shall assure water quality adequate to protect existing uses fully. Further, the director shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.

(c) Where high quality waters constitute an outstanding national resource, such as waters of national and state parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected.

§11-54-2 Classification of state waters.

(a) State waters are classified as either inland waters or marine waters.

(b) Inland waters may be fresh, brackish, or saline.

(1) All inland fresh waters are classified as follows, based on their ecological characteristics and other natural criteria (n/a)

(2) All inland brackish or saline waters are classified as follows, based on their ecological characteristics and other natural criteria:

(A) Standing waters.

(i) Anchialine pools; and

(ii) Saline lakes.

(B) Wetlands.

(i) Coastal wetlands (marshes, swamps, and associated ponds).

(C) Estuaries.

(i) Natural estuaries (stream-fed estuaries and spring-fed estuaries); and

(ii) Developed estuaries.

(c) Marine waters.

(1) All marine waters are either embayments, open coastal, or oceanic waters;

(2) All marine waters which are embayments or open coastal waters are also classified according to the following bottom subtypes:

(A) Sand beaches;

(B) Lava rock shorelines and solution benches;

(C) Marine pools and protected coves;

(D) Artificial basins;

(E) Reef flats; and

(F) Soft bottoms.

§11-54-3 Classification of water uses.

(a) The following use categories classify inland and marine waters for purposes of applying the standards set forth in this chapter, and for the selection or definition of appropriate quality parameters and uses to be protected in these waters. Storm water discharge into State waters shall be allowed provided it meets the requirements specified in this section and the basic water quality criteria specified in section 11-54-4.

(b) Inland waters.

(1) Class 1. It is the objective of class 1 waters that these waters remain in their natural state as nearly as possible with an absolute minimum of pollution from any human caused source. To the extent possible, the wilderness character of these areas shall be protected. Waste discharge into these waters is prohibited. Any conduct which results in a demonstrable increase in levels of point or nonpoint source contamination in class 1 waters is prohibited.

(A) Class 1.a. The uses to be protected in class 1.a waters are scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class;

(B) Class 1.b. The uses to be protected in class 1.b waters are domestic water supplies, food processing, protection of native breeding stock, the support and propagation of aquatic life, baseline references from which human-caused changes can be measured, scientific and educational purposes, compatible recreation, and aesthetic enjoyment. Public access to these waters may be restricted to protect drinking water supplies;

(2) Class 2. The objective of class 2 waters is to protect their use for recreational purposes, the support and propagation of aquatic life, agricultural and industrial water supplies, shipping, and navigation. The uses to be protected in this class of waters are all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. These waters shall not act as receiving waters for any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class. No new treated sewage discharges shall be permitted within estuaries. No new industrial discharges shall be permitted within estuaries, with the exception of:

(A) Acceptable non-contact thermal and drydock or marine railway discharges within Pearl Harbor, Oahu;

(B) Stormwater discharges associated with industrial activities (defined in 40 C.F.R. Section 122.26(b)(14) and(b)(15), except (b)(15)(i)(A) and (b)(15)(i)(B)) which meet, at the minimum, the basic water quality criteria applicable to all waters as specified in section 11-54-4(a), and all applicable requirements specified in chapter 11-55, titled "Water Pollution Control"; and

(C) Discharges covered by a National Pollutant Discharge Elimination System general permit, approved by the U.S. Environmental Protection Agency and issued by the Department in accordance with 40 C.F.R. Section 122.28 and all applicable requirements specified in chapter 11-55, titled "Water Pollution Control.".

(c) Marine waters.

(1) Class AA. It is the objective of class AA waters that these waters remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions. To the extent practicable, the wilderness character of these areas shall be protected. No zones of mixing shall be permitted in this class:

(A) Within a defined reef area, in waters of a depth less than 18 meters (ten fathoms); or

(B) In waters up to a distance of 300 meters (one thousand feet) off shore if there is no defined reef area and if the depth is greater than 18 meters (ten fathoms). The uses to be protected in this class of waters are oceanographic research, the support and propagation of shellfish and other marine life, conservation of coral reefs and wilderness areas, compatible recreation, and aesthetic enjoyment. The classification of any water area as Class AA shall not preclude other uses of the waters compatible with these objectives and in conformance with the criteria applicable to them;

(2) Class A. It is the objective of class A waters that their use for recreational purposes and aesthetic enjoyment be protected. Any other use shall be permitted as long as it is compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. These waters shall not act as receiving waters for any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class. No new sewage discharges will be permitted within embayments. No new industrial discharges shall be permitted within embayments, with the exception of:

(A) Acceptable non-contact thermal and drydock or marine railway discharges, in the following water bodies: (n/a)

(B) Storm water discharges associated with industrial activities (defined in 40 C.F.R. Section 122.26(b)(14) and (b)(15), except (b)(15)(i)(A) and (b)(15)(i)(B)) which meet, at the minimum, the basic water quality criteria applicable to all waters as specified in section 11-54-4, and all applicable requirements specified in the chapter 11-55, titled "Water Pollution Control;" and

(C) Discharges covered by a National Pollutant Discharge Elimination System general permit, approved by the U.S. Environmental Protection Agency and issued by the Department in accordance with 40 C.F.R. Section 122.28 and all applicable requirements specified in chapter 11-55, titled "Water Pollution Control."

(d) Marine bottom ecosystems.

(1) Class I. It is the objective of class I marine bottom ecosystems that they remain as nearly as possible in their natural pristine state with an absolute minimum of pollution from any human-induced source. Uses of marine bottom ecosystems in this class are passive human uses without intervention or alteration, allowing the perpetuation and preservation of the marine bottom in a most natural state, such as for nonconsumptive scientific research (demonstration, observation or monitoring only), nonconsumptive education, aesthetic enjoyment, passive activities, and preservation;

(2) Class II. It is the objective of class II marine bottom ecosystems that their use for protection including propagation of fish, shellfish, and wildlife, and for recreational purposes not be limited in any way. The uses to be protected in this class of marine bottom ecosystems are all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation. Any action which may permanently or completely modify, alter, consume, or degrade marine bottoms, such as structural flood control channelization, (dams); landfill and reclamation;

navigational structures (harbors, ramps); structural shore protection (seawalls, revetments); and wastewater effluent outfall structures may be allowed upon securing approval in writing from the director, considering the environmental impact and the public interest pursuant to sections 342D-4, 342D-5, 342D-6, and 342D-50, HRS in accordance with the applicable provisions of chapter 91, HRS.

§11-54-4 Basic water quality criteria applicable to all waters.

(a) All waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants, including:

(1) Materials that will settle to form objectionable sludge or bottom deposits;

(2) Floating debris, oil, grease, scum, or other floating materials;

(3) Substances in amounts sufficient to produce taste in the water or detectable off-flavor in the flesh of fish, or in amounts sufficient to produce objectionable color, turbidity or other conditions in the receiving waters;

(4) High or low temperatures; biocides; pathogenic organisms; toxic, radioactive, corrosive, or other deleterious substances at levels or in combinations sufficient to be toxic or harmful to human, animal, plant, or aquatic life, or in amounts sufficient to interfere with any beneficial use of the water;

(5) Substances or conditions or combinations thereof in concentrations which produce undesirable aquatic life; and soil particles resulting from erosion on land involved in earthwork, such as the construction of public works; highways; subdivisions; recreational, commercial, or industrial developments; or the cultivation and management of agricultural lands.

(b) To ensure compliance with paragraph (a)(4), all state waters are subject to monitoring and to the following standards for acute and chronic toxicity and the protection of human health.

(1) As used in this section:

(A) "Acute Toxicity" means the degree to which a pollutant, discharge, or water sample causes a rapid adverse impact to aquatic organisms. The acute toxicity of a discharge or receiving water is measured using the methods in section 11-54-10, unless other methods are specified by the director.

(B) "Chronic Toxicity" means the degree to which a pollutant, discharge, or water sample causes a longterm adverse impact to aquatic organisms, such as a reduction in growth or reproduction. The chronic toxicity of a discharge or receiving water is measured using the methods in section 11-54-10, unless other methods are specified by the director.

(C) "Dilution" means, for discharges through submerged outfalls, the average and minimum values calculated using the models in the EPA publication, Initial Mixing

Characteristics of Municipal Ocean Discharges (EPA/600/3-85/073, November, 1985), or in the EPA publication, Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (Cormix 1) (EPA/600/3-90/073), February, 1990.

(D) "No Observed Effect Concentration Observed Effect Concentration" (NOEC), means the highest per cent concentration of a discharge or water sample, in dilution water, which causes no observable adverse effect in a chronic toxicity test. For example, an NOEC of 100 percent indicates that an undiluted discharge or water sample causes no observable adverse effect to the organisms in a chronic toxicity test.

(2) Narrative toxicity and human health standards.

(A) Acute Toxicity Standards: All state waters shall be free from pollutants in concentrations which exceed the acute standards listed in paragraph (3). All state waters shall also be free from acute toxicity as measured using the toxicity tests listed in section 11, or other methods specified by the director.

(B) Chronic Toxicity Standards: All state waters shall be free from pollutants in concentrations which on average during any twenty-four hour period exceed the chronic standards listed in paragraph (3). All state waters shall also be free from chronic toxicity as measured using the toxicity tests listed in section 11-54-10, or other methods specified by the director.

(C) Human Health Standards: All state waters shall be free from pollutants in concentrations which, on average during any thirty day period, exceed the "fish consumption" standards for non-carcinogens in paragraph (3). All state waters shall also be free from pollutants in concentrations, which on average during any 12 month period, exceed the "fish consumption" standards for pollutants identified as carcinogens in paragraph (3).

(3) Numeric standards for toxic pollutants applicable to all waters. The freshwater standards apply where the dissolved inorganic ion concentration is less than 0.5 parts per thousand; saltwater standards apply above 0.5 parts per thousand. Values for metals refer to the dissolved fraction. All values are expressed in micrograms per liter.

	Freshwater		Saltwater		Fish Consumption
Pollutant	Acute	Chronic	Acute	Chronic	
Acenapthene	570	ns	320	ns	ns
Acrolein	23	ns	18	ns	250
Acrylonitrile*	2,500	ns	ns	ns	0.21
Aldrin*	3.0	ns	1.3	ns	0.000026
Aluminum	750	260	ns	ns	ns
Antimony	3,000	ns	ns	ns	15,000
Arsenic	360	190	69	36	ns
Benzene*	1,800	ns	1,700	ns	13
Benzidine*	800	ns	ns	ns	0.00017
Beryllium*	43	ns	ns	ns	0.038
Cadmium	3+	3+	43	9.3	ns
Carbon tetrachloride*	12,000	ns	16,000	ns	2.3
Chlordane*	2.4	0.0043	0.09	0.004	0.000016
Chlorine	19	11	13	7.5	ns
Chloroethersethy-(bis-2)*	ns	ns	ns	ns	0.44
isoprophyl	ns	ns	ns	ns	1,400
methyl(bis)*	ns	ns	ns	ns	0.00060
Chloroform*	9,600	ns	ns	ns	5.1
Chlorophenol(2)	1,400	ns	ns	ns	ns
Chlorpyrifos	0.083	0.041	0.011	0.0056	ns
Chromium_(VI)	16	11	1,100	50	ns
Copper	6+	6+	2.9	2.9	ns
Cyanide	22	5.2	1	1	ns
DDT*	1.1	0.001	0.013	0.001	0.000008
metabolite_TDE*	0.03	ns	1.2	ns	ns
Demeton	0.1	ns	0.1	ns	
Dichlorobenzenes*	370	ns	660	ns	850
benzidine*	ns	ns	ns	ns	0.007
ethane(1,2)*	39,000	ns	38,000	ns	79
ehenol(2,4)	670	ns	ns	ns	ns
propanes	7,700	ns	3,400	ns	ns
propene(1,3)	2,000	ns	260	ns	4.6
Dieldrin*	2.5	0.0019	0.71	0.0019	0.000025
Dinitroo-cresol(2,4)	ns	ns	ns	ns	250
toluenes*	110	ns	200	ns	3.0
Dioxin*	0.003	ns	ns	ns	5.0x10^{-9}
Diphenylhydrazine(1,2)	ns	ns	ns	ns	0.018
Endosulfan	0.22	0.056	0.034	0.0087	52
Endrin	0.18	0.0023	0.037	0.0023	ns
Ethylbenzene	11,000	ns	140	ns	1,070
Fluoranthene	1,300	ns	13	ns	18

	Freshwater		Saltwater		Fish Consumption
Pollutant	Acute	Chronic	Acute	Chronic	
Guthion	ns	0.01	ns	0.01	ns
Heptachlor*	0.52	0.0038	0.053	0.0036	0.00009
Hexachlorobenzene*	ns	ns	ns	ns	0.00024
butadiene*	30	ns	11	ns	16
cyclohexane-alpha*	ns	ns	ns	ns	0.010
beta*	ns	ns	ns	ns	0.018
technical*	ns	ns	ns	ns	0.014
cyclopentadiene	2	ns	2	ns	ns
ethane*	330	ns	310	ns	2.9
Isophorone	39,000	ns	4,300	ns	170,000
Lead	29+	29+	140	5.6	ns
Lindane*	2.0	0.08	0.16	ns	0.020
Malathion	ns	0.1	ns	0.1	ns
Mercury	2.4	0.55	2.1	0.025	0.047
Methoxychlor	ns	0.03	ns	0.03	ns
Mirex	ns	0.001	ns	0.001	ns
Naphthalene	770	ns	780	ns	ns
Nickel	5+	5+	75	8.3	33
Nitrobenzene	9,000	ns	2,200	ns	ns
Nitrophenols*	77	ns	1,600	ns	ns
Nitrosamines*	1,950	ns	ns	ns	0.41
Nitroso-dibutylamine-N*	ns	ns	ns	ns	0.19
diethylamine-N*	ns	ns	ns	ns	0.41
dimethylamine-N*	ns	ns	ns	ns	5.3
diphenylamine-N*	ns	ns	ns	ns	5.3
Pyrrolidine-N*	ns	ns	ns	ns	30
Parathion	0.065	0.013	ns	ns	ns
Pentachloroethanes	2,400	ns	130	ns	ns
benzene	ns	ns	ns	ns	28
phenol	20	13	13	ns	ns
Phenol	3,400	ns	170	ns	ns
2,4-dimethyl	700	ns	ns	ns	ns
Phthalate	esters				
dibutyl	ns	ns	ns	ns	50,000
diethyl	ns	ns	ns	ns	590,000
di-2-ethylhexyl	ns	ns	ns	ns	16,000
dimethyl	ns	ns	ns	ns	950,000
Polychlorinated biphenyls*	2.0	0.014	10	0.03	0.000079
Polynuclear aromatic hydrocarbons*	ns	ns	ns	ns	0.01
Selenium	20	5	300	71	ns

	Freshwater		Saltwater		Fish Consumption
Pollutant	Acute	Chronic	Acute	Chronic	
Silver	1+	1+	2.3	ns	ns
Tetrachloroethanes	3,100	ns	ns	ns	ns
benzene(1,2,4,5)	ns	ns	ns	ns	16
ethane(1,1,2,2)*	ns	ns	3,000	ns	3.5
ethylene*	1,800	ns	3,400	145	2.9
phenol(2,3,5,6)	ns	ns	ns	440	ns
Thallium	470	ns	710	ns	16
Toluene	5,800	ns	2,100	ns	140,000
Toxaphene*	0.73	0.0002	0.21	0.0002	0.00024
Tributyltin	ns	0.026	ns	0.01	ns
Trichloroethane(1,1,1)	6,000	ns	10,400	ns	340,000
ethane(1,1,2)*	6,000	ns	ns	ns	14
ethylene*	15,000	ns	700	ns	26
phenol(2,4,6)*	ns	ns	ns	ns	1.2
Vinyl chloride*	ns	ns	ns	ns	170
Zinc	22+	22+	95	86	ns

ns -No standard has been developed.
* - Carcinogen.
+ - The value listed is the minimum standard. Depending upon the receiving water $CaCO_3$ hardness, higher standards may be calculated using the respective formula in the U. S. Environmental Protection Agency publication Quality Criteria for Water (EPA 440/5-86-001, Revised May 1, 1987).
Note - Compounds listed in the plural in the "Pollutant" column represent complex mixtures of isomers. Numbers listed to the right of these compounds refer to the total allowable concentration of any combination of isomers of the compound, not only to concentrations of individual isomers.

§11-54-5 Uses and specific criteria applicable to inland waters. Inland water areas to be protected are described in section 11-54-5.1, corresponding specific criteria are set forth in section 11-54-5.2; water body types are defined in section 11-54-1.

§11-54-5.1 Inland water areas to be protected.

(a) Freshwaters (n/a)

(b) Brackish or saline waters (anchialine pools, saline lakes, coastal wetlands, and estuaries).

(1) Class 1.a.

(A) All inland brackish or saline waters within natural reserves, preserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195, HRS, or similar reserves for the protection of aquatic life established under chapter 195, HRS.

(B) All inland brackish or saline waters in national and state parks.

(C) All inland brackish or saline waters in state or federal fish and wildlife refuges.

(D) All inland brackish or saline waters which have been identified as a unique or critical habitat for threatened or endangered species by the U.S. Fish and Wildlife Service.

(D) All inland brackish and saline waters in Wai-manu National Estuarine Research Reserve (Hawai‘i).

(F) The following natural estuaries: Lumaha‘i and Kilauea estuaries (Kaua‘i).

(2) Class 1.b. All inland brackish or saline waters in protective subzones designated under chapter 13-5 of the state board of land and natural resources.

(3) Class 2. All inland brackish and saline waters not otherwise classified.

§11-54-5.2 Inland water criteria.

(a) Criteria for springs and seeps, ditches and flumes, natural freshwater lakes, reservoirs, low wetlands, coastal wetlands, saline lakes, and anchialine pools. Only the basic criteria set forth in section 11-54-4 apply to springs and seeps, ditches and flumes, natural freshwater lakes, reservoirs, low wetlands, coastal wetlands, saline lakes, and anchialine pools. Natural freshwater lakes, saline lakes, and anchialine pools will be maintained in the natural state through Hawai‘i's "no discharge" policy for these waters. Waste discharge into these waters is prohibited (see paragraph 11-54-3(b)(1)).

(b) Specific criteria for streams (n/a).

(c) Specific criteria for elevated wetlands (n/a).

(d) Specific criteria for estuaries.

(1) The following table is applicable to all estuaries except Pearl Harbor:

Parameter	Units	Criterion		
		GM (1)	GM 10% (2)	GM 2% (3)
TDN	µg N/l	200.00	350.00	500.00
NH4	µg NH4-N/l	6.00	10.00	20.00
NO3+NO2	µgNO3-N/l	8.00	25.00	35.00
TDP	µg P/l	25.00	50.00	75.00
Chl-a	µg/l	2.00	5.00	10.00
Turb	ntu	1.5	3.00	5.00

(1) Geometric mean not to exceed the given value
(2) Geometric mean not to exceed the given value more than 10% of the time
(3) Geometric mean not to exceed the given value more than 2% of the time

Parameter	Units	Criterion
pH	n/a	7.0 – 8.6, deviate ≤0.5 units from ambient
Dissolved Oxygen	% saturation	≥75% saturation
Temperature	°C	Deviate ≤1°C from ambient
Salinity	ppt	Deviate ≤10% from ambient
EH	mV	≥ -100 mV in upper 10 cm of sediment

§11-54-6 Uses and specific criteria applicable to marine waters.

(a) Embayments.

(1) As used in this section: "Embayments" means land-confined and physically protected marine waters with restricted openings to open coastal waters, defined by the ratio of total bay volume to the cross-sectional entrance area of seven hundred to one or greater. "Total bay volume" is measured in cubic meters and "cross-sectional entrance area" is measured in square meters, and both are determined at mean lower low water.

(2) Water areas to be protected.

(A) Class AA.

(i) Hawaiʻi: Puako Bay, Waiulua Bay, Anaehoomalu Bay, Kiholo Bay, Kailua Harbor, Kealakekua Bay, Honaunau Bay

(ii) All embayments in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life established under chapter 190, HRS.

(iii) All waters in state or federal fish and wildlife refuges and marine sanctuaries.

(iv) All waters which have been officially identified as a unique or critical habitat for threatened or endangered species by the U.S. Fish and Wildlife Service.

(B) Class A. Hawai‘i: Hilo Bay (inside breakwater), Kawaihae Boat Harbor, Honokohau Boat Harbor, Keauhou Bay

(3) The following criteria are specific for all embayments excluding those described in section 11-54-06(d).(Note that criteria for embayments differ based on fresh water inflow.)

Table 5a. Water quality criteria applicable to Honokohau Harbor. (DOH 2004).

Parameter	Units	Season (1)	Criterion		
			GM (2)	GM 10% (3)	GM 2% (4)
TDN	µg N/l	Wet Dry	200.00 150.00	350.00 250.00	500.00 350.00
NH4	µg NH4-N/l	Wet Dry	6.00 3.50	13.00 8.50	20.00 15.00
NO3+NO2	µgNO3-N/l	Wet Dry	8.00 5.00	20.00 14.00	35.00 25.00
TDP	µg P/l	Wet Dry	25.00 20.00	50.00 40.00	75.00 60.00
Chl-a	µg/l	Wet Dry	1.50 0.50	4.50 1.50	8.50 3.00
Turb	ntu	Wet Dry	1.5 0.40	3.00 1.00	5.00 1.50

(1) “Wet” and “Dry” criteria apply when average freshwater inflow to harbor is greater than, or less than, one percent of the harbor volume per day, respectively
(2) Geometric mean not to exceed the given value
(3) Geometric mean not to exceed the given value more than 10% of the time
(4) Geometric mean not to exceed the given value more than 2% of the time

Parameter	Units	Criterion
pH	n/a	7.6 – 8.6, except where freshwater influence depresses pH to 7.0 (min)
Dissolved Oxygen	% saturation	≥75% saturation
Temperature	°C	Deviate ≤1°C from ambient
Salinity	ppt	Deviate ≤10% from ambient

(b) Open coastal waters.

(1) As used in this section: "Open coastal waters" means marine waters bounded by the 183 meter or 600 foot (100 fathom) depth contour and the shoreline, excluding bays named in subsection (a);

(2) Water areas to be protected (measured in a clockwise direction from the first-named to the second-named location, where applicable):

(A) Class AA.

(i)Hawaiʻi - The open coastal waters from Leleiwi Point to Waiulaula Point;

(ii)Maui (n/a)

(iii)Kahoolawe (n/a)

(iv)Lanai (n/a)

(v)Molokai (n/a)

(vi)Oahu (n/a)

(viii)Niihau (n/a)

(ix)All other islands of the state - All open coastal waters surrounding the islands not classified in this section;

(x)All open waters in preserves, reserves sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS or similar reserves for the protection of marine life established under chapter 190, HRS, as amended; or in the refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service;

(B) Class A - All other open coastal waters not otherwise specified.

(3) The following criteria are specific for all open coastal waters, excluding those described in section 11-54-6(d). (Note that criteria for open coastal waters differ, based on fresh water discharge.) (n/a)

(c) Oceanic waters (n/a)

(d) Area-specific criteria for the Kona (west) coast of the island of Hawaiʻi.

(1) For all marine waters of Hawaiʻi Island from Loa Point, South Kona District, clockwise to Malae Point, North Kona District, excluding Kawaihae Harbor and Honokohau Harbor, and for all areas from the shoreline at mean lower low water to a distance 1000 m seaward:

(i) in areas where nearshore marine water salinity is greater than 32.00 parts per thousand the following specific criteria apply:

Parameter	Units	Criterion
TDN	µg N/l	100.00
NO3+NO2	µg(NO3+NO2)-N/l	4.50
TDP	µg P/l	12.50
PO4	µg PO4-P/l	5.00
NH4 (1)	µg NH4-N/l	2.50
Chl-a (1)	µg/l	0.30
Turb (1)	ntu	0.10

(1) Criterion also applicable to coastal waters with salinities less than 32.00 ppt.

Parameter	Units	Criterion
pH	n/a	Deviate ≤0.5 units from ambient except where freshwater influence depresses pH to 7.0 min.
Dissolved Oxygen	% saturation	≥75% saturation
Temperature	°C	Deviate ≤1°C from ambient
Salinity	ppt	Deviate ≤10% from ambient

(ii) If nearshore marine water salinity is less than or equal to 32.00 parts per thousand the following parameters shall be related to salinity on the basis of a linear least squares regression equation:

$Y = MX + B$
where:

Y = parameter concentration (in ug/L)
X = salinity (in ppt)
M = regression coefficient (or "slope")
B = constant (or "Y intercept").

The absolute value of the upper 95 per cent confidence limit for the calculated sample regression coefficient (M) shall not exceed the absolute value of the following values:

Parameter	Units	M
NO3+NO2	µg(NO3+NO2)-N/l	-31.92
TDN	µg N/l	-40.35
PO4	µg PO4-P/l	-3.22
TDP	µg P/l	-2.86

(iii) Parameter concentrations shall be determined along a horizontal transect extending seaward from a shoreline sample location using the following method: water samples shall be obtained at distances of 1, 10, 50, 100, and 500 meters from the shoreline sampling location. Samples shall be collected within one meter of the water surface and below the air-water interface. Dissolved nutrient samples shall be filtered through media with particle size retention of 0.7 um. This sampling protocol shall be replicated not less than three times on different days over a period not to exceed fourteen days during dry weather conditions. The geometric means of sample measurements for corresponding offshore distances shall be used for regression calculations.

(iv) pH Units - shall not deviate more than 0.5 units from a value of 8.1, except at coastal locations where and when freshwater from stream, storm drain or groundwater discharge may depress the pH to a minimum level of 7.0. Dissolved Oxygen - Not less than seventy-five per cent saturation, determined as a function of ambient water temperature and salinity. Temperature - Shall not vary more than one degree Celsius from ambient conditions. Salinity - Shall not vary more than ten per cent from natural or seasonal changes considering hydrologic input and oceanographic factors. L - liter N.T.U. - Nephelometric Turbidity Units. A comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity. ug - microgram or 0.000001 grams.

§11-54-7 Uses and specific criteria applicable to marine bottom types.

(a) Sand beaches.

(l) As used in this section: "Sand beaches" means shoreline composed of the weathered calcareous remains of marine algae and animals (white sand), the weathered remains of volcanic tuff (olivine), or the weathered remains of lava (black sand). Associated animals are largely burrowers and are related to particle grain size, slope, and color of the beach;

(2) Water areas to be protected:

(A) Class I - All beaches on the Northwestern Hawaiʻian Islands (n/a)

(B) Class II - All beaches not in Class I;

(3) The following criteria are specific to sand beaches:

(A) Episodic deposits of flood-borne sediment shall not occur in quantities exceeding an equivalent thickness of ten millimeters (0.40 inch) twenty four hours after a heavy rainstorm;

(B) Oxidation - reduction potential (EH) in the uppermost ten centimeters (four inches) of sediment shall not be less than +100 millivolts;

(C) No more than fifty per cent of the grain size distribution of sediment shall be smaller than 0.125 millimeters in diameter.

(b) Lava rock shoreline and solution benches.

(1) As used in this section: "Lava rock shorelines" means sea cliffs and other vertical rock faces, horizontal basalts, volcanic tuff beaches, and boulder beaches formed by rocks falling from above or deposited by storm waves. Associated plants and animals are adapted to the harsh physical environment and are distinctly zoned to the degree of wave exposure; “Solution benches" means sea level platforms developed on upraised reef or solidified beach rock by the erosive action of waves and rains. Solution benches are distinguished by a thick algal turf and conspicuous zonation of plants and animals;

(2) Water areas to be protected:

(A) Class I - All lava rock shorelines and solution benches in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life established under chapter 190, HRS, as amended; or in refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service;

(B) Class II

(i) All other lava rock shorelines not in Class I;

(ii) The following solution benches: (n/a)

(3) The following criteria are specific to lava rock shorelines and solution benches:

(A) Episodic deposits of flood-borne sediment shall not occur in quantities exceeding an equivalent thickness of five millimeters (0.20 inch) for longer than twenty-four hours after a heavy rainstorm

(B) The director shall determine parameters, measures, and criteria for bottom biological communities which may be affected by proposed actions. The location and boundaries of each bottom-type class will be clarified when situations require their identification. For example, when a discharge permit is applied for or a waiver pursuant to Section 301(h) of the Federal Water Pollution Control Act (33 U.S.C. Section 1311) is required. Permanent benchmark stations may be required where necessary for monitoring purposes. The water quality standards for this subsection shall be deemed to be met if time series surveys of benchmark stations indicate no relative changes in the relevant biological communities, as noted by biological community indicators or by indicator organisms which may be applicable to the specific site.

(c) Marine pools and protected coves.

(1) As used in this section: "Marine pools" means waters which collect in depressions on sea level lava rock outcrops and solution benches and also behind large boulders fronting the sea. Pools farthest from the ocean have harsher environments and less frequent renewal of water and support fewer animals. Those closest to the ocean are frequently renewed with water, are essentially marine, and support more diverse fauna; "Protected coves" means small inlets which are removed from heavy wave action or surge;

(2) Water areas to be protected;

(A) Class I.

(i) All marine pools and protected coves in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter 190, HRS, or similar reserves for the protection of marine life established under chapter 190, HRS, as amended; or in refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Fisheries Service;

(ii) Hawai‘i: Honaunau, Kiholo

(B) Class II. Hawai‘i: Kalapana, Pohakuloa, Kapalaoa, Kapoho, King's Landing (Papai), Hilo, Leileiwi Point, Wailua Bay

(d) Artificial basins (n/a)

(e) Reef flats and reef communities

(1) As used in this section: "Nearshore reef flats" means shallow platforms of reef rock, rubble, and sand extending from the shoreline. Smaller, younger flats projected out as semicircular aprons while older, larger flats form wide continuous platforms. Associated animals are mollusks, echinoderms, worms, crustaceans (many living beneath the surface), and reef-building corals. "Offshore reef flats" means shallow, submerged platforms of reef rock and sand between depths of zero to three meters (zero to ten feet) which are separated from the shoreline of high volcanic islands by lagoons or ocean expanses. Dominant organisms are bottomdwelling algae. Biological composition is extremely variable. There are three types: patch, barrier, and atoll reef flats; quite different from one another structurally. The presence of heavier wave action, water more oceanic in character, and the relative absence of terrigenous influences distinguish offshore reef flats. "Protected reef communities" means hard bottom aggregations, including scattered sand channels and patches, dominated by living coral thickets, mounds, or platforms. They are found at depths of ten to thirty meters (thirty-two to ninety-six feet) along protected leeward coasts or in shallow water (up to sea level) in sheltered lagoons behind atoll or barrier reefs and in the calm reaches of bays or coves. "Wave-exposed reef communities" means aggregations, including scattered sand channels and patches, dominated by corals. They may be found at depths up to forty meters (approximately one hundred thirty feet) along coasts subject to continuous or heavy wave action and surge. Wave-exposed reef communities are dominated biologically by benthic algae, reef-building corals, and echinoderms.

(2) Water areas to be protected:

(A) Class l.

(i) All reef flats and reef communities in preserves, reserves, sanctuaries, and refuges established by the department of land and natural resources under chapter 195 or chapter

190, HRS, or similar reserves for the protection of marine life under chapter 190, HRS, as amended; or in refuges or sanctuaries established by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service;

(ii) Nearshore reef flats: Hawaiʻi: Puako

(iii)Offshore reef flats: (n/a)

(iv) Wave exposed reef communities: Hawaiʻi (n/a)

(v) Protected reef communities: Hawaiʻi: Puako, Honaunau, Kealakekua, Kiholo, Anaehoomalu, Hapuna, Kahaluu Bay, Keaweula (North Kohala), Milolii Bay to Keawaiki, Kailua-Kaiwi (Kona), Onomea Bay, 1801 Lava Flow (Keahole or Kiholo), 1850 Lava Flow (South Kona), 1859 Lava Flow (Kiholo), 1919 Lava Flow (Milolii), 1926 Lava Flow (Milolii)

(B) Class II.

(i) Existing or planned harbors may be located within nearshore reef flats showing degraded habitats and only where feasible alternatives are lacking and upon written approval by the director, considering environmental impact and the public interest pursuant to section 342D-6, HRS. [Hawaiʻi: Blonde Reef (Hilo Harbor), Kawaihae Small Boat Harbor] All other nearshore reef flats not in Class I;

(ii) Offshore reef flats: (n/a)

(iii)All other wave exposed or protected reef communities not in Class I.

(3) Specific criteria to be applied to all reef flats and reef communities: No action shall be undertaken which would substantially risk damage, impairment, or alteration of the biological characteristics of the areas named herein. When a determination of substantial risk is made by the director, the action shall be declared to be contrary to the public interest and no other permits shall be issued pursuant to chapter 342, HRS.

(A) Oxidation-reduction potential (EH) in the uppermost ten centimeters (four inches) of sand patches shall not be less than +100 millivolts;

(B) No more than fifty per cent of the grain size distribution of sand patches shall be smaller than 0.125 millimeters in diameter

(C) Episodic deposits of flood-borne soil sediment shall not occur in quantities exceeding equivalent thicknesses for longer than twenty-four hours after a heavy rainstorm as follows:

(i) No thicker than an equivalent of two millimeters (0.08 inch) on living coral surfaces;

(ii) No thicker than an equivalent of five millimeters (0.2 inch) on other hard bottoms;

(iii) No thicker than an equivalent of ten millimeters (0.4 inch) on soft bottoms;

(D) The director shall determine parameters, measures, and criteria for bottom biological communities which may be affected by proposed actions. The location and boundaries of each bottom-type class shall be clarified when situations require their identification. For example, the location and boundaries shall be clarified when a discharge permit is applied for or a waiver pursuant to Section 301(h) of the Federal Water Pollution Control Act of 1972 (33 U.S.C. 1251 et seq.) is required. Permanent benchmark stations may be required where necessary for monitoring purposes. The water quality standards for this subsection shall be deemed to be met if time series surveys of benchmark stations indicate no relative changes in the relevant biological communities, as noted by biological community indicators or by indicator organisms which may be applicable to the specific site.

(f) Soft bottom communities.

(1) As used in this section: "Soft bottom communities" means poorly described and "patchy" communities, mostly of burrowing organisms, living in deposits at depths between two to forty meters (approximately six to one hundred thirty feet). The particle size of sediment, depth below sea level, and degree of water movement and associated sediment turnover dictate the composition of animals which rework the bottom with burrows, trails, tracks, ripples, hummocks, and depressions.

(2) Water areas to be protected: Class II - All soft bottom communities;

(3) Specific criteria to be applied - Oxidation-reduction potential (EH) in the uppermost ten centimeters (four inches) of sediment should not be less than -100 millivolts. The location and boundaries of each bottom-type class shall be clarified when situations require their identification. For example, the location and boundaries shall be clarified when a discharge permit is applied for or a waiver pursuant to Section 301(h) of the Act is required.

§11-54-8 Specific criteria for recreational areas.

(a) In inland recreational waters:

(1) Enterococcus content shall not exceed a geometric mean of 33 per one hundred milliliters in not less 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 CFU per 100 milliliters or the site-specific one-sided 82 per cent confidence limit. Inland recreational waters in which

(2) enterococcus content does not exceed the standard shall not be lowered in quality.

(3) At locations where sampling is less frequent than five samples per twenty-five to thirty days, no single sample shall exceed the single sample maximum nor shall the geometric mean of these samples taken during the 30-day period exceed 33 CFU per 100 milliliters.

(4) Raw or inadequately treated sewage, sewage for which the degree of treatment is unknown, or other pollutants of public health significance, as determined by the director of health, shall not be present in natural public swimming, bathing or wading areas. Warning signs shall be posted at locations where human sewage has been identified as temporarily contributing to the enterococcus count.

(b) In marine recreational waters:

(1) Within 300 meters (one thousand feet) of the shoreline, including natural public bathing or wading areas, enterococcus content shall not exceed a geometric mean of seven per one hundred milliliters in not less than five samples which shall be spaced to cover a period between twenty-five and thirty days. No single sample shall exceed the single sample maximum of 100 CFU per 100 milliliters or the site-specific one-sided 75 per cent confidence limit. Marine recreational waters along sections of coastline where enterococcus content does not exceed the standard, as shown by the geometric mean test described above, shall not be lowered in quality.

(2) At locations where sampling is less frequent than five samples per twenty-five to thirty days, no single sample shall exceed the single sample maximum nor shall the geometric mean of these samples taken during the thirty-day period exceed 7 CFU per 100 milliliters.

(3) Raw or inadequately treated sewage, sewage for which the degree of treatment is unknown, or other pollutants of public health significance, as determined by the director of health, shall not be present in natural public swimming, bathing or wading areas. Warning signs shall be posted at locations where human sewage has been identified as temporarily contributing to the enterococcus count.

NPS D-37, December 2005