NATIONAL PARK SERVICE
U.S. Department of the Interior

Water Resources Division
Natural Resource Program Center

Technical Report NPS/NRWRD/NRTR-2006/359

ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS AT PU‘UKOHOLA HEIAU NATIONAL HISTORIC SITE, HAWAI‘I

Dr. Daniel J. Hoover and Colette Gold

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, marine resource management, 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

Cover photos:

Top: NPS photo
Left: Carolyn Stewart
Right: Kristen Keteles
Bottom: Daniel Hoover

ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS AT PU‘UKOHOLA HEIAU NATIONAL HISTORIC SITE, HAWAI‘I

Dr. Daniel J. Hoover
Colette Gold

Technical Report NPS/NRWRD/NRTR-2006/359

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

November 2006

This report was prepared under Task Order J2380040120 of the Hawai‘i-Pacific Islands Cooperative Ecosystems Study Support 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. National Park Service personnel, cooperators and researchers working in and around the site were major resources for data, documents, and insight into the site and into related NPS activities: Eric Brown, Kuʻulei Rodgers, Daniel Kawaiaea, Clifford Lee, Kimber DeVerse, Page Else, Glenda Jackson, Peter Amerling, Carol DiSalvo, Terry Cacek, Cheryl Squair, Fritz Klasner, Gordon Dicus, Leslie HaySmith and Noelani Puniwai all are gratefully acknowledged for their input. Carolyn Stewart provided insight and materials relating to the Pelekane watershed and generously shared personal photographs. Sandy Margriter, Lisa Wedding, Matt Barbee, Viet Doan, and Nadine Golden provided GIS data and expertise, while Page Else, Mark Flora, Jeff Hughs, Roy Irwin, Kristin Keteles, and Fritz Klasner provided invaluable feedback on the draft report and Reuben Wolff provided expert assistance with the USGS PACN water quality database. Kathy Kozuma provided her usual expert assistance and positive attitude, Kellie Gushiken provided exceptional trans-Pacific support, Fred Mackenzie provided office space and computer resources, and Rebecca Scheinberg is gratefully acknowledged for her (still) tireless support, patience, and good cheer.

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
GPS	Global Positioning System
ha	hectare
HAVO	Hawai‘i Volcanoes National Park
HI	Hawai‘i
HUC	Hydrologic Unit Code
I&M	Inventory & Monitoring Program (NPS)
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 Network (NPS)
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	Pu‘ukohola Heiau National Historic Site
PUHO	Pu‘uhonua o Honaunau National Historical Park
RA	Rapid Assessment (CRAMP)
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 Hawai‘i
USGS	U.S. Geological Survey
VOGNET	Volcanic Fog Monitoring Network
WHAP	West Hawai‘i 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

Pu‘ukohola Heiau National Historic Site (PUHE) is a small site (25 ha/61 acres) located on the west coast of the island of Hawai‘i. The site includes two major Hawaiian temples (heiau) and the homestead of John Young, an important historical figure associated with early western influence on Hawaiian culture. The site was established primarily to preserve and protect native Hawaiian culture and cultural resources, but the site and adjacent marine waters (technically outside of NPS jurisdiction, but included here as a site resource) also contain important water resources. The climate is arid, and aside from an intermittent stream and a normally-dry gulch, there are no freshwater resources in or near the site. Brackish groundwater flows seaward through the site and is exposed in the stream channel and the gulch near the coast, and occasional stream discharges and persistent groundwater seeps along the shoreline affect intertidal and coastal water quality. Brackish and marine waters in and adjacent to the site support a variety of flora and fauna – coastal waters adjacent to the site are impacted heavily by sediment, but the coral reef offshore of the site is one of the best-developed shallow-water coral reef systems in west Hawai‘i. Water resources in and around the site have significant cultural and ecological value, but are vulnerable to impacts associated with upslope and adjacent development, which have affected coastal circulation and appear to have affected groundwater supply and possibly quality, to impacts associated with maintenance of cultural and archaeological resources in the site, and to degradation due to visitor activities. While development in the upslope watershed so far has been less intense than in many other areas of west Hawai‘i, future development likely will result in further reductions in groundwater flow and increases in nutrient and other contaminant loading to site resources. No point-source pollutant discharges are present in PUHE, but a number of non-point sources in and around the site have the potential to affect coastal water resources, particularly cattle grazing upslope of the site, activities associated with the deep-draft and small-boat harbors immediately north and offshore of the site, activities associated with a popular County beach park to the south, and operation of a septic leach field and various maintenance activities in the site.

Despite the potential value of water resources in and adjacent to the site, there are very few data available for quantitative assessment of water quality and biological resource condition. The National Park Service (NPS) ‘Horizon’ report (National Park Service 1999) and a new USGS water quality database (Wolff unpubl. 2005) include a number of monitoring locations in and near the site, but most are too distant to provide insight into the quality of site waters, and data from the remaining locations mostly are limited either to very short periods of measurement (one day to two months) or include measurements of only a few water quality parameters. As a result, available data are inadequate to characterize water quality in and around the site.

Biological assessments are more numerous than water quality measurements, but biological assessments of site water resources also have been sporadic, usually limited in scope, and often have not used quantitative methods, making it difficult to compare results across studies. However, combining available data from the water quality databases with additional water quality and biological data from published reports does provide some insight into water quality and biological resource conditions in the site’s groundwater, anchialine pools, intertidal areas, and coastal waters.

Although quantitative data are sparse, coastal waters adjacent to PUHE clearly are degraded significantly compared to neighboring coastal areas and likely compared to historical conditions. Degradation appears to be due primarily to the large quantities of terrigenous sediment trapped in Pelekane Bay, which results in persistent turbid conditions and has prevented recovery of the coral reef ecosystem that existed prior to construction of Kawaihae harbor. The most effective solution to the problem would be removal of the harbor, which would allow sediments reaching nearshore waters to be transported along- and offshore as they were prior to harbor construction. More practical approaches might include options for sediment removal from Pelekane Bay or reduction of sediment delivery to the bay. Unfortunately, while the complete lack of data on sediment fluxes to the bay makes it difficult to quantify the potential for remediation, these approaches seem unlikely to have a significant impact on coastal water quality and ecosystem structure under the current conditions of drastically reduced circulation in the bay. Management of site lands and adjacent harbor lands to minimize dust might benefit site waters and would enhance the visitor experience in the terrestrial portion of the site, although there are cultural considerations that favor maintaining PUHE's landscape in a relatively unvegetated, and thus dust-prone, state. Similarly, the complete lack of water quality data prevents precise assessment of the condition of affected site resources; a basic program of water quality monitoring thus is needed to provide baseline data for effective management. Overall, priority should be given to characterizing sediment supply to coastal waters, the fate of sediment after delivery, and the short- and long-term impacts of sediment on water quality and coastal biota. Other high-priority work should include characterizing groundwater fluxes to coastal waters, which appear to have declined dramatically in recent years, characterizing the unique anchialine/estuarine system in the lower reaches of Makeahua Stream and investigating the factors responsible for the persistent presence of sharks in Pelekane Bay.

Biological resources in site waters also are poorly characterized, but available data do indicate that 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 water quality and biological data adequate for assessing current status and future trends. Key features and issues in each of the major water resource areas are summarized briefly below.

Surface water

There are no perennial streams or other surface water bodies in the site. Pohaukole Gulch and the portion of the Makeahua Stream channel that is adjacent to the site normally are dry and contain freshwater only during occasional high-runoff events, and no water quality or biological resource data are available for either system. Surface water thus is not considered as a resource in this report, although the brackish anchialine/estuarine systems found in the lower reaches of the stream channels are considered below.

Groundwater

Coastal water quality data and anecdotal information and observations show that significant amounts of groundwater do discharge along PUHE's coastline, but no data are available to assess the quality of the groundwater in the site itself. Data from one long-term coastal water quality monitoring location just south of the site suggest that the quality of groundwater in the area is relatively similar to uncontaminated groundwater in other areas in west Hawaiʻi, but that groundwater flows have declined significantly over at least the last 16 years. The absence of obvious nutrient contamination in nearby groundwater and the lack of major contaminant sources in the watershed suggests that the risk of groundwater contamination in the site is fairly low. However, the recent installation of a septic leach field in the site may provide a significant source of nutrients to site groundwater, and groundwater may provide important habitat for hypogeal anchialine organisms. As a result, toxic contaminants still may be a concern, as are invasive species that could displace endemic hypogeal species. Groundwater also contributes significantly to water in the anchialine pools in Makeahua Stream and Pohaukole Gulch, and affects water quality in intertidal and nearshore areas, so groundwater quantity and quality are concerns in those areas.

Anchialine pools

Anchialine pools are rare, and associated ecosystems are poorly understood. The two major pools in the stream channels in the site are unusual compared to 'typical' anchialine pools in that they are subject to occasional flushing by high runoff events, and the pool in Makeahua Stream seasonally is connected to Pelekane Bay when high runoff events breach the sand berm at the mouth of the stream. Data either are not available or are insufficient to adequately assess water quality or biological conditions in these pools, although historical data suggest that alien fish (*Tilapia* spp.) are established in one or both pools. Anchialine pools are affected significantly by groundwater quality, but because the probability of groundwater contamination seems low, groundwater contaminants seem unlikely to be a major issue for the site's pools. However, excess sediment (due to enhanced erosion in the watershed) delivered during storm runoff events may affect pool ecosystems, and the lack of chemical and biological data suggests that it is prudent to leave open the possibility that contamination by metals and toxic compounds could be an issue, particularly given the presence of numerous potential sources in and around Kawaihae harbor to the north and associated with the highway immediately inland of the site, and the presence of significant quantities of waste concrete around the pool in Pohaukole Gulch. Pool ecosystems also may be impacted by changes in groundwater flow due to upslope development. While anchialine ecosystems in general 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 and to changes in atmospheric CO_2. Anchialine pools have been impacted significantly by coastal development throughout the state, despite the fact that pools provide habitat for some rare and candidate endangered species, such as the orange-black damselfly (*Megalagrion xanthophelas*), which may be vulnerable to changes in habitat and to predation by alien species, such as orb-weaver spiders.

Wetlands

PUHE's wetlands primarily are associated with the large anchialine/estuarine pool in Makeahua Stream. Wetlands are rare in west Hawaiʻi, so PUHE's wetlands provide potentially important habitat for insects, plants, and transient birds. No water quality data are available for PUHE's wetland habitat, but there is no obvious indication of water quality issues in groundwater, which supplies most of the freshwater to the system, or of water quality impacts on existing biota. However, wetlands are subject to flooding and sediment loading during storm runoff events and can accumulate metals and toxic compounds, so problems could exist in these areas given the excessive erosion occurring in the watershed and the proximity of potential contaminant sources associated with Kawaihae harbor and the highway adjacent to the site. Wetlands also may be susceptible to salinity changes due to changing groundwater flux. Alien species that displace native species are another concern - efforts to eradicate *B. maritima* appear to have been successful, but continued monitoring is needed to prevent reestablishment, and other alien species still are present and may be affecting wetland function. Light pollution also may be an issue for wetland fauna if lighting associated with the harbor reaches the wetland area.

Intertidal

Biological resources in PUHE's intertidal have received only cursory study, but available data and a site visit suggest that the generally poor water quality in Pelekane Bay probably is impacting the intertidal community. The degree to which individual water quality factors are impacting intertidal resources is not known, but it seems likely that elevated nutrient concentrations (due to enhanced groundwater residence time in intertidal areas and nutrient release from sediments, and possibly due to nutrient inputs from the on-site septic leach field) and sediment loading may be issues. Increasing atmospheric CO_2 levels also may affect calcifying organisms in intertidal areas. No data are available on the degree to which recreational harvesting of intertidal organisms may be impacting this resource, but harvesting does affect resources in many areas and the proximity of PUHE's intertidal zone to high-use areas in Spencer Beach Park suggests that this could be an issue. Intertidal zones also may provide habitat for green sea turtles (*Chelonia mydas*), and for threatened hawksbill turtles (*Eretmochelys imbricata*) and endangered Hawaiian monk seals (*Monachus schauislandi*), creating potential behavioral impacts due to visitor activities in these areas. Intertidal areas also are vulnerable to sea level rise, and possibly to light pollution from harbor or site sources.

Coastal waters

Coastal waters include both pelagic habitat and a variety of benthic habitats, from subtidal sediments to coral communities, that support resident and transient fish, reptiles, mammals, invertebrates, and other organisms, including turtles, sharks, and threatened humpback whales (*Megaptera novaeangliae*) that seasonally are found offshore of the site. Studies that have addressed pelagic and benthic biological resources generally have concluded that they are degraded significantly in nearshore areas, with conditions improving rapidly in more offshore waters. The principal factor responsible for the degraded conditions appears to be sediment deposited in Pelekane Bay by Makeahua Stream, which is retained in the bay due to sluggish circulation. Sediments may impact coastal resources in several ways, including via the direct effects of sediment loading on biota, via nutrient, metal, and toxic compound release from sediments, and via increased turbidity, which affects biota directly and also enhances survival of fecal bacteria by reducing ultraviolet penetration into the water. Groundwater discharging to Pelekane Bay also affects water quality, and the effects of groundwater additions (e.g., decreased salinities and increased nutrient concentrations) may be increased by the extended residence time of nearshore waters in Pelekane Bay. However, the effects of increased residence times may have been offset to some degree by recent (over at least the last 16 years) reductions in groundwater discharge to coastal waters. Contaminant inputs from the highway adjacent to the site, from the new visitor facilities, and from sources in the small boat harbor offshore of the site are possible concerns. Fecal bacteria potentially may be an issue based on monitoring at an adjacent coastal site off of Spencer Beach Park, but data from that site may be confounded by the persistence of enterococcus in Hawaiian soils. At least three alien fish species are established around the site, and stressors such as sound and light pollution and behavioral impacts due to visitor activities (e.g. wading, swimming, snorkeling, SCUBA diving, and boating) have not been addressed but may be significant for organisms like turtles and sharks that frequent the bay. 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. Alien species introductions are a particular concern at this site because of its proximity to Kawaihae harbor, where vessel hulls and ballast water provide regular opportunities for alien species introductions, and vessel traffic is expected to increase in the near future.

Table i summarizes the above discussion in terms of the major stressors affecting site coastal water resources and our assessment of existing and potential degradation due to these stressors. Because so few quantitative data are available, most assessments were made using primarily professional judgement, and even areas known to be degraded have insufficient data to adequately characterize the stressors involved and the associated impacts. Some stressors are associated with development around the site and with visitor impacts on the site, 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. Degradation of resources in and around the site is well established only for sediment impacts on coastal waters and invasive species in wetlands around the anchialine pool in Makeahua Stream, but invasive species also may be impacting other resources, and potential problems exist in many other areas.

Recommendations for studies, monitoring, and actions to address existing and potentially degraded resources are summarized in Table ii. Although a number of ongoing and planned studies will improve knowledge of the status of some resources, major 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 current water quality and biological resource conditions in the site, and will allow for a more complete assessment of vulnerability to the stressors listed in Table i.

Table i. Degraded and potentially degraded coastal water resources in and adjacent to PUHE.

	Resources				
Stressor	Ground-water	Anchialine Pools	Wetlands	Intertidal	Coastal Waters
Water Quality					
Nutrients	OK	OK	OK	PP	PP
Fecal bacteria	OK	OK	OK	OK	PP
Dissolved oxygen	OK	OK	OK	OK	PP
Metal contamination	OK	PP	PP	OK	PP
Toxic compounds	PP	PP	PP	OK	PP
Sediment	na	PP	PP	PP	EP
Increased temperature	OK	OK	OK	OK	PP
Increasing CO2	OK	PP	OK	PP	OK
Water Quantity					
Changing GW flux	OK	PP	PP	OK	PP
Population Effects					
Fish/shellfish harvest	na	OK	OK	PP	PP
Invasive species	PP	PP	EP	PP	PP
Physical impacts	na	OK	OK	OK	OK
Behavioral impacts	na	OK	OK	PP	PP
Habitat Disruption					
Sea level rise	OK	OK	OK	PP	PP
Sound pollution	na	OK	OK	OK	PP
Light pollution	na	OK	PP	PP	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 problems.

Studies

1. Characterize stormwater runoff frequency, intensity, and quality in Makeahua Stream
2. Characterize groundwater flow through PUHE, and its sensitivity to existing and planned development (withdrawals and wastewater inputs) in the site and in adjacent and upslope areas.
3. Characterize groundwater quality in the site in conjunction with Study 8 and with Study 1 and/or Study 11.
4. Map, describe, and document the biological status of anchialine pools and associated wetland areas in the site.
5. Characterize water quality and major physical (including hydrology and sediment delivery and removal), and biological processes affecting water quality in the anchialine/estuarine pools and associated wetland areas in the site. Study should be coordinated with Study 1 to determine the short- and long-term impacts of runoff events on anchialine and wetland ecosystems.
6. Characterize ecosystem structure and function in the anchialine/estuarine pools at the mouth of Makeahua Stream and in Pohaukole Gulch. If appropriate, evaluate the impact of alien fish on ecosystem function and include an assessment of the feasibility and benefits of removing alien species.
7. Assess the feasibility and benefits of eradicating alien species in site wetlands.
8. Characterize the locations and intensity of groundwater inputs to coastal waters, preferably in association with Study 2
9. Perform a quantitative survey of biological resources in rocky intertidal zones in the site.
10. Characterize coastal circulation in Pelekane Bay and offshore to determine the residence time of pollutants delivered to the bay, and the potential for contaminant inputs from Kawaihae harbor.
11. Characterize water quality at a nearshore site in Pelekane Bay off the mouth of Makeahua Stream, and at at least one, and preferably two additional sites along an onshore-offshore transect to characterize the water quality gradient in the bay. Data from an offshore ‘clean’ site also will be needed to facilitate interpretation of results from sites in Pelekane Bay.
12. Use results from studies above to assess ecosystem function in Pelekane Bay and the potential benefits of removing existing sediments and /or reducing sediment inputs to the bay.
13. Characterize recreational fishing catch and effort in waters around to the site.
14. Characterize recreational snorkeling and SCUBA activity in and around the site.
15. Characterize frequency and type of use of the small-boat harbor offshore of the site and of boating activities in and around Pelekane Bay.
16. Perform a preliminary assessment of underwater noise pollution in coastal waters adjacent to the site and the potential for impacts to biological resources.
17. Conduct a preliminary assessment of shark populations and activity in Pelekane Bay.
18. Conduct a preliminary assessment of the sea turtle population and associated activities in waters adjacent to the site. The assessment should be coordination with ongoing monitoring being performed at KAHO and with other west Hawai‘i turtle monitoring being performed by NMFS.

Monitoring

1. Monitor storm runoff frequency, intensity, and water quality in Makeahua Stream.
2. Monitor groundwater levels and groundwater quality in the site.
3. Monitor water quality and biological status of anchialine pools, including rare and endangered species.
4. Monitor PUHE’s coastal waters and intertidal areas for *A. spicifera* and other invasive alien algae.
5. Monitor nearshore water quality in Pelekane Bay at a site off of the mouth of Makeahua Stream.
6. Monitor benthic ecosystem status on permanent transects for comparison to historical assessments and ongoing WHAP and CRAMP monitoring at other west Hawai‘i sites, including coral health and alien species.

Actions

1. If determined to be feasible and beneficial, remove alien fish from anchialine pools.
2. If justified by studies, remove sediments from Pelekane Bay and/or reduce sediment loads to the bay, and work with appropriate State and local agencies to manage sediment sources in the Pelekane watershed.

3. If determined to be feasible and beneficial, eradicate alien wetland plants from the site.
4. If appropriate, work with the State of Hawaiʻi to increase public education regarding fishing regulations and impacts on site resources.
5. Collaborate with researchers working in the site to maximize the relevance of ongoing and planned studies to site needs for basic, robust data on water quality and aquatic biological resources in the site.
6. Expand site interpretive materials to include information on site water resources and their vulnerability to development in and around the site, and cultural aspects of current and historic water resources.
7. Coordinate with appropriate State agencies to provide informational materials to boaters using the small-boat harbor to minimize pollutant releases and impacts to coastal water resources.
8. Collaborate with the State of Hawaiʻi and others to enhance the level of resource protection and conservation of adjacent lands and coastal waters, including Pelekane Bay.

A. INTRODUCTION

This project was conducted to assess coastal water resources in Pu‘ukohola Heiau National Historic Site (PUHE), on the west coast of the island of Hawai‘i (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. 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 and around the watershed also were considered as they might affect coastal water quality and resources. A variety of information sources were reviewed to obtain data on coastal water resources in and adjacent to the site. Sources cited in the text are listed in the Literature Cited section; other relevant sources are included in Appendix A.

B. SITE DESCRIPTION

B.1. Background

B.1.a. Location, setting, and site holdings

Pu‘ukohola Heiau National Historic Site (PUHE) is located on the western shoreline of the island of Hawai‘i at the base of the Kohala volcano (Figure 1). The main site parcel contains the visitor center and two heiau (Pu‘ukohola and Mailekini), and includes about 300 m of rocky shoreline. A small parcel immediately north and west of the main parcel is not owned by the site, but is managed by the site and includes a sandy beach and an inland area (Pelekane) that was used as a Royal Courtyard by Kamehameha I, as well as the lower reaches of Makeahua Stream and Pohaukole Gulch, which contain brackish pools and/or estuarine segments near the coast. Another small parcel is situated inland of Highway 270, but does not contain any significant water resources and is not considered in this report. Coastal waters adjacent to the site originally were intended to be included in the site but currently are under the jurisdiction of the State of Hawai‘i. These waters do contain cultural and biological resources relevant to the site, so they are considered site resources in this report. Coastal waters adjacent to the site are shallow and are dominated by extensive areas of sand and silt, while offshore waters contain an unusually well-developed shallow-water coral reef system. Waters adjacent to the site are reported to contain a shark heiau (Hale o Kapuni), although no visible evidence of the heiau exists today.

PUHE formally was authorized in 1972, with the primary purpose of preserving and providing interpretation of this major Hawaiian cultural site, including the three heiau (two onshore and one offshore) and the remnants of the homestead of John Young, a key figure in early western influence on Hawai‘i. The focus of the site is Pu‘ukohola Heiau, due to its central role in the consolidation of Kamehameha I’s power in Hawai‘i. The Royal Courtyard (Pelekane) also is a significant feature as it was a place of residence for Kamehameha I and thus figured prominently in Hawaiian life during the years following initial western contact in 1778. Little is known of the purpose or history of Mailekini heiau, and the shark heiau is known only from sparse anecdotal information and possibly a few photos.

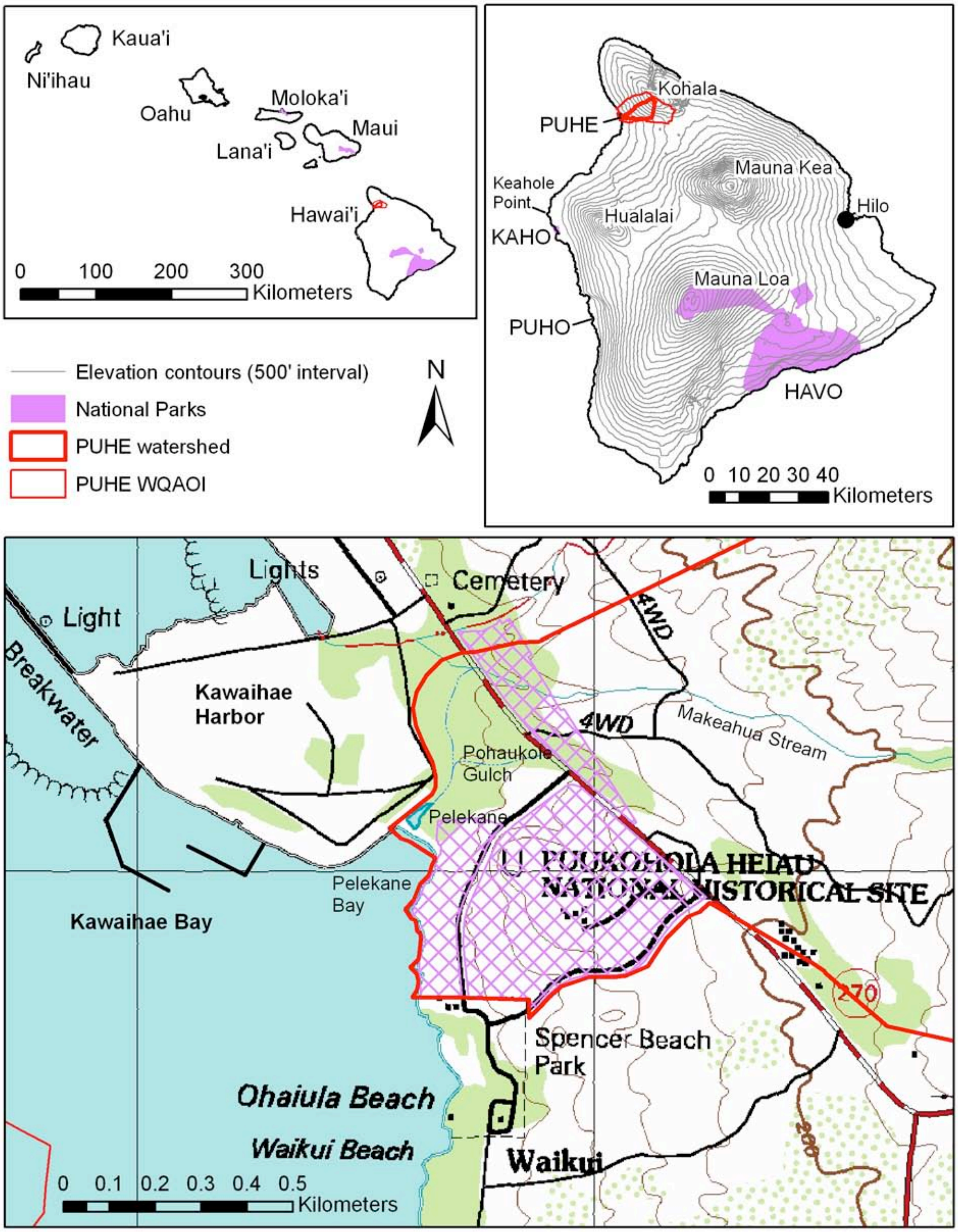


Figure 1. PUHE and its associated watershed and Water Quality Area of Interest (WQAOI). Contour lines in USGS topographic map in lower panel are at 40' (12.1 m) intervals.

While PUHE primarily is an archaeological/cultural site, site waters and associated habitats also are potentially significant resources. Anchialine/estuarine habitat can be found throughout the year in the lower reaches of Makeahua Stream and Pohaukole Gulch, and the lower reaches of Makeahua Stream support an extensive riparian zone, including salt marsh habitat, that is rare in this region of Hawai‘i. Intertidal areas include a sand beach (also rare in this region), with a narrow rocky intertidal zone along most of the western margin of the site. Groundwater discharges offshore of the site appear to have unusually elevated temperatures due to residual volcanic heat, and an intertidal groundwater spring in or near the site historically was used for bathing and was thought to have curative powers. Coastal waters immediately adjacent to the site are shallow and impacted significantly by terrestrial sediment, resulting in high turbidity and relatively low biological diversity, but offshore waters contain one of the most extensive shallow-water coral reef ecosystems in west Hawai‘i, and sharks frequently are sighted in the shallow waters of Pelekane Bay in the presumed vicinity of Hale o Kapuni. Threatened green sea turtles frequently can be found in waters around the site, and threatened humpback whales can be observed seasonally in offshore waters.

B.1.b. Land use

PUHE is located in a relatively undeveloped region of the island (Figure 2), but is sandwiched between the major development of Kawaihae Harbor on the north and a popular county beach park on the south (Figure 1). Harbor construction in the late 1950s included dredging of a large area of pristine reef in Kawaihae Bay and the construction of an extensive breakwater system. Filled areas along the shoreward and southern portions of the harbor created extensive new land area north of PUHE, drastically modifying the local coastline and circulation in nearshore waters (Figure 3). The coastline was altered further by the additions of two breakwaters to the outer wall of the main harbor to form a small boat harbor (Figure 3). The main portion of the northwestern breakwall was completed by at least 1971; an extension and the southern breakwall were added in the late 1990’s. Harbor construction apparently also redirected the outflow of Makeahua Stream, diverting it around the harbor to the south to its current discharge point at Pelekane Beach. Sediments discharged from Makeahua Stream subsequently have caused significant accretion of the beach area in front of Pelekane (Figure 3), and shoaling of Pelekane Bay. Development in the beach park to the south consists primarily of a paved parking area and restroom facilities, which presumably use a septic system for waste disposal. Upslope development includes a quarry about one-half mile inland in or adjacent to the Makeahua Stream channel (apparently now inactive, originally developed for construction material for the harbor), and Kawaihae Village, a small urban development just east of the intersection of Kawaihae Road and Queen Ka‘ahumanu Highway. Both of these are in an area currently zoned for urban use (Figure 4a). Most of the remainder of the watershed upslope of the site is zoned for agriculture and is used for grazing, with a small area of conservation land at the top of the watershed, and a tiny patch of cultivated land near the southern border of the watershed. Land use planning for the area includes conversion of much of the urban area to industrial uses, with a large area of agricultural land immediately upslope of the site slated for urban expansion (Figure 4b). While development immediately upslope of PUHE currently is relatively minor, activities upslope of the site still may affect the site as groundwater can carry contaminants downslope to the site, and development in the area likely will increase in coming years.

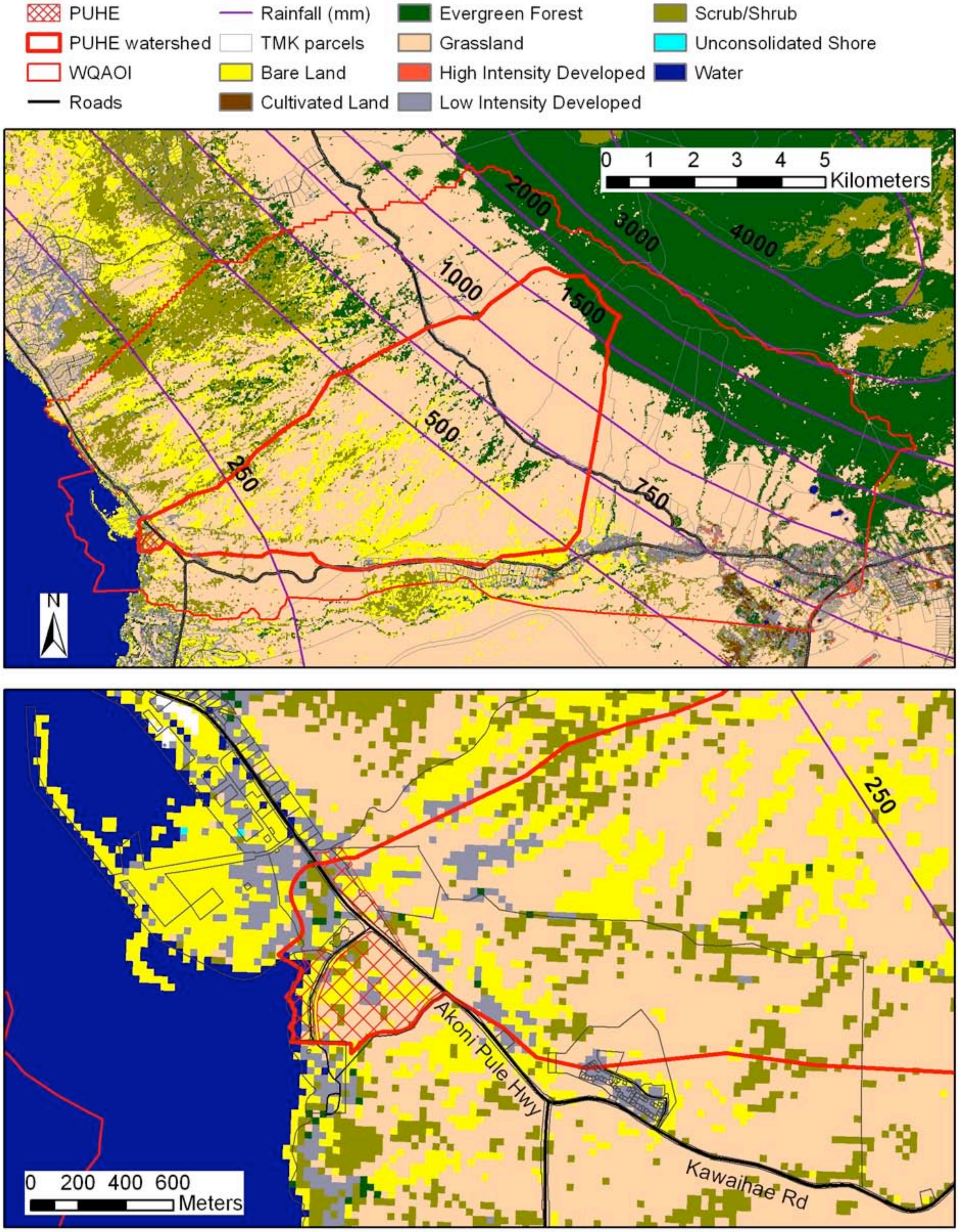


Figure 2. Land cover and development in the PUHE watershed and WQAOI circa 2001. Data from NOAA (http://www.csc.noaa.gov/crs/lca/hawaii.html).

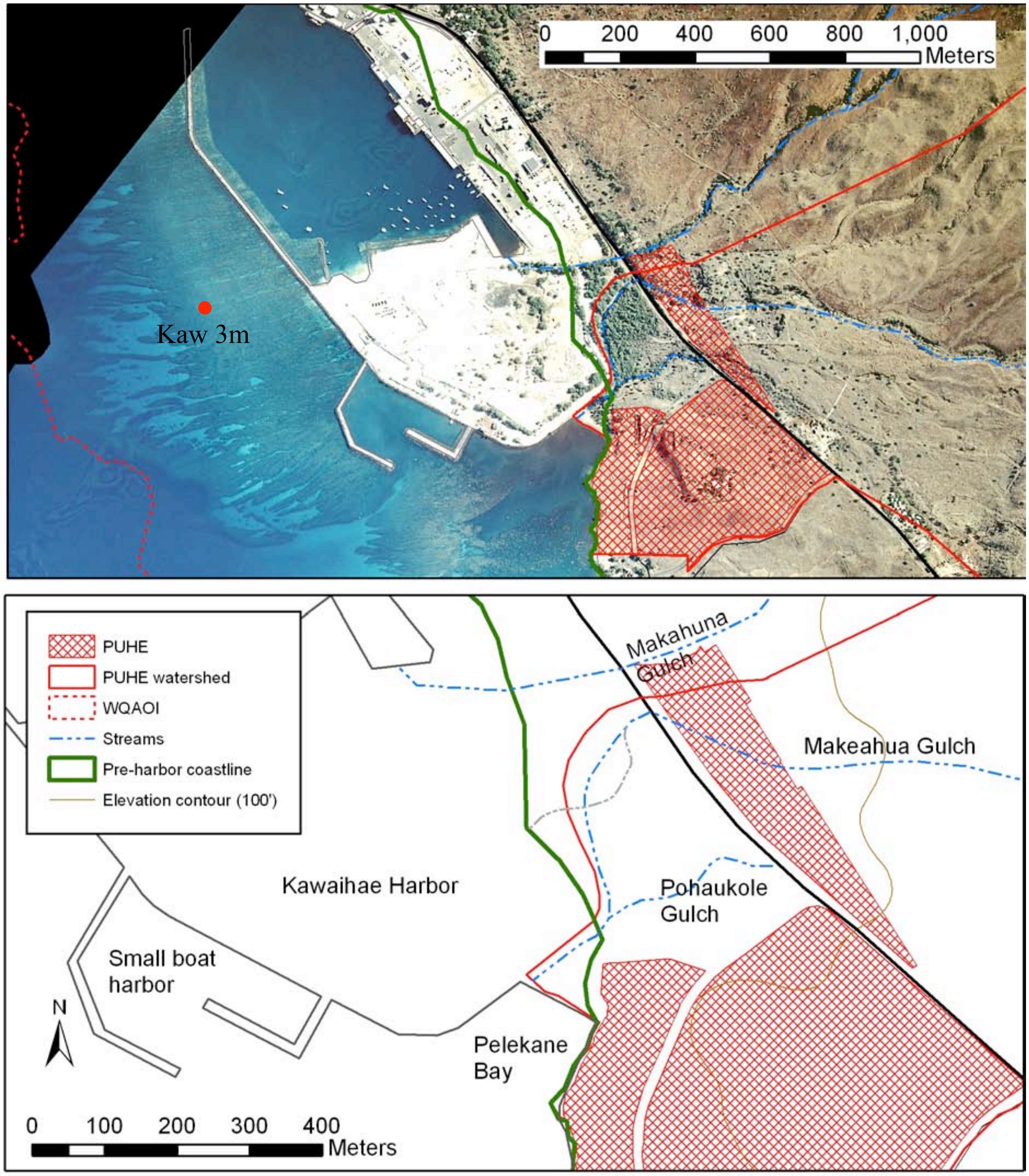


Figure 3. Coastline modification resulting from Kawaihae Harbor construction in the late 1950s and subsequent filling of Pelekane Bay by sediments from Makeahua Stream. Pre-harbor coastline is drawn from aerial photo in Kelly (1974) and from 1956 coastline trace in Figure 8 in Harbors Division (1985). Likely pre-harbor outlet for Makeahua Stream is shown in gray in lower panel based on features in aerial photo in Kelly (1974). The approximate position of the CRAMP 3m Kawaihae monitoring site also is shown in the upper panel.

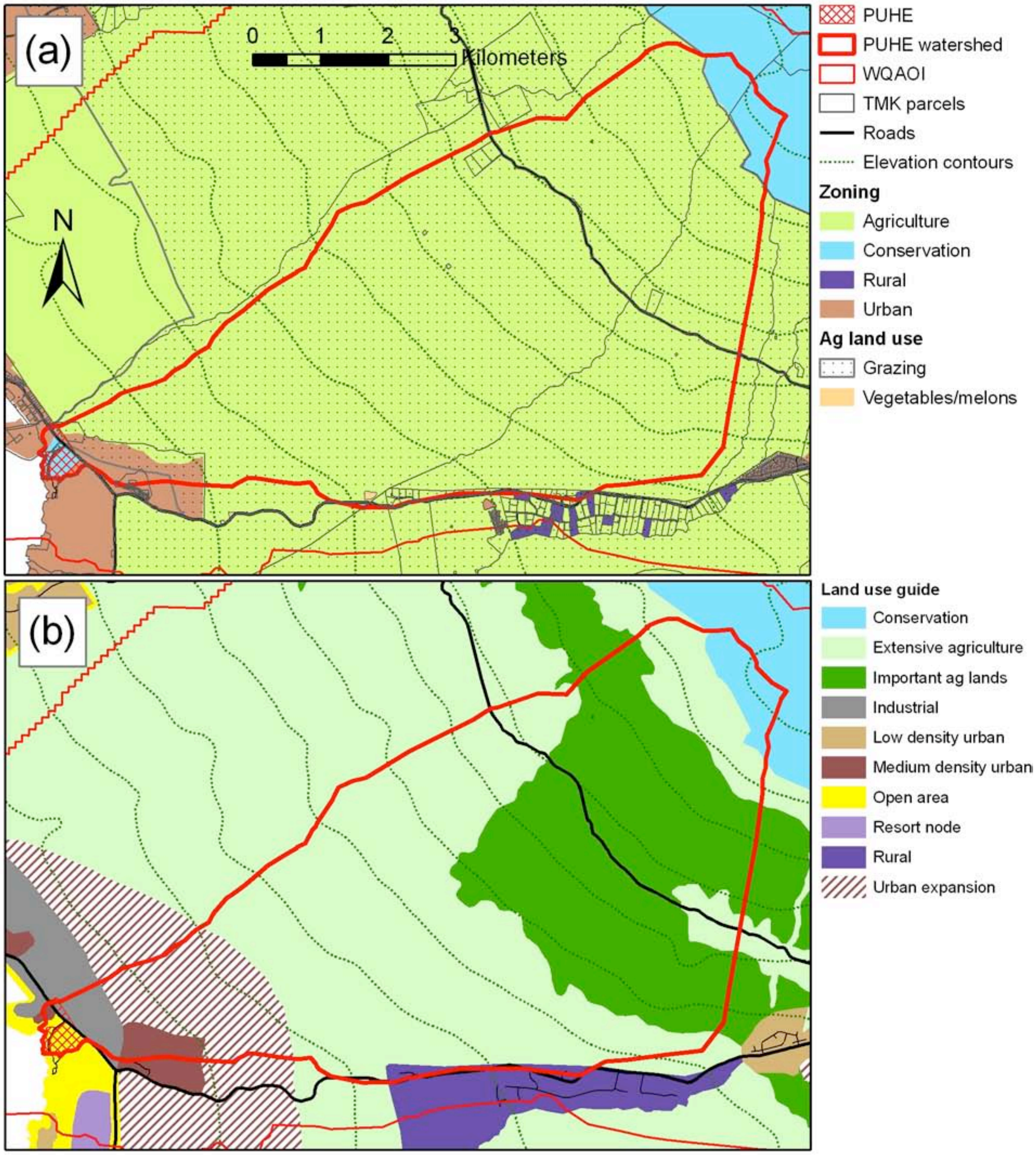


Figure 4. (a). Zoning (2004 State land use districts) and agricultural land use (circa ~1979) in the PUHE watershed. (b) Future land use pattern allocation guide from the 2005 Hawaii County general plan.

Development inside the site currently is limited to the site visitor facilities and parking lot. The park restroom facilities use a septic system with a leach field located in the upslope portion of the site. Pratt (1998) states that a concrete plant was placed in the Pelekane area in the 1960's, but that "no obvious sign of the plant remains at the site", although concrete waste still is visible on the walls and floor of Pohaukole Gulch. Pratt (1998) also notes that "earlier uses of the area included a railway and charcoal production".

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

The Kawaihae area is one of the driest and in many ways one of the least hospitable areas on the island of Hawaiʻi. Despite this, Kawaihae has a long history of human occupation and has played a central role in a number of important events in ancient and recent Hawaiian history. Prior to construction of the artificial harbor, Kawaihae Bay provided one of the best natural anchorages along the west coast of the island of Hawaiʻi. Because marine resources also are unusually abundant in the area, human occupation and activity probably dates back to the time of early Hawaiian colonization of the west coast of the island. In addition to the natural anchorage and marine resources, Kawaihae also had a significant brackish spring (apparently destroyed during construction of the deep-draft harbor (Greene 1993)) - freshwater is virtually nonexistent in coastal areas in west Hawaiʻi, and brackish sources usable for consumption were highly prized. In fact, the name Kawaihae means "water of wrath" which has been interpreted to refer to battles over water from this spring (Greene 1993). Kawaihae has played an important role in post-contact Hawaiian history, as it was the site of the building and consecration of Puʻukohola heiau and the place where Kamehameha I established his preeminence as the ruler of the island. It also served as the royal residence from 1790 to 1794, as well as in 1819 immediately following Kamehameha I's death.

Kawaihae has been an important trade center throughout its history. Prior to western contact, Kawaihae's suitability for landing canoes made it the logical site for the seaward end of the historical trail between the coast and rich agricultural fields in the Waimea area, upslope of Kawaihae. Following western contact, Kawaihae was known as the best place on the island to buy fish, and salt produced in the area was an important commodity that was both exported and used to preserve fish and meat that was traded with visiting ships. Sandalwood had become an important trade item by 1812, but supplies were essentially exhausted by the mid 1830's and overharvesting resulted in significant damage to the Kawaihae watershed. Although the prehistoric Kohala forests apparently reached nearly to the shore as late as 1815, deforestation due to overharvesting and the effects of cattle introduced in 1793 (and 'running wild by 1807' (Greene 1993)) eventually converted most of the lower elevation areas to scrub grassland. Following the decline of the sandalwood trade, activity in the Kawaihae area centered around supplying visiting whaleships and other traders with food from upslope areas. Later, as the cattle industry grew in upslope areas, Kawaihae became the main port for export of live cattle and cattle products to other islands. Population in the Waimea-Kawaihae area declined significantly throughout the 1800s, but Kawaihae remained the principal port for the area. In the late 1950's Kawaihae Harbor was built to accommodate deep-draft vessels, and the small boat harbor outside of the main harbor was completed in the late 1990s.

Today, human activity around PUHE is centered on commercial and recreational boating associated with Kawaihae harbor to the north and recreational use of Spencer Beach Park to the south, with a small amount of residential development upslope of the site. Activities within the site focus on cultural aspects, including both interpretive materials and continuing use of the site by cultural practitioners (Tetra Tech 2004). Visitation to the site is relatively modest due to its small size, remote location and limited facilities, but visitation has increased in recent years (from 61,000 visitors in 2002 to 100,000 in 2004; http://www.nps.gov/puhe/pphtml/facts.html) and is expected to continue to increase with recent improvements to the site's infrastructure and as tourism and population increase statewide and in the neighboring Kona district in particular.

B.2. Hydrologic information

B.2.a. Oceanographic setting

Oceanographic features of site waters are not well characterized. Some data are available from studies performed in support of construction and modification of Kawaihae Harbor, north of the site, and some general aspects can be inferred from the location of the island relative to large-scale oceanographic features, from the position of the site on the island's west coast, and from local topography and limited nearshore oceanographic data. Nearshore circulation probably has been simplified considerably by the construction of Kawaihae harbor, which blocks longshore currents and produces relatively stagnant conditions in Pelekane Bay, although intertidal and subtidal brackish groundwater discharges and occasional stream water discharges also may have significant effects on circulation and stratification in the bay.

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 Hawaiian 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 (Bidigare et al. 2003), but their importance to the resources immediately adjacent to PUHE is not known. Coastal currents offshore of the site probably vary significantly with tides (Neighbor Island Consultants 1974; Armstrong 1983) and with the presence and location of the eddies noted above (Seki et al. 2002) and of smaller eddies adjacent to Kawaihae Harbor off of Pelekane Bay (Neighbor Island Consultants 1974). Tides along the west Hawai‘i 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); rates probably vary over time, but present-day rates probably are on the order of 0.34 cm (0.13 inch) per year (Hapke et al. 2005).

The location of the site on the west coast of the island of Hawai‘i causes site waters to be sheltered from wave action associated with the prevailing NE tradewinds, and reduces the intensity of wave energy associated with northerly and southerly swells. Northerly swells can be particularly large, but significant protection from these swells is provided by ‘shadowing’ by the island of Maui and the other islands in the Hawaiian archipelago, and by Kawaihae Harbor immediately north of the site. Southerly swells also are attenuated by the sheltering effect of Keahole Point to the south of the site (Figure 1).

Details of PUHE’s nearshore oceanography are not well known. Currents offshore of the site are thought to flow in a southerly direction at velocities on the order of 0.4 knot (Armstrong 1983), but the construction of Kawaihae Harbor in 1959 resulted in the formation of a protected nearshore zone (Pelekane Bay) immediately adjacent to the mouth of Makeahua Stream and the beach at Pelekane (Figure 3). Waters in this area are shallow (mostly less than 2 m (7’) deep; Figure 5) , and deposition of sediments from occasional storm runoff discharges has resulted in significant areas of soft sediments and little vertical relief. Topography thus probably has little influence on circulation in nearshore areas. Winds and tides likely are the most important factors affecting circulation in Pelekane Bay, although winds normally are light (nearly calm at night with an onshore sea breeze on the order of 3 – 6 m/s (7 – 13 mph) during the day (Figure 6)), tidal range is small (normally about 0.4 m (http://tidesandcurrents.NOAA.gov/, Kawaihae Harbor Station 1617433), and the enclosed nature of the bay should limit current development. For instance, currents off of the site during typical wind conditions have been measured at just 0.02 to 0.1 knot, while significantly higher velocities were observed in the less protected waters off of Spencer Beach Park, just south of PUHE (Harbors Division 1985). Transient events may result in increases in local circulation: occasional strong, gusty offshore wind events can drive nearshore surface waters offshore, resulting in upwelling of deeper, cooler waters along the coast (Figure 6), and high surf breaking on the reef seaward of Pelekane Bay can result in wave set-up and associated currents in the bay. Although the tidal range is small, the generally shallow depths in the bay suggest that a significant portion of bay water still may be exchanged with offshore waters during a tidal cycle. However, the degree of exchange ultimately depends on mixing of bay waters with offshore or deeper waters, or of advection of bay waters away from the area, and both of these processes may frequently be inefficient given the relatively weak circulation in the area.

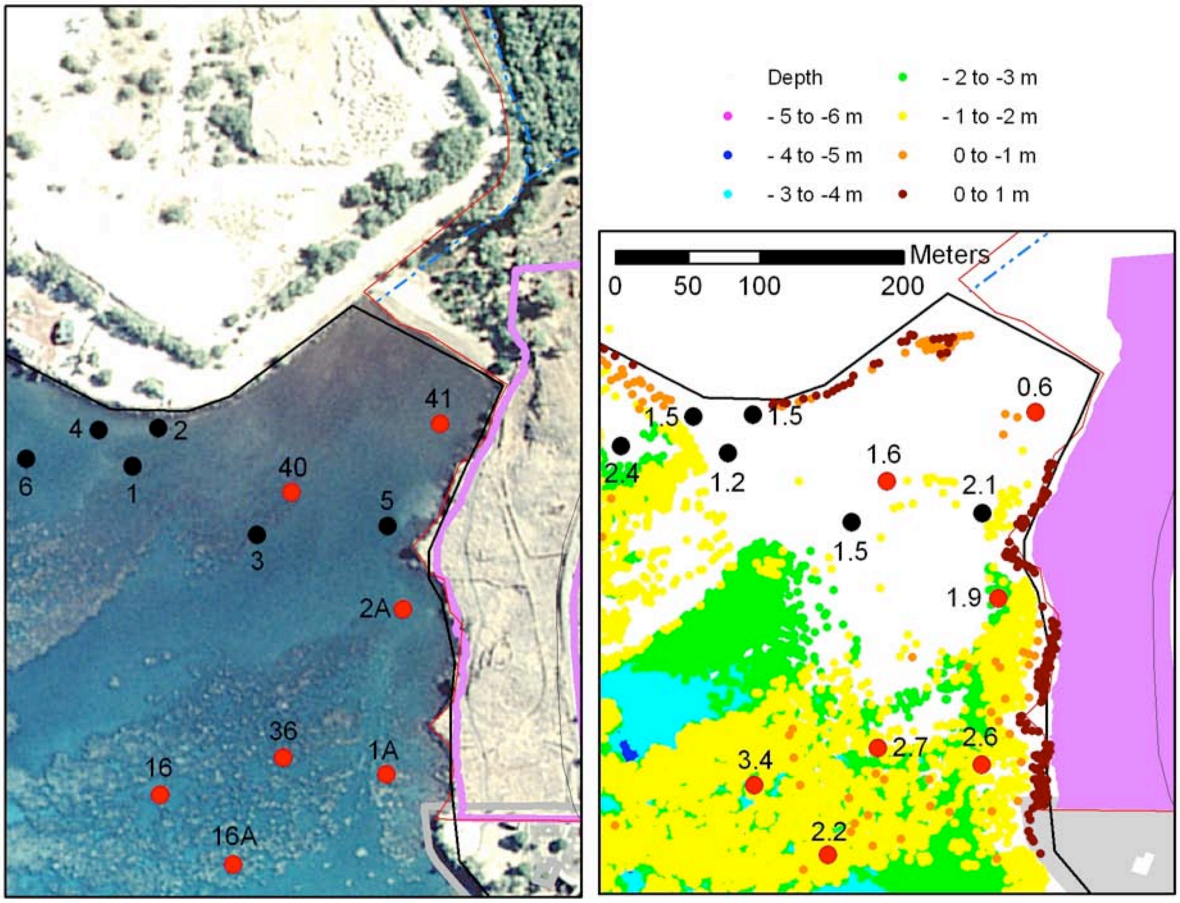


Figure 5. Coastal bathymetry around PUHE. Aerial photo in left panel shows general distribution of reef and soft bottom habitats (www.ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html). Data in right panel are from a 2000 USACE SHOALS survey (http://shoals.sam.usace.army.mil/hawaii/pages/Hawaii_Data.htm). White areas are missing data, likely due to high turbidity interfering with data collection and interpretation. Black circles are approximate locations of transects surveyed by CRAMP in 2002 (K. Rodgers, CRAMP co-PI, pers. comm. 2006). Red circles are locations of transects surveyed by Beets et al. (in review). Transect numbers are shown in left panel, with depths (in meters, with Beets et al. (in review) data adjusted to MLLW) in the right panel.

B.2.b. Hydrology affecting the site

PUHE's climate generally is warm, dry and windy. Annual rainfall typically is less than 250 mm (Figure 7), with most rainfall occurring during the winter months of January and February. The average temperature is about 25°C (77° F) with little daily, seasonal, or interannual variation (Figure 6). Winds at the site consist primarily of a regular cycle of a light land breeze at night and a stronger sea breeze during the day driven by differential heating and cooling of the land surface and adjacent ocean, with occasional stronger winds associated with interactions between local atmospheric disturbances and local topography (Figure 6). Direct tradewind flow is blocked by the Kohala volcano, but topographic effects can redirect high-elevation winds, resulting in strong, gusty conditions around the site. The typically sunny and windy conditions contribute to the general aridity of the area by enhancing evaporation. Tradewind flow over the Kohala volcano promotes fairly steady rainfall at higher elevations, with over 4 m of rain just east of the

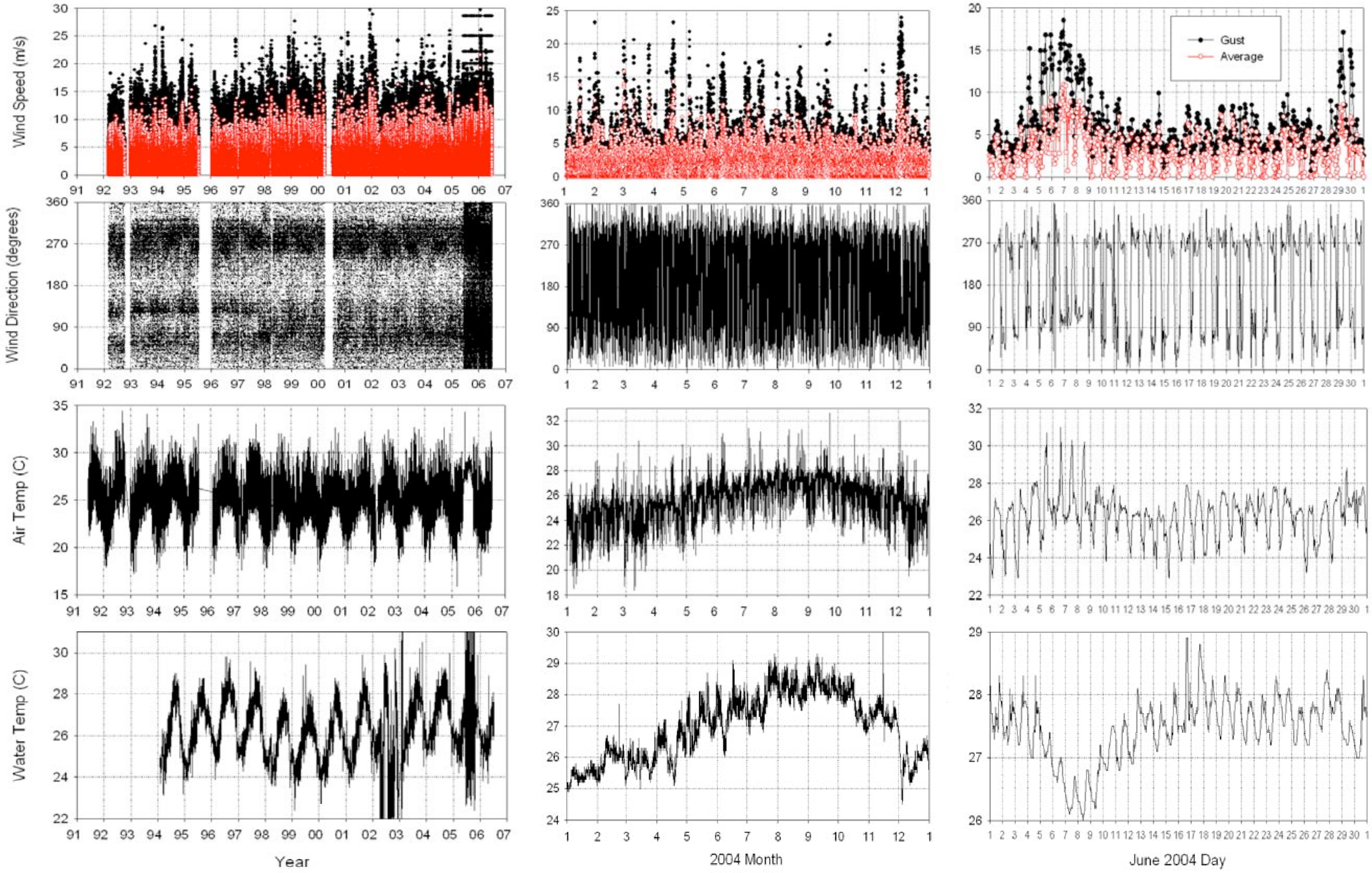


Figure 6. Meteorological data from NOAA Kawaihae Station 1617433. Data are not quality controlled, but general trends and cycles still are clearly visible. Data from http://tidesandcurrents.noaa.gov/

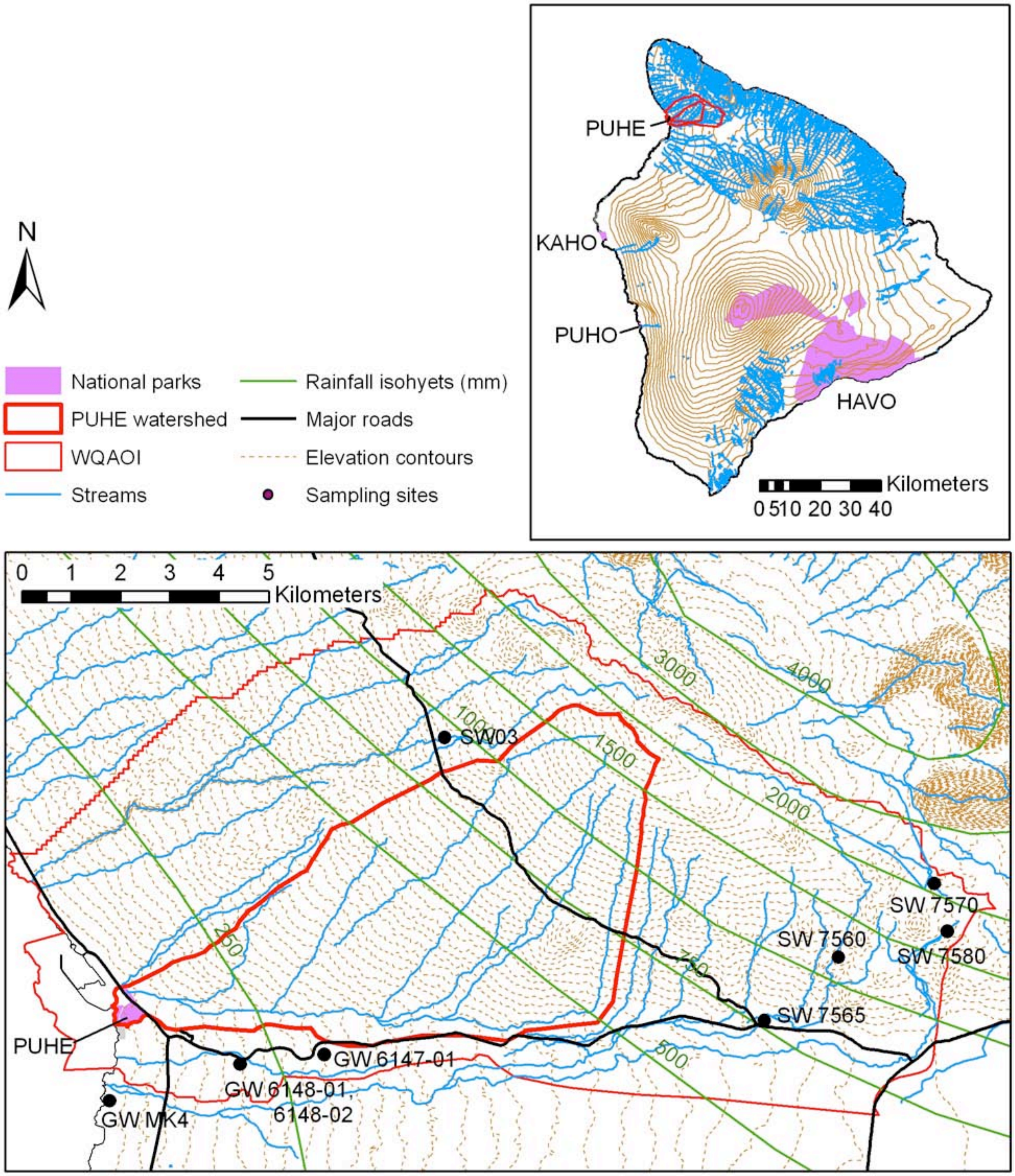


Figure 7. PUHE topography and hydrologic features. Elevation contours are at 100' (30 m) intervals in detail map, 500' (152 m) in island map. PUHE and its associated Water Quality Area of Interest (WQAOI) lie within USGS HUC 20010000, which covers the entire island of Hawai‘i. Groundwater (GW) and surface water (SW) monitoring sites in the area are shown in their approximate positions. Surface water stations are not discussed in text because all sites are at high elevations and none are within the PUHE watershed.

crest of the mountains. Almost 2 m falls on the top of the PUHE watershed, but rainfall declines steadily downslope to the coast (Figure 7). Rainfall in the PUHE watershed can be augmented significantly by cyclonic frontal ('Kona') storms that move up from the south during the winter. Rainfall from these systems can be intense, resulting in flashy runoff in the normally dry gulches in the region. Two gulches discharge through PUHE; Makeahua Stream collects runoff from most of the watershed upslope of PUHE, while Pohaukole Gulch drains a much smaller area, most of which is within the site. The large cobbles in the dry portions of Makeahua Stream are evidence of the strong flow occurring during runoff events, which flushes sediments and smaller stones out of the stream channel and into Pelekane Bay (Figure 8c-e). Pohaukole Gulch (Figure 9d-f) is unlikely to carry large quantities of runoff due to its small contributing watershed.

While the Kawaihae area always has been know for its aridity, land use in the watershed upslope of PUHE appears to have exacerbated the scarcity of fresh water in the area. Precipitation amounts and patterns likely have been altered by changes in vegetation in the watershed, and population growth and water use in upslope areas, particularly around the town of Kamuela (Waimea) probably has reduced surface and groundwater flows in lower portions of the watershed. Large-scale vegetation changes occurred in the early to mid-1800s after sandalwood harvesting and the introduction of cattle combined to eliminate large areas of forest in the lower portions of the watershed. The shift from forest to grassland would have changed the watershed's ability to absorb and reflect heat, affecting local climate, and also would have affected the local water balance through impacts on evapotranspiration and interception of rainfall and cloud moisture by plants. Some anecdotal accounts suggest that Makeahua Stream may have been a perennial, or at least a more persistent, stream in the pre-contact era, and that groundwater discharges may have been more extensive. Recent changes in the watershed that may have affected water and sediment fluxes to site waters include increasing population growth in the town of Waimea (Kamuela) in the upper portion of the watershed, and the operation of a quarry just inland from the site for building materials for Kawaihae harbor, which has been cited as a possible source of increased sediment loads to Pelekane Bay. A significant amount of sediment reaching Pelekane Bay also may be derived from dust blown from the watershed and from adjacent Kawaihae Harbor lands into the bay. Present-day groundwater impacts on circulation in nearshore waters probably are relatively minor due to the small quantity that appears to be discharging to the region, and the relatively strong mixing produced by winds in the area. Storm runoff events occasionally will enhance stratification in nearshore areas, but wind-driven mixing probably limits effects to a few days or less in most cases.

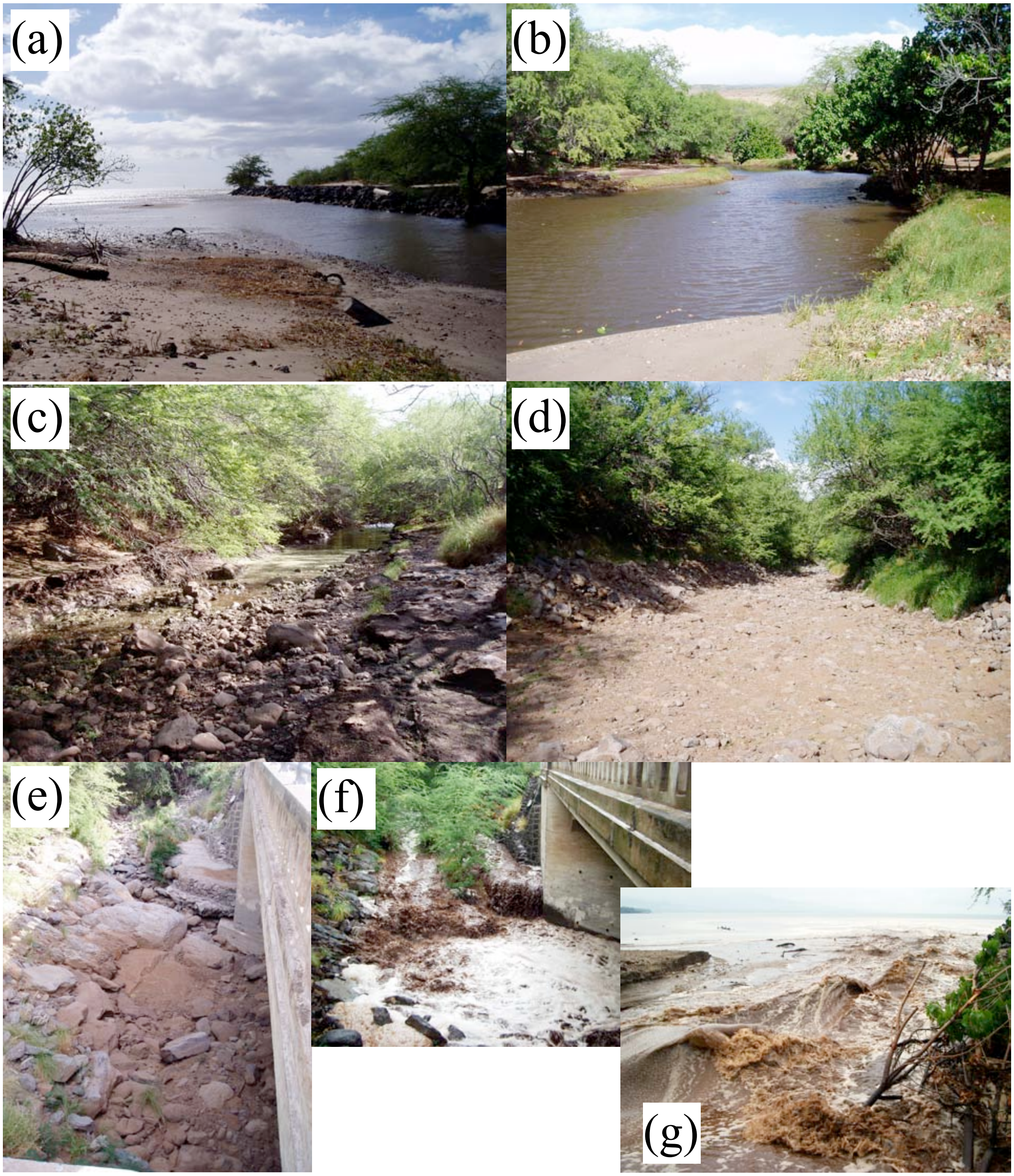


Figure 8. Makeahua Stream. (a) Looking out from stream mouth into Pelekane Bay. Note exposed bar just offshore. (b) View looking upstream from near mouth. (c) Upper limit of estuarine segment. (d) Dry streambed upstream of (c) (Highway 270 is ~100 – 200 m upstream). (e) View looking up stream channel above Highway 270 bridge. (f) Stormflow above bridge. (g) Stormflow into Pelekane Bay ~15 minutes after the stream breached the sand berm at the mouth. Photos (a) – (e) are from December 2004 (D. Hoover photos). Photos (f) and (g) are from March 9, 2003 (C. Stewart photos).

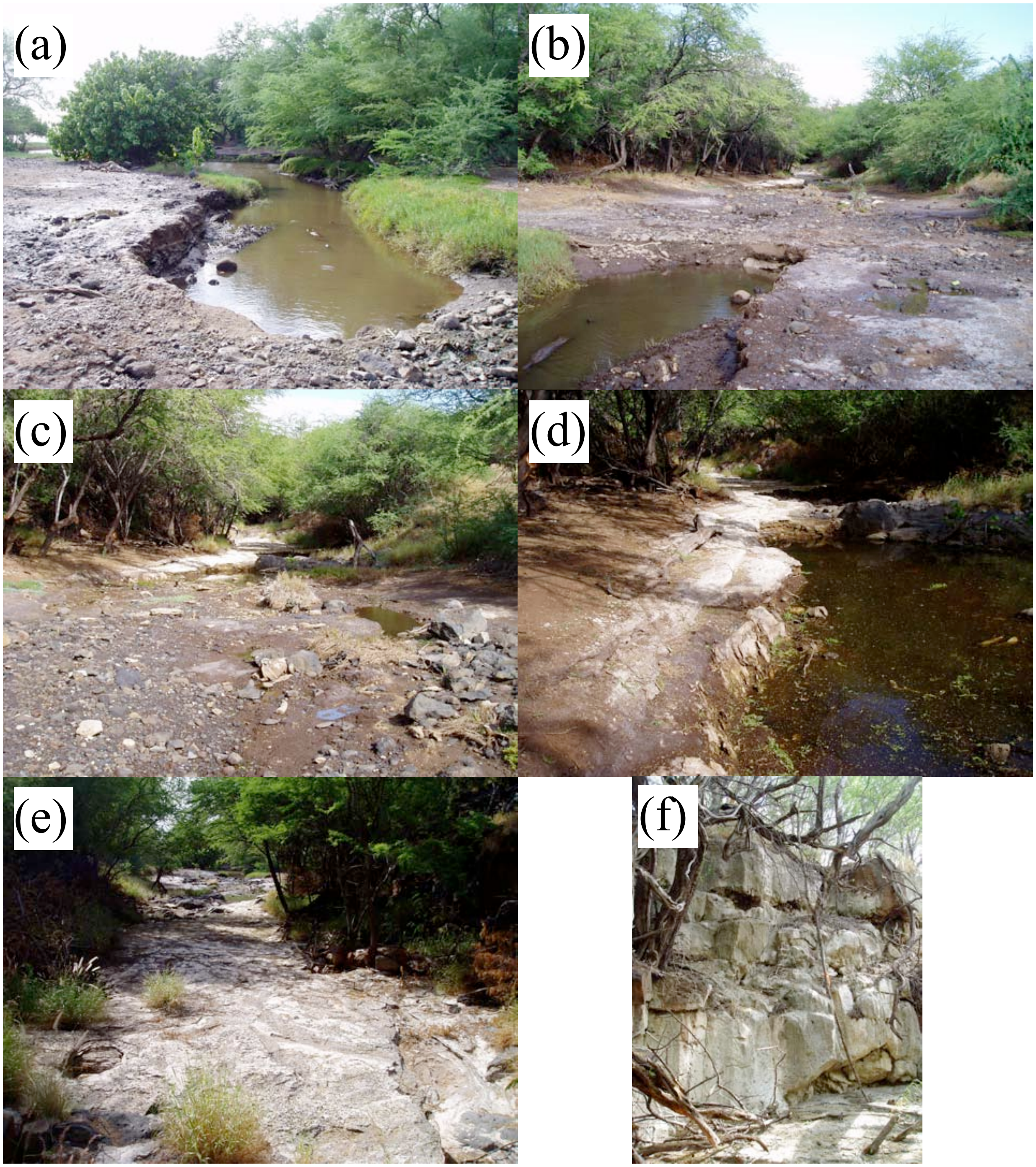


Figure 9. Pohaukole Gulch. (a) Junction of Pohaukole Gulch with Makeahua Stream from dirt road crossing. (b) View upstream from bank of Makeahua Stream. (c) View upstream from dirt road; anchialine pools are visible in the center of the image. (d) Closeup of main pool and bank. (e) View downstream from concrete ‘pavement’ upstream of pools; pools are visible near the top of the image, with the confluence with Makeahua Stream at the top. (f) Gulch wall to the left of (e). The white rock forming the layered bank in (d), the pavement in (e), and the coating on the gulch walls in (f) is concrete waste from a concrete plant previously located in the site (site superintendent D. Kawaiaea, pers. comm. 2006).

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

PUHE has a number of significant water resources. Fresh water normally is not found in the main site parcel, although occasional large runoff events can result in flow in the lower portions of Makeahua Stream and Pohaukole Gulch. Groundwater is a significant resource as it was the main source of drinking water for early inhabitants and because it passes through the site and affects water quality in the site's anchialine habitats and wetland areas. Groundwater discharges also affect nearshore water quality. Marine resources include rocky and sandy intertidal areas along the shoreline and coastal waters and benthic habitats offshore of the site. Kawaihae Harbor is not within the site, but its proximity results in potentially significant effects on site resources.

B.2.c.i. Groundwater

Groundwater in the site has not been studied directly, but in geologically and hydrologically similar areas groundwater consists mostly of a relatively thin basal layer floating on underlying seawater. Perched groundwater also occurs in some areas, and a recent geotechnical survey encountered "possible [perched] ground water" in a drilled probe in the eastern portion of the site at an elevation of roughly 90 feet (Pacific Geotechnical Engineers Inc. 2000). Perched groundwater is rare in Hawai'i due to the relatively porous nature of the volcanic bedrock, so this source seems likely to be less important than basal groundwater in the site. Based on similar areas along the Kona coast, maximum basal groundwater heads in the site probably are less than 1 foot (Oki et al. 1999). Because so little rain falls in the site, groundwater flow through the site must be maintained primarily by recharge upslope of the site in higher rainfall areas. Groundwater intersects the land surface in the lower portions of stream channels, and groundwater flow through the site results in groundwater intrusions or springs along the site coastline and from submarine discharges offshore (Fischer et al. 1966; Adams 1969; Oki et al. 1999). Although basal groundwater head gradients in the site likely are quite low, significant groundwater flows still can occur because of the highly permeable nature of the lavas making up the west Hawai'i coast (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 site 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, such as the septic leach field recently installed in the site. Present-day groundwater flow through the site also may have been affected by the construction of Kawaihae Harbor in the late 1950's which included extensive landfilling along the coast. Upslope activities may affect groundwater quality via the direct introduction of wastewater, or contamination of runoff by non-point sources.

B.2.c.ii. Anchialine habitat

PUHE's anchialine resources are associated with the lower reaches of Makeahua Stream and Pohaukole Gulch. Seasonally (Makeahua) and permanently (Pohaukole) impounded segments of these streams contain a mixture of seaward-flowing brackish groundwater and more saline seawater (Brock et al. 1987; Brock and Kam 1997). During a site survey in December 2004 the sand berm at the mouth of Makeahua Stream was absent and there was free exchange of water between the lower reach of the stream and Pelekane Bay (Figure 8a), but a sand berm frequently isolates the pool as observed by Cheney et al. (1977) and as shown in aerial photos of the area (e.g., Figure 5) and in photos of the berm being breached by stormflows in 2003 (Figure 8g). The anchialine portion of Makeahua Stream was characterized by Cheney et al. (1977) as “a series of small anchialine ponds”, which were “1 – 3 m in width, and no more than 1 m in depth…[and containing] much organic debris, [with] very soft muddy bottoms”. Although anchialine resources in PUHE are limited and occur in a different setting than most anchialine pools found along the west Hawai‘i coast, anchialine habitat in the site may be important biogeographically, as anchialine habitat is scarce in this portion of the island (Oceanic Institute et al. 1992). Because anchialine habitats 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. Wetlands

PUHE’s wetlands are associated primarily with riparian and salt marsh habitat around the anchialine/estuarine portion of Makeahua Stream. Although the areal extent of PUHE’s wetlands is relatively small, they provide unique habitat for flora and fauna that is rare along this portion of Hawai‘i’s coast (Macneil and Hemmes 1977, Morin 1996).

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

PUHE’s shoreline includes about 300 m of narrow (1 – 5 m wide) rocky intertidal habitat along the southern portion of the shoreline, and about 50 m of sandy beach adjacent to Makeahua Stream in the north (Cheney et al. 1977). Rocky intertidal habitat also is found in association with the basalt blocks of the harbor revetment along the northern boundary of the site. Rocky intertidal zones are areas of active water exchange and contains tide pools and associated flora and fauna, as well as flora and fauna associated with rocky substrates that are subject to cyclic submergence by tides and wave action, or receive intermittent moisture in the form of splash and spray. Most of the rocky intertidal area around PUHE is relatively steep, so tidepools are uncommon and small (Cheney et al. 1977; D. Hoover pers. obs. 2004). The beach in the Pelekane area is an important cultural and visitor resource (Daniel and Minton 2004), but there was evidence of erosion during a site visit in 2004 when roots of palm trees were exposed along the beach front (Figure 10). It is not clear whether the erosion represents a long-term trend or a recent event, but as the tide was low when the photos were taken, it seems possible that the palm trees may be relatively recent additions that actually are stabilizing flood deposits near the stream mouth. A bar visible off of the stream mouth during the site visit suggests that significant infilling of Pelekane Bay is continuing and that continuing sediment inputs are likely to result in the beach continuing to accrete into the bay.

Figure 10. Pelekane beach looking northwest from the beginning of the rocky portion of PUHE’s coastline (top), and closeup of erosion around palms on beach (bottom). Photos D. Hoover 2004.

B.2.c.v. Coastal waters

PUHE’s legislated boundary ends at the shoreline, but adjacent coastal waters represent an important resource, both for their relevance to the cultural history of the site, and for their biological and recreational values. Coastal waters adjacent to the site are shallow (mostly less than 2 m) and turbid due to resuspension of sediments deposited in Pelekane Bay. Benthic resources in Pelekane Bay are associated mostly with sandy and muddy sediments trapped in the bay. Circulation in Pelekane Bay is sluggish due to the sheltering effect of Kawaihae harbor to the north; prior to harbor construction, coastal waters were exposed to alongshore currents and would have been much less turbid, and benthic resources likely included more hard substrate and associated flora and fauna. Coastal waters include a unique cultural feature, the Hale o Kapuni shark heiau, which is known only from oral tradition and possibly a few old photographs. The actual location of the heiau is not known, but early accounts suggest that it may have been located just offshore and roughly in line with Puʻukohola and Mailekini heiau; if this is the case, the heiau now may be buried under the prograding beach.

Consolidated coral reefs do not form extensive substrate in nearshore waters immediately adjacent to PUHE, but corals are a significant component of the benthic biota in offshore waters, and scattered coral colonies are present in nearshore waters, particularly off the southern portion of the site (Figure 11). Significant changes in the overall morphology of PUHE's benthic substrate are unlikely in hard-bottom areas due to the robust nature of lava and coral substrates, but occasional changes probably do occur in the distribution of soft sediments in Pelekane Bay due to large runoff and wave events.

B.2.c.vi. Kawaihae Harbor

Kawaihae Harbor is located immediately north of PUHE. While the harbor itself is not a resource for the site, the presence of the harbor affects coastal water resources around the site, and activity in and around the harbor also may affect site water resources. The main harbor basin is physically separated from PUHE's coastal waters by the harbor breakwall and an extensive landfill area (Figure 3), so biological communities and water quality inside the harbor are not considered here, as there is unlikely to be significant interaction between water and biota in the two areas. Significant pollution events inside the harbor (e.g. an oil spill) might affect PUHE coastal waters if pollutants left the harbor and were transported south, and leaching of contaminants through landfill might result in contaminant inputs into the anchialine/estuarine portion of Makeahua Stream or PUHE coastal waters. Small boat traffic to and from the small boat harbor outside of the main harbor, and activities inside the small boat harbor also may affect coastal water resources around PUHE.

B.3. Biological resources

B.3.a. Freshwater

Fresh water can occasionally be found in Makeahua Stream and Pohaukole Gulch during high runoff events, but because the lower reaches of both normally are dry, biological resources related only to fresh water are not considered in this study. Resources related to anchialine and estuarine habitats in the lower reaches of these streams are considered separately below.

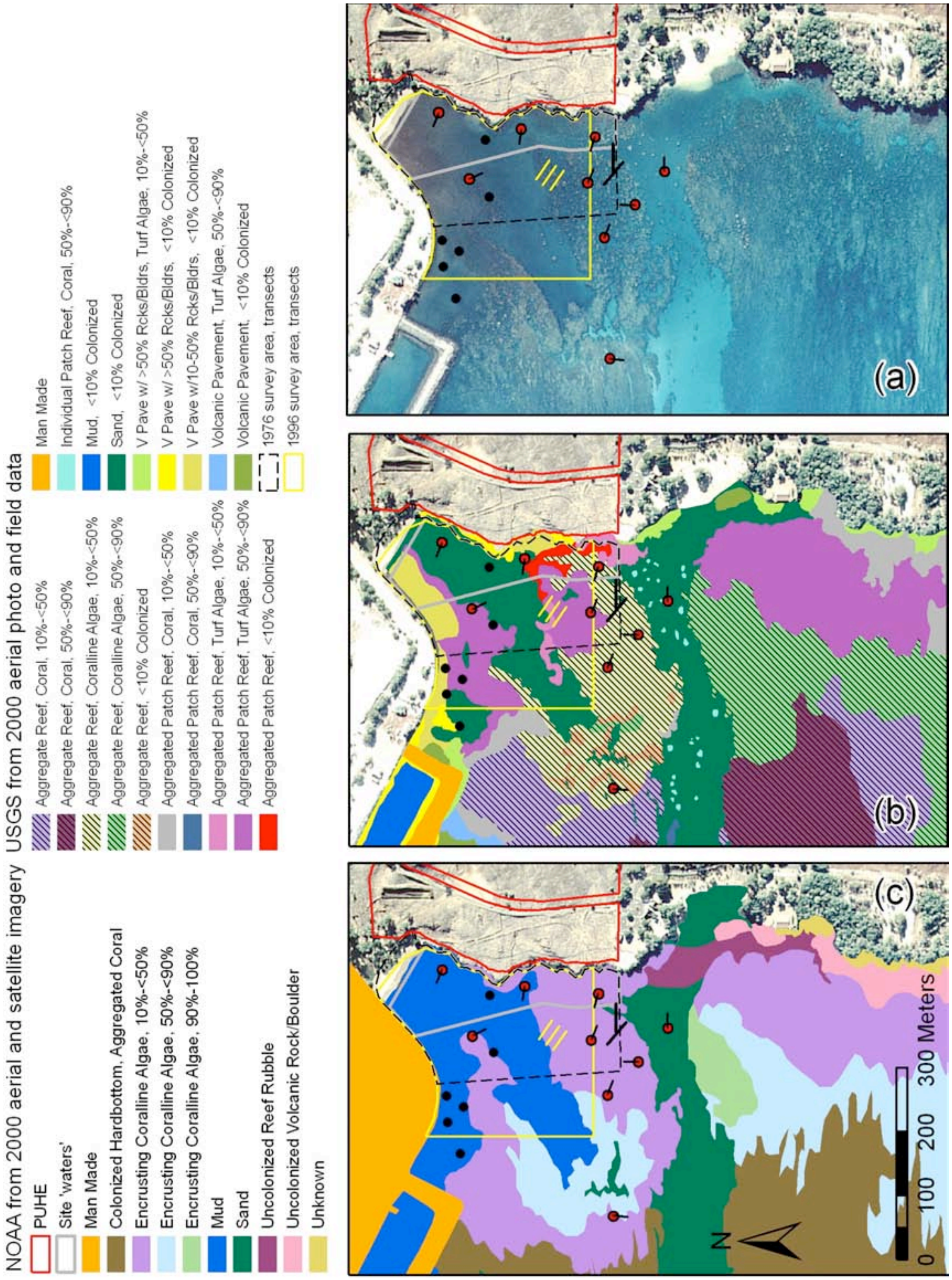


Figure 11. Benthic habitat around PUHE. (a). Aerial photo showing general distribution of reef and soft bottom areas in 2000 (www.ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html). (b) Benthic habitat classified by USGS from aerial photos obtained in 2000 and 2004-05 field data (Cochran et al. in review). (c) Habitat classified by NOAA from aerial photos and satellite images obtained in 2000 (www.ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html). Black dots are 2002 CRAMP RA transects (K. Rodgers, CRAMP co-PI, pers. comm. 2006). Red dots with lines are 2005 transects surveyed by Beets et al. (in review).

B.3.b. Groundwater

Groundwater typically is not considered to contain biological resources. However, the mixohaline fauna found in anchialine pools and fishponds includes hypogeal fauna that can live in brackish groundwater. Their distribution in groundwaters is not known quantitatively, but shrimp commonly found in anchialine pools also have been observed in water samples collected from a well in Kaloko-Honokohau National Historical Park (KAHO – Figure 1) (Brock and Kam 1997). Their presence in widely separated anchialine habitats along the Kona coast of Hawai‘i suggests that groundwater may provide an important pathway for dispersal and colonization of mixohaline flora and fauna, including endemic and threatened and endangered species. No data are available on biological resources in groundwater in PUHE, but the apparently elevated temperature of groundwater in the PUHE area may create a unique environment for groundwater biota in this area compared to other coastal areas around the island.

B.3.c. Anchialine habitat

Anchialine habitats in Hawai‘i typically harbor a unique assemblage of organisms, including crustaceans (shrimps and amphipods), fish, mollusks, a hydroid, sponges, polychaetes, tunicates, aquatic insects, algae, aquatic macrophytes, and a unique cyanobacterial mat community (Brock and Kam 1997; Foote 2005). Species of concern and species being considered for listing under the U.S. Endangered Species Act include the shrimp *Metabeteaus lohena* and a native damselfly (*Megalagrion xanthophelas*) (Pratt 1998; Else 2004). The only published biological data for PUHE’s anchialine habitat is from Cheney et al. (1977), who noted the presence of glass shrimp (*Palaemon debilis*) and two species of *Tilapia* (all < 20 cm in length). Based on their map (Figure 12) and description it seems likely that their survey focused on the pool in Makeahua Stream, which was isolated at the time of their survey by a sand berm, and not the much smaller pool in Pohaukole Gulch. A ~50 cm barracuda (probably *Sphyraena barracuda*) and numerous *Tilapia* spp. were stranded in the estuarine portion of Makeahua Stream as floodwaters receded following a high runoff event in 2003, although it is not clear whether the barracuda was in the area before the flood event or whether it had arrived after the stream breached the sand berm (area resident/eyewitness C. Stewart pers. comm. 2006). While no other biological data are available for the Makeahua and Pohaukole pools, it seems likely that the characteristic biota will differ significantly from ‘typical’ anchialine fauna due to their intermittent inundation with fresh water and to the seasonal connection of the Makeahua Stream pool with Pelekane Bay, and due to their apparently degraded condition compared to ‘typical’ pools (D. Hoover pers. obs. 2004).

B.3.d. Wetlands

PUHE’s wetland area is relatively extensive for the Kohala coast, and consists of riparian and salt marsh habitat associated with the anchialine pool/estuarine segment at the mouth of Makeahua Stream. The pool and surrounding wetland habitat has not been mapped in detail, but in 1975-76, Macneil and Hemmes (1977) noted that the associated halophytic plant community “extends in a narrow strip for nearly 200 yards (180 m) inland from the small sand beach”. Their vegetation map (Figure 13) shows the halophytic community covering a larger area than just the riparian/wetland zone because it also includes the beach area of Pelekane. The species list

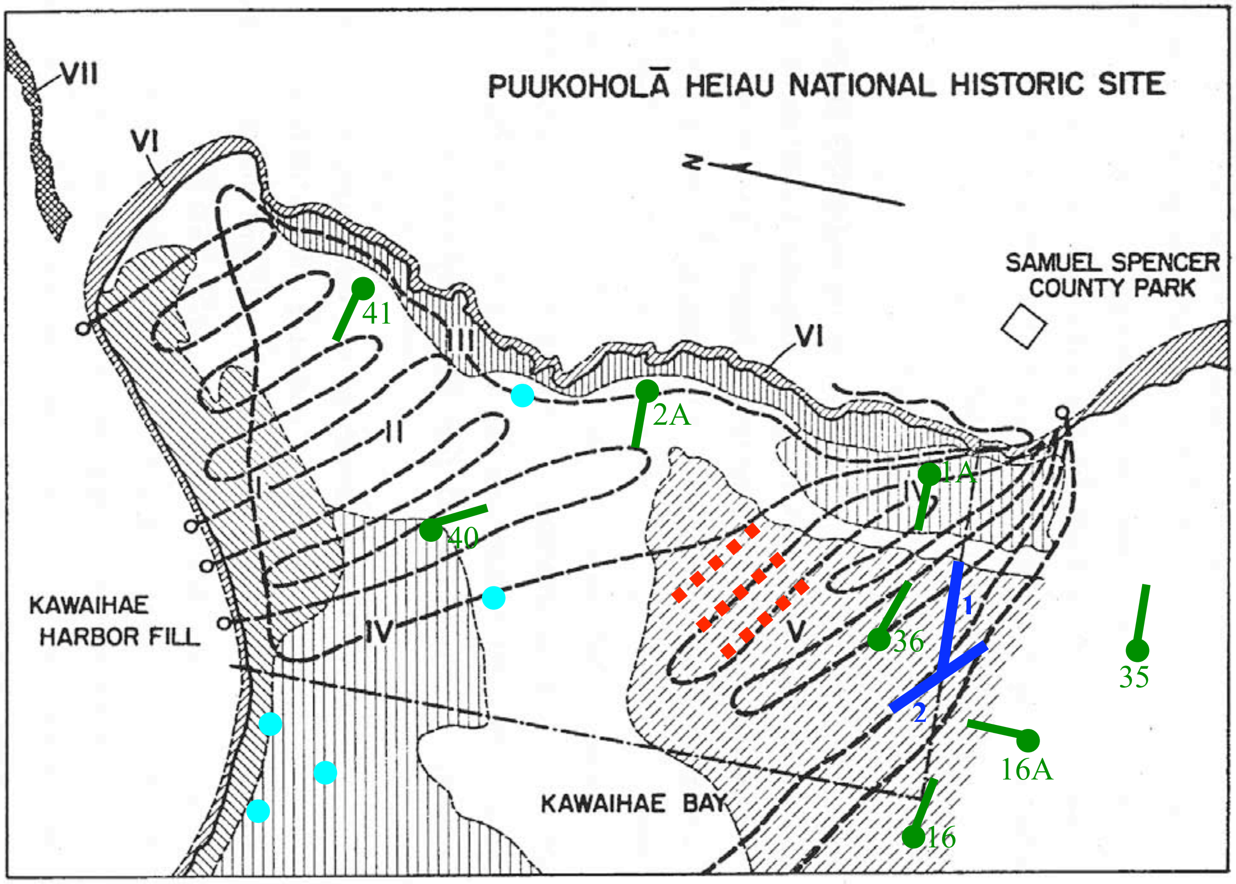


Figure 12. Aquatic habitat zones (Biotopes I – VII) around PUHE in 1976. For scale, seaward edge of surveyed area is roughly 150 m from shore (Cheney et al. 1977). Transects 1 and 2 (blue lines) are drawn in their approximate locations from descriptions in Cheney et al. (1977). Approximate locations of transects surveyed in 1996 by Tissot et al. (1998) (dashed lines), in 2002 by CRAMP (light blue dots – K. Rodgers, CRAMP co-PI, pers. comm. 2006) and in 2005 by Beets et al. (in review) (green dots with lines) also are shown for comparison. Curved dashed line is survey path used for marine flora survey in 1976. Figure modified from Ball (1977).

provided for the halophytic community thus includes flora from both the riparian/marsh areas and the beach area (Table 1). Some information on which species were associated specifically with the riparian and marsh habitats is available from their description of the community:

> "The marsh area, between the pond and the beach, contains large populations of sea purslane or akulikuli (*Sesuvium portulacastrum*) and saltwort (*Batis maritima*), as well as scattered representatives of nena (*Heliotropium curassavicum*), hairy spurge (*Euphorbia hirta*), and pakai (*Amaranthus dubius*). Near the brackish pond young Canary island date palm (*Phoenix canariensis*) as well as aheahea (*Chenopodium oahuense*) are located. Vigorously growing populations of Australian saltbush (*Atriplex semibaccata*) and another saltbush (*Atriplex muelleri*) are found around the periphery of the pond and are much more robust than those populations encountered on the beach".

Vascular plants in PUHE were resurveyed by Pratt and Abbott (1996) and discussed in the vegetation management plan for the site (Pratt 1998). One new species (hala) was noted to occur along the northern shore of the site in the vicinity of the mouth of Makeahua Stream, possibly due to planting after the Macneil and Hemmes (1977) survey. Pratt (1998) provides a summary

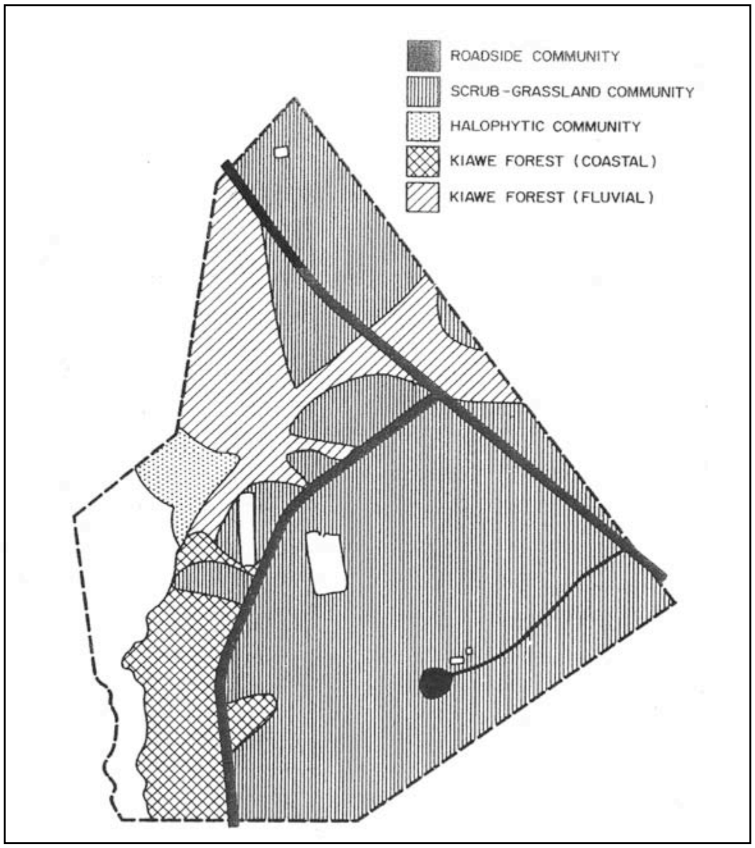


Figure 13. Major plant communities in PUHE. From Macneil and Hemmes (1977).

Table 1. Plants associated with the halophytic community in PUHE in 1975-1976. From Macneil and Hemmes (1977).

Family	Species
Gramineae (Poaceae)	*Pennisetum ciliare*
Palmae (Arecaceae)	*Cocos nucifera*
	Phoenix canariensis
Chenopodiaceae	*Atriplex ? johnstonii*
	Atriplex muelleri
	Atriplex semibaccata
	Chenopodium murale
	Chenopodium oahuense
Amaranthaceae	*Amaranthus dubius*
Batidaceae	*Batis maritima*
Aizoaceae	*Sesuvium portulacastrum*
Portulacaceae	*Portulaca oleracea*
Leguminosa (Fabaceae	*Prosopsis pallida*
Euphorbiaceae	*Euphorbia hirta*
Malvaceae	*Thespesia populnea*
Passifloraceae	*Passiflora foetida*
Convulvulaceae	*Ipomoea brasiliensis (1)*
Boraginaceae	*Heliotropium curassavicum*
	Messerschmidia argentea
Goodeniaceae	*Scaevola taccada*

(1) More commonly known as *I. pes-caprae*

of the vegetation around the anchialine pond in the lower reaches of Makeahua Stream circa ~1997:

> "Vegetation along the edge of the pond is mostly ʻakiʻaki grass (*Sporobolus virginicus*) and ʻakulikuli (*Sesuvium portulacastrum*); prior to an alien plant removal project there was a large infestation of pickleweed [*Batis maritima*] here. Milo trees also grow on the edge of the wetland, and one large Canary date palm (*Phoenix canariensis*) has persisted here for more than twenty years (Macneil and Hemmes 1977, Pratt and Abbott 1996). Kiawe trees form a dense forest to the north and east. Herbaceous plants along the trail near the pond are a mix of natives and aliens. Natives include paʻu o hiʻiaka, ʻakulikuli, and kipukai (*Heliotropium curassavicum*); ʻaweoweo (*Chenopodium oahuense*) was formerly found here, but was not noted in the most recent survey. Several species of alien saltbush are common near the pond".

Pickleweed eradication was performed in 1996 using the herbicide Rodeo®, with complete control achieved by the end of 1997 (Pratt 1998). Pratt (1998) noted that "control of additional alien species near the pond may permit the eventual reintroduction of native wetland species", and recommended continued monitoring of pickleweed status and retreatment if necessary, removal of the Canary date palm, and removal of saltbush near the pond "to enhance the recovery of native herbaceous species". Native species suggested for reintroduction included ʻaweoweo (*Chenopodium oahuense*) and makaloa sedge (*Cyperus laevigatus*).

Birds associated with coastal resources were included in Morin's (1996) 1992 – 1993 bird inventory in the site. She noted that historically "the endemic Koloa (*Anas wyvilliana*) and ʻAlae ke'oke'o (*Fulica alai*) probably swam in the stream", and that "the indigenous Black-crowned Night-Heron or ʻAuku'u (*Nycticorax nycticorax hoactli*) is reported to occasionally visit the creek drainage', but the only native species observed in the site during her survey were two migratory shorebirds (the Ruddy Turnstone (*Arenaria interpres*) and Wandering Tattler (*Heteroscelus incanus*)), and none of the birds seen during her surveys appear to have been associated specifically with the riparian/wetland habitat. She did note that "the tidal shoreline and stream outlet at Puukohola are an important avian habitat because they provide a feeding and resting site for migratory shorebirds. These species represent the only avifauna that visitors will regularly see at Puukohola that were part of the original pristine ecosystem". She also suggested that "the tidal shoreline and stream outlet should be managed to minimize human disturbance thereby providing habitat for migratory shorebirds and waterbirds for feeding and resting. These restrictions are especially important during the September to May time period when the migratory species are visiting Hawaiʻi and when some of the indigenous waterbirds (such as Stilts (*Himantopus mexicanus knudseni*) or Black-crowned Night-Herons) are feeding at many sites along the coast during their non-breeding season".

B.3.e. Rocky and Sandy Intertidal

The intertidal habitat around PUHE was surveyed by Cheney et al. (1977) and Ball (1977) as part of their survey of marine resources around PUHE. The area surveyed included the sand beach in front of Pelekane Bay, the rocky intertidal zone along the PUHE shoreline, and the basalt block revetment on the Kawaihae breakwater north of the site. Although the species list provided by Cheney et al. (1977) (Appendix B) does not specify where organisms were observed within the intertidal area, and mollusks and bivalves are only reported for all of the littoral biotopes combined, their description of biological features in the biotopes does provide some insight into the distribution of organisms within the different habitats:

> "Large movable blocks along the natural basaltic shoreline exhibit very little surface fauna or flora except coralline algae and vermetids. The bottom surfaces hold a rich epifauna consisting mainly of small *Echinometra mathaei*, *E. oblonga*, and serpulids (spirorbinae). Sea cucumbers are quite common in the subintertidal region, more so than in other biotopes. The tidepools contain a euryhaline fauna, and mussels and nerites (live and crabbed) are very common. The bottoms of smaller pools and protected pavement are sometimes encrusted with zoanthids and algae forming a crust or mat 1 to 3 cm in thickness. Echiuroids and crabs are often found beneath or within these layers. The loose gravel in the upper intertidal zone contains sipunculoids (about 2 per 0.25 m^2).
>
> The beach portion of the biotope contains ghost crab (*Ocypode ceratophthalamus*) burrows and a typical onshore strand vegetation. Schools of juvenile mullet (*Mugil cephalus*) and aholehole (*Kuhlia sandvicensis*) can be seen feeding near the surface in calm waters around clumps of *Enteromorpha* and beneath the overhanging kiawe (*Prosopsis pallida*) trees near the southern edge of the beach.
>
> The rocks along the Kawaihae breakwater hold a narrow band of nerites, littorines, and *Siphonaria*. Grapsid crabs (*Grapsus grapsus* and *Metapograpsus messor*) are common on all rocky portions of the biotope."

From this description it appears that rocky intertidal areas probably contained most of the fauna included in the species list. Excluding mollusks and bivalves, 23 species were noted from intertidal areas overall, with an additional 25 species of mollusks and 5 species of bivalves noted from littoral biotopes, many of which probably were found in intertidal areas.

Intertidal areas also were surveyed in 1976 specifically for macroscopic algae (Ball 1977). His discussion suggests that the list of species provided (Table 2) may have been primarily from observations in the rocky area bordering the site (i.e., not the Kawaihae breakwater), as he contrasts his observations with "adjacent areas …":

Table 2. Benthic marine algae observed in intertidal habitat around PUHE in April 1976. Modified from Ball (1977).

Species	Abundance(1)	Status(2)
Ulva fasciata	Infrequent	I
Valonia aegagrophilia	Abundant	I
Dictyosphaeria versluyii	Infrequent	I
Ahnfeltia concinna	Moderate	I

(1) Infrequent: <20% cover/m^2, Moderate: 20-60% cover/m^2, Abundant: >60% cover/m^2.
(2) I = indigenous, X = exotic.

> "Algal diversity and density along the rocky edges of the shore were conspicuously low compared to adjacent areas beyond the proposed boundaries of Puukohola Heiau National Historic Site. Four species of algae collected in this area were *Ulva fasciata*, *Valonia aegagrophilia*, *Dictyosphaeria versluyii*, and *Ahnfeltia concinna*. The low density of algae in this area is probably the result of heavy

> shading from the kiawe trees which overhang the shoreline. The *Ahnfeltia* was an atypical morphological form which may have been due to shading."

However, he also notes in his abstract that "Two species which are sometimes indicators of polluted water, *Ulva fasciata* and *Enteromorpha* sp., were present along the Kawaihae revetment".

B.3.f. 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. Coastal waters adjacent to PUHE are not a significant recreational resource for site visitors due to their small size and generally poor water quality, but the waters of Pelekane Bay do contain plankton and pelagic organisms that can be considered biological site resources.

B.3.f.i. Planktonic and pelagic biological resources

Coastal waters off PUHE provide habitat for planktonic and pelagic animals and phytoplankton. No data are available on plankton in the area, but pelagic resources include the resident fish community, including an unusual concentration of sharks, pelagic invertebrates such as cuttlefish, and endangered green sea turtles (*Chelonia mydis*) and possibly hawksbill turtles (*Eretmochelys imbricata*). The endangered Hawaiian monk seal (*Monachus schauislandi*) has not been sighted in site waters but can be considered a potential resource. Humpback whales (*Megaptera novaeanglia*) and other marine mammals that are found in waters offshore of the bay (false killer whales (*Pseudorca crassidens*), spotted dolphins (*Stenella attenuata*, locally known as kiko), bottlenose dolphins (*Tursiops truncatus*) and melon-headed whales (*Peponocephala electra*)) (Daniel and Minton 2004) also can be considered site resources. Fish in waters around the site were surveyed in 1969-1970 by Kanayama and Kawamoto (1970), in 1976 by Cheney et al. (1977), in 1996 by Tissot et al. (1998), and in 2005 by Beets et al. (in review). Shark sightings in Pelekane Bay have been documented by site personnel since 1979, but data were not easily available and thus were not reviewed for this report. Marine mammals around Kawaihae Harbor have been monitored since 1988 from a shore-based observation site by the Hawaiian Marine Mammal Consortium (Daniel and Minton 2004).

The State of Hawai'i Division of Fish and Game conducted marine biological surveys in 1969 – 1970 in Kawaihae Bay in conjunction with Project Tugboat (the explosive excavation of the small-boat harbor basin) (Kanayama and Kawamoto 1970). Visual surveys were conducted along 11 transects, all of which were well offshore of PUHE (Figure 14). Transects were 600' (183 m) long and surveys included fish observed within 10' (3 m) on either side of the transect, for a total area surveyed of 12,000 ft^2 (1,100 m^2) per transect. Surveys focused on fish species, numbers, and size. No visual transects were established in the area of detonations a-d (Figure 14) because high turbidity precluded the use of the visual survey method. Low standing crops of fishes were observed on transects 1, 2, 5, and 9, likely due to "murky water conditions" (Kanayama and Kawamoto 1970). Quantitative results thus are most relevant to clear offshore waters with reef and sand bottoms, and are less useful for the turbid waters immediately adjacent to PUHE that mostly overlie soft bottom substrates.

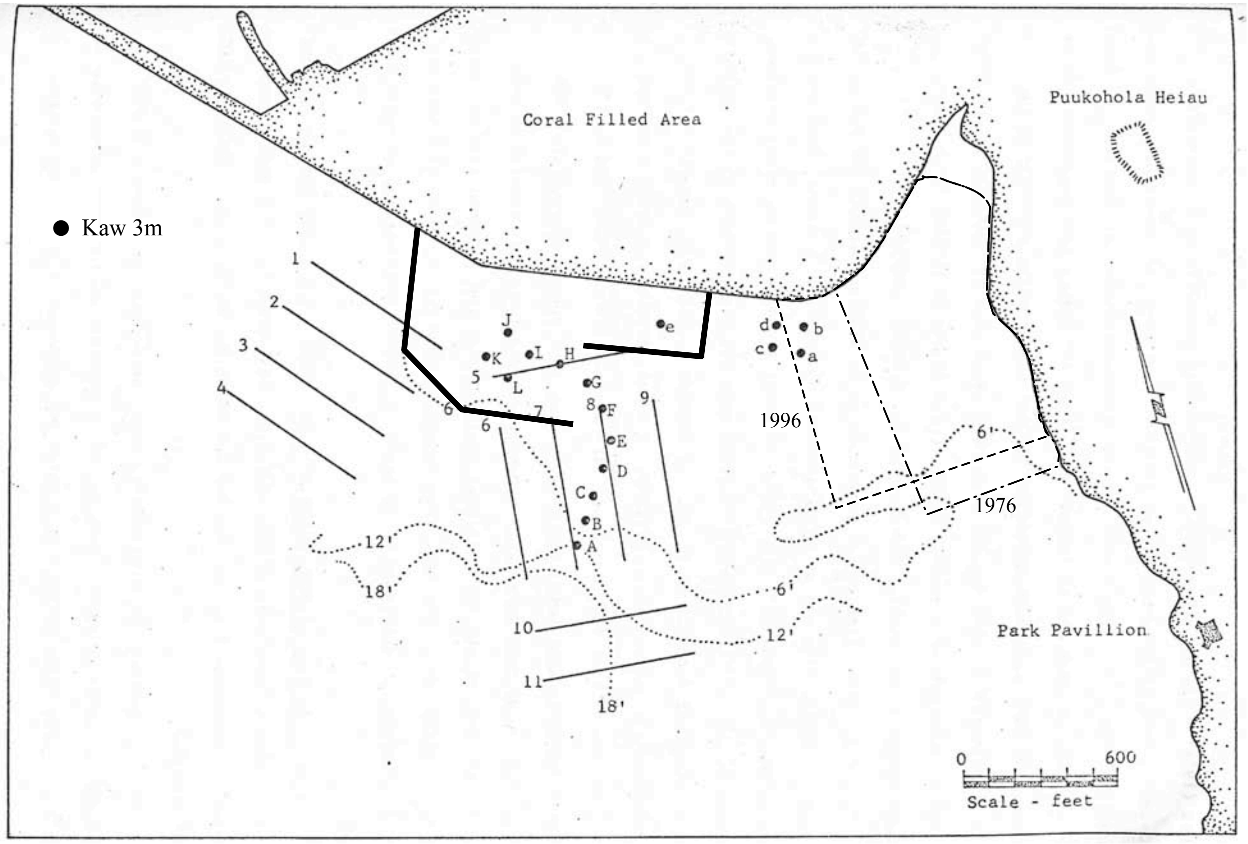


Figure 14. Sampling sites for pre-and post-detonation (1969-70) marine surveys around the Kawaihae small boat harbor site. Dots are detonation sites; lines are transects used for underwater visual surveys. Approximate locations of completed small boat harbor breakwalls and of subtidal areas surveyed in 1976 (Cheney et al. 1977) and 1996 (Tissot et al. 1998), and current CRAMP 3 m monitoring site (Kaw 3m – K. Rodgers, CRAMP co-PI, pers. comm. 2006) also are shown. Modified from Kanayama and Kawamoto (1970)

Surveys were performed two times before detonations began (9/22-25: all 11 transects, and 11/3/1969: transects 4, 6, and 8) and two times after the detonations (April and June 1970; transects 3 and 6, and 1-4 and 6-8 respectively), and results were compared to dead and injured fish collected from the surface after detonations. Seventy-six species were observed during underwater surveys, and seventy-four were identified in fish collected following detonations, with a total of 111 species identified overall. The species distributions in the visual survey and post-detonation collection data were significantly different, demonstrating that visual surveys did not detect a large number of species and that some visually abundant species either were less susceptible to injury or did not float to the surface when injured or killed. The twelve most abundant fish observed in their initial survey of all 11 transects are listed in Table 3; three other species also were noted as being common: the butterflyfishes *Chaetodon ornatissimus* and *C. trifasciatus*, and the wrasse *Thalassoma ballieui*, all of which were observed on at least 8 of the 11 transects. A complete list of species observed on the visual surveys and in post-detonation collections is included in Appendix C. No sharks were observed on visual surveys or in post-detonation collections, but ‘several unidentified species’ were observed from the surface in September 1969 and April 1970.

Table 3. The twelve most abundant fish species observed during visual surveys on 11 underwater transects in September 1969. Except for *C. ovalis* and *M. samoensis*, all of the species listed were observed on at least 9 of the transects surveyed. Table modified from Kanayama and Kawamoto (1970).

Rank	Species	#/1000 m^2	# of transects observed on
1	*Scarus dubius*	17.3	11
2	*Thalassoma duperreyi*	16.0	11
3	*Chromis ovalis*	11.0	6
4	*Pomacentris jenkinsi* (1)	8.52	11
5	*Ctenochaetus strigosus*	8.43	10
6	*Gomphosus varius*	7.59	11
7	*Mulloidichthys samoensis* (2)	6.30	5
8	*Acanthurus nigroris*	4.65	10
9	*Parupeneus multifasciatus*	4.47	11
10	*Acanthurus nigrofuscus*	3.98	9
11	*Cirripectus variolosus*	3.26	10
12	*Exallius brevis*	3.26	10

(1) Currently accepted name is *Stegastes fasciolatus*
(2) Currently accepted name is *M. flavolineatus*

Cheney et al. (1977) surveyed nearshore waters around PUHE in 1976, six years after excavation of the offshore reef for the small boat harbor. Biotopes in an area from Kawaihae Harbor in the north to the boundary with Spencer Beach Park in the south and to about 150 m (500 ft) offshore (Figure 12) were determined from aerial photos, by swimming and wading, and by using associated water quality data (temperature, salinity and turbidity) (Table 4). Fish species and relative abundance were recorded throughout the entire area during six hours of underwater observations using SCUBA. Quantitative data on fish species and abundance also were collected along two transects established in biotope V in the southeastern portion of the survey area (Figure 12). Transects were surveyed three times: once on 4/2/76 (10:00 AM), and twice on 4/10/76 (10:00 AM and 2:00 PM). No sharks were observed on transect surveys, but adults of three species (grey reef (*Carcharhinus menisorrah*), black-tip (*C. melanopterus*), and whitetip reef (*Triaenodon obesus*) were noted as being common in biotopes I, II and III, with whitetips also noted as common in biotopes IV and V, and all three species "were commonly seen breaking the surface near the presumed site of Hale o Kapuni heiau" (Cheney et al. 1977). Qualitative surveys observed only 51 fish species in subtidal waters (i.e., excluding intertidal and pond data; Appendix D), and only "very limited fish populations" were found in silt and rubble areas, suggesting that the fish community there had not increased dramatically since Kanayama and Kawamoto's (1970) surveys. Quantitative transect surveys in biotope V (patch reefs) identified 36 fish species (Appendix E), 6 of which were found only on the transects. The twelve most common species observed on transects are listed in Table 5.

Cheney et al. (1977) concluded that the fish fauna in waters off of PUHE was depauperate, "due perhaps to a combination of environmental disturbances associated with harbor construction and unrestricted resource use". This conclusion was based in large part on the fact that almost twice as many species (111) were observed by Kanayama and Kawamoto (1970) than were observed in their study (63 total, with 2 occurring only in biotope VII and 5 found only in biotope VI, neither of which was surveyed by Kanayama and Kawamoto (1970)). However, this conclusion implies

Table 4. Biotopes and physical properties in nearshore waters surveyed by Cheney et al. (1977).

#	Biotope	T (°C)	S (ppt)	Visibility	Depth (m)
I	Mixed rubble and silt bottom	29.5	31.4	Low	0.1 – 1
II	Sand and silt bottom	24.0	32.5	Medium	1 – 5
III	Basalt pavement with rubble	25.5	25.7	Medium	0.1 – 2
IV	Coral in mixed rubble	24.0	32.5	Medium to high	1 – 5
V	Patch reefs	24.0	32.5	High	0.1 – 5
VI	Intertidal	25.0 – 28.5	3.0 – 25.0	Medium to high	n/a
VII	Brackish pool	27.0	2.0 – 8.0	Medium	0.1 - 1

Table 5. The twelve most abundant fish species observed during visual surveys on underwater transects in patch reefs in April 1976 (Cheney et al. 1977). Surveyed area was within 5 m on either side of the 50 m line, or 500 m^2 total per transect. Averages are recalculated from raw data in Appendix E; as a result values and ranks differ in some cases from those reported in Table 2 in Cheney et al. (1977).

Rank	Species	#/1000 m^2
1	*Mulloidichthys samoensis* (1)	61.6
2	*Chromis ovalis*	58.8
3	*Scarus sordidus*	29.4
4	*Thalassoma duperreyi*	28.6
5	*Abudefdef abdominalis*	23.4
6	*Pomacentrus jenkinsi* (2)	17.7
7	*Ctenochaetus strigosus*	13.0
8	*Acanthurus nigrofuscus*	7.00
9	*Gomphosus varius*	6.34
10	*Chaetodon trifasciatus*	4.00
11	*Scarus dubius*	2.67
12	*Chaetodon unimaculatus* (3)	1.66

1. Currently accepted name is *M. flavolineatus*
2. Currently accepted name is *Stegastes fasciolatus*
3. Tie with *Parupeneus multifasciatus* and *Thallasoma ballieui*

that the data obtained by Kanayama and Kawamoto (1970) are an appropriate reference for comparison, and methods differed significantly in the two studies making comparisons somewhat problematic. The 111 total species observed by Kanayama and Kawamoto (1970) includes both species observed on underwater transect surveys and dead and injured species collected from the surface after detonations, and the area surveyed did not include the nearshore area surveyed by Cheney et al. (1977). Because transects in both studies were in different areas but appear to have been established mostly at locations with predominantly hard bottom reef substrate, the most appropriate data for comparison probably are the species lists obtained from the transects, although there are significant methodological issues there as well. In particular, a much greater total area was surveyed by Kanayama and Kawamoto (1970): their initial survey used 11 transects covering about 1,100 m^2 each, or a total area of about 12,300 m^2, compared to Cheney et al.'s two transects, which covered a total area of 1,000 m^2. The area surveyed alone thus could explain a significant portion of the greater number of species observed in the earlier study (76) compared to the number observed by Cheney et al. (1977) (36). Comparing the most abundant species observed in the two studies (Tables 3 and 5) shows that 7 of the top 10 are common to both lists, and while transect abundances overall actually are higher in the later survey (the top 10 species in Table 5 account for a total of 250 individuals per 1000 m^2, versus 88 per 1000 m^2 for the top 10 species in Table 3), the higher total in the later study is affected strongly by two unusually abundant species (*C. ovalis* and *M. samoensis*, now known as *M. flavolineatus*). These two species often are found in schools, and were specifically noted by Kanayama and Kawamoto (1970) as being more patchily distributed than other abundant species (Table 3). Overall, the abundances of many of the other species listed are rather similar, and the data thus suggest that the fish community in Cheney et al.'s (1977) transect survey area actually may have been in relatively good condition, or at least not degraded significantly compared to the community surveyed by Kanayama and Kawamoto (1970).

Tissot et al. (1998) surveyed PUHE's nearshore marine resources in 1996 specifically to assess changes in habitat and biota in the 20 years since the 1976 survey by Cheney et al. (1977). The general distribution of habitat was found to be similar (Figure 15), although a quantitative comparison was not possible because biotopes were not delineated quantitatively by Cheney et al. (1977). Quantitative fish surveys were conducted on three parallel transects (50 m long and 20 m apart) near the northwestern limit of biotope V (Figure 15) for comparison to transect data from Cheney et al. (1977). Surveys were performed on three separate days (1/21/1996, 3/8/1996. and 4/28/1996) by 2 to 3 observers, with each observer counting fish within 2 m on either side of the transect line on all three of the transects, The total unreplicated survey area thus was 600 m^2, and surveys appear to have been replicated 8 times (Tissot et al. 1998).

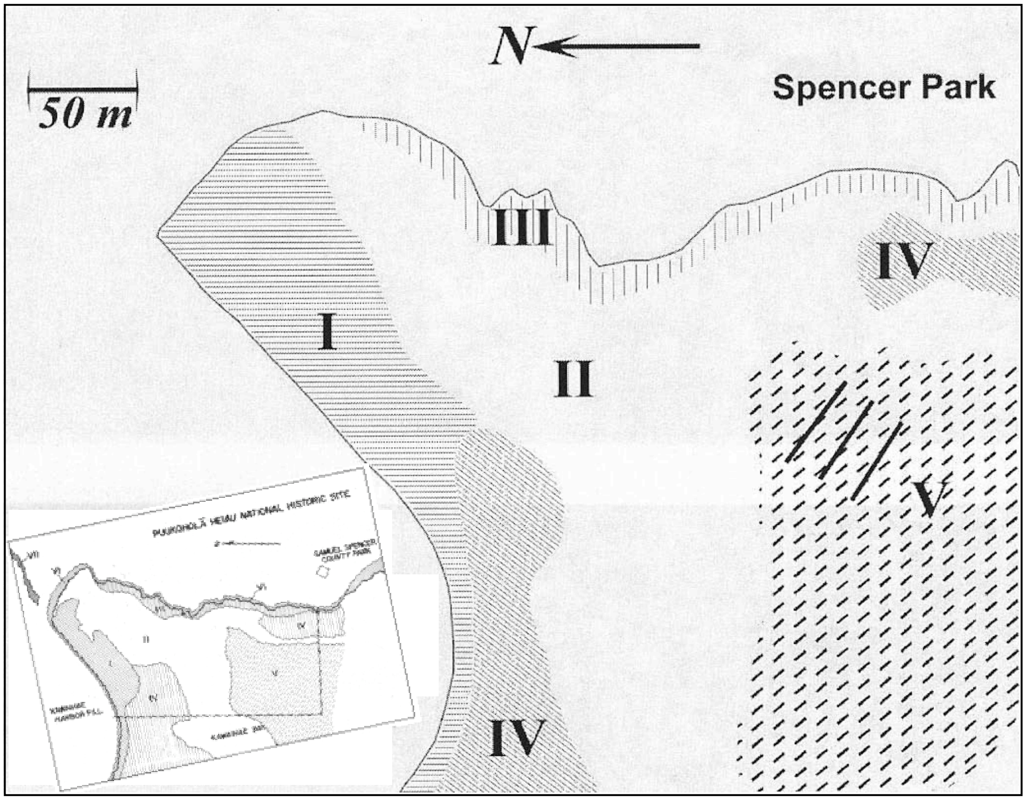


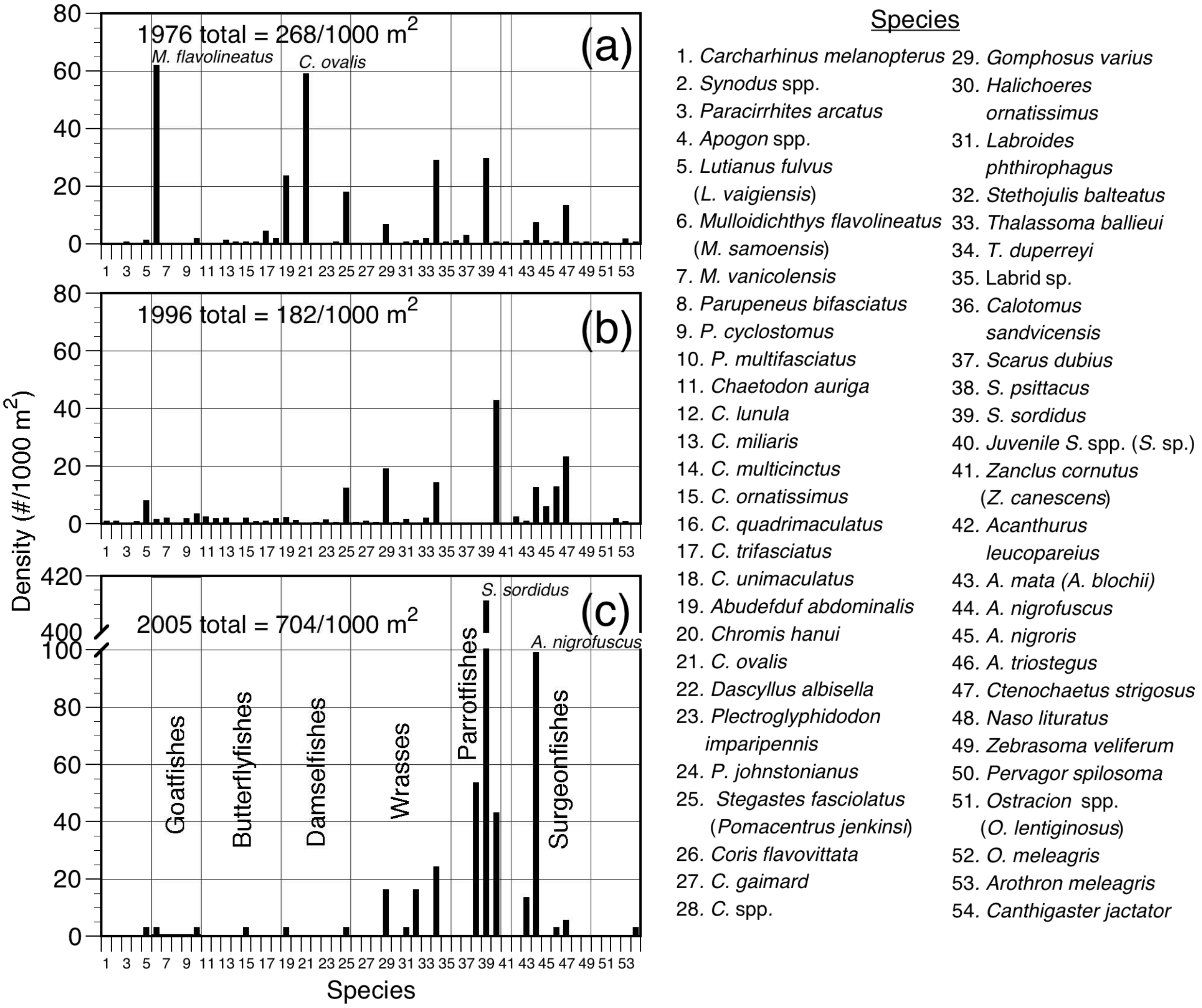
Figure 15. Habitat zones and transects used for marine surveys around PUHE in 1996. Note that biotope distributions are quite similar to those determined in 1976 by Cheney et al. (1977) (inset), but do not include the intertidal (biotope VI) and estuarine (biotope VII) habitats surveyed by Cheney et al. (1977). Figure modified from Tissot et al. (1998).

Tissot et al. (1998) concluded that were had been a significant decline in fish species (64 to 57) and abundance (279 to 181 per 1000 m^2) since 1976, "likely … in response to chronic terrestrial run-off and reduced ocean circulation in Pelekane Bay". The species composition of the 1976 and 1996 communities also was found to be quite different. In particular, two of the three most abundant species in the 1976 surveys were completely absent in 1996, and the most abundant species in 1996 (juvenile *Scarus* sp.) was not observed on transects in 1976 (Figure 16). Overall, 14 of the species observed in 1976 were not seen in 1996, while 17 species observed in 1996 were not seen in 1976, resulting in an overall similarity between the observed communities of only 30% (Tissot et al. 1998).

Unfortunately, as for the apparent differences between the Kanayama and Kawamoto (1970) and Cheney et al. (1977) results, some or all of the differences that Tissot et al. (1998) ascribed to changing environmental and use factors probably were due to methodological differences and natural variability. As noted above, total abundances in 1976 may have been anomalously high due to two unusually abundant species, and Tissot et al (1998) did not survey biotopes VI and VII – removing species observed only in biotopes VI and VII from Cheney et al.'s (1977) list reduces the total to 57 – identical to the number observed by Tissot et al. (1998). The total number of species observed on transects actually <u>increased</u> from 1976 (36) to 1996 (39) despite the smaller area surveyed in the later study, although the apparent increase could be a methodological artifact of the much greater number of replicate surveys conducted in 1996. Perhaps most importantly, transect surveys were not performed at the same location in the two studies; while transects for both studies were located in biotope V, the 1998 transects appear to have been located much closer to the boundary with biotope II (Figures 12 and 15) and thus in what likely were more turbid waters, which could well have led to significant differences in fish abundance and community composition. Tissot et al. (1998) also noted that reef fish communities may be characterized by "low temporal similarity" simply due to differences in recruitment effects on community structure (i.e. the "lottery hypothesis" – Sale and Dybdahl 1975). Thus, while it seems quite likely that sedimentation and reduced circulation have adversely affected the pelagic community in nearshore portions of Pelekane Bay, the data obtained by Tissot et al. (1998) are not sufficient to establish a decline in the fish community between 1976 and 1996, particularly in more offshore reef habitats.

CRAMP personnel surveyed the fish population in Pelekane Bay in 2002 using 6 transects in primarily soft-bottom habitats around the mouth of the bay and in the area just south of the small-boat harbor (Figure 5). Transect sites appear to fall within biotopes I – IV as delineated by Cheney et al. (1977) (Figure 12) and Tissot et al. (1998) (Figure 15). Transects were surveyed once using CRAMP Rapid Assessment Techniques (RAT) methods (http://cramp.wcc.hawaii.edu/Rapid_Assessment_Files/rapid_assessment.htm). Information on the species identified was not available for this study, but the number of species seen on transects, abundances, and biomass all were extremely low compared to data from an offshore hard-bottom CRAMP monitoring site (Table 6). Significant abundance was observed on only one transect (2), and that was considered unusual as "an anomalous large school of fish swam by" (K. Rodgers, CRAMP co-PI, pers. comm. 2006).

Beets et al. (in review) surveyed the marine fish community on 4/6/2005 at 9 locations off of PUHE (Figure 11, Table 7). Quantitative data on species presence, abundance, and size were



Species

1. *Carcharhinus melanopterus*
2. *Synodus* spp.
3. *Paracirrhites arcatus*
4. *Apogon* spp.
5. *Lutianus fulvus* (*L. vaigiensis*)
6. *Mulloidichthys flavolineatus* (*M. samoensis*)
7. *M. vanicolensis*
8. *Parupeneus bifasciatus*
9. *P. cyclostomus*
10. *P. multifasciatus*
11. *Chaetodon auriga*
12. *C. lunula*
13. *C. miliaris*
14. *C. multicinctus*
15. *C. ornatissimus*
16. *C. quadrimaculatus*
17. *C. trifasciatus*
18. *C. unimaculatus*
19. *Abudefduf abdominalis*
20. *Chromis hanui*
21. *C. ovalis*
22. *Dascyllus albisella*
23. *Plectroglyphidodon imparipennis*
24. *P. johnstonianus*
25. *Stegastes fasciolatus* (*Pomacentrus jenkinsi*)
26. *Coris flavovittata*
27. *C. gaimard*
28. *C.* spp.
29. *Gomphosus varius*
30. *Halichoeres ornatissimus*
31. *Labroides phthirophagus*
32. *Stethojulis balteatus*
33. *Thalassoma ballieui*
34. *T. duperreyi*
35. Labrid sp.
36. *Calotomus sandvicensis*
37. *Scarus dubius*
38. *S. psittacus*
39. *S. sordidus*
40. *Juvenile S.* spp. (*S.* sp.)
41. *Zanclus cornutus* (*Z. canescens*)
42. *Acanthurus leucopareius*
43. *A. mata (A. blochii)*
44. *A. nigrofuscus*
45. *A. nigroris*
46. *A. triostegus*
47. *Ctenochaetus strigosus*
48. *Naso lituratus*
49. *Zebrasoma veliferum*
50. *Pervagor spilosoma*
51. *Ostracion* spp. (*O. lentiginosus*)
52. *O. meleagris*
53. *Arothron meleagris*
54. *Canthigaster jactator*

Figure 16. Mean density of fishes observed on transects in biotope V (patch reefs) in Pelekane Bay. (a) 1976 (Cheney et al. 1977). (b) 1996 (Tissot et al. 1998). (c) 2005 (transects 16, 16A, and 36 from Beets et al. (in review)). Species names in key are from Beets et al. (in review); synonyms used by previous investigators are shown in parentheses.

collected during a single SCUBA survey along one randomly oriented transect (25 m x 5m) at each site. Additional data on species presence was obtained by qualitatively surveying a larger area (~twice the quantitative survey area) around each transect (study coauthor E. Brown, pers. comm. 2006). Transect locations were chosen randomly within habitat strata defined by existing habitat data (cf., Figure 11) with three major habitat types (colonized hard bottom, uncolonized hard bottom, and unconsolidated sediment) and 11 subhabitat types, 5 of which are found in coastal waters off of PUHE (Table 7). A total of 57 fish species were observed, 28 during quantitative surveys and an additional 29 on qualitative surveys. Abundance averaged over all transects was 429/1000 m^2, but the number of species observed and total abundances both were significantly higher at more offshore transects. For instance, a total of 16 species were observed on the quantitative survey of transect 18, while only one species each were observed on transects 2A, 35 and 41 (Table 7). Abundance also was highest at transect 18 (1,550/1000 m^2) and lowest at 2A, 35 and 41 (8, 56 and 8/1000 m^2, respectively).

Table 6. Summary statistics for fish observed on transects in Pelekane Bay on 3/20/2002. Data from the 3/27/02 survey on the CRAMP Kawaihae 3m transect (Kaw 3) also are shown for comparison. Data from K. Rodgers, CRAMP co-PI, pers. comm. 2006.

Category	RA 1	RA 2	RA 3	RA 4	RA 5	RA 6	Kaw 3
Species[1]	0	2[2]	2[3]	0	1	0	47 – 322[4]
Diversity (Shannon-Weaver H')	0	0.06	0.69	0	0	0	2.13
Evenness	0	0.08	1	0	0	0	0.72
Endemic (%)	0	0	0	0	0	0	21.28
Indigenous (%)	0	100	50	0	100	0	76.6
Introduced (%)	0	0	50	0	0	0	2.13
Corallivores (%)	0	0	0	0	0	0	4.26
Detritivores (%)	0	0	0	0	0	0	10.64
Herbivores (%)	0	0	0	0	100	0	42.55
Mobile Inverts (%)	0	0.99	100	0	0	0	38.3
Zooplanktivores (%)	0	99.01	0	0	0	0	0
Piscivores (%)	0	0	0	0	0	0	2.13
Sessile Inverts (%)	0	0	0	0	0	0	2.13
<5 cm (#)	0	4	0	0	1	0	0
5-15 cm (#)	0	400	2	0	0	0	214
>15 cm (#)	0	0	0	0	0	0	108
<5 cm (% of total)	0	1	0	0	100	0	0
5 – 15 cm (% of total)	0	99	100	0	0	0	66.5
>15 cm (% of total)	0	0	0	0	0	0	33.5
Total fish (#)	0	404	2	0	1	0	322
Density (#/ha/1000)	0	32.32	0.16	0	0.08	0	25.76
Biomass (grams)	0	2119.31	20.05	0	0.29	0	25335.55
Biomass (t/ha)	0	0.17	0	0	0	0	2.03

1. No total species or richness category in original data, values shown are estimated from other parameters.
2. Based on number observed, H' and evenness values
3. Based on number observed and proportions of indigenous and introduced species
4. Lower limit based on proportions of total # in various trophic guilds

Table 7. Fish community and habitat type data from transects (25m x 5m) surveyed by Beets et al. (in review). Habitats (Hab): HB = Hard Bottom, US = Unconsolidated Sediment. Subhabitats (Shab): SR = Scattered Rock/coral in unconsolidated sediment, M = Mud, AR = Aggregated Reef, PV = Pavement, S = Sand. Rugosity is the ratio of the length of chain draped along the transect to transect length. Data from study coauthor E. Brown, pers. comm. 2006.

Transect	Hab	Shab	Rugosity	Species #	Abundance #/1000 m^2	Biomass kg/1000 m^2	Diversity H'	Evenness
1A	HB	SR	1.52	4	40	0.092	1.33	0.96
2A	US	M	1.04	1	8	0.67	0	0
16	HB	SR	2.16	8	744	53.9	1.14	0.55
16A	HB	AR	1.92	10	1100	50	1.32	0.57
18	HB	PV	1.36	16	1550	115	1.66	0.60
35	US	S	1.00	1	56	0.041	0	0
36	HB	SR	1.96	8	264	8.4	1.47	0.71
40	HB	SR	1.32	5	88	6.6	1.41	0.88
41	US	S	1.00	1	8	0.0038	0	0
Average			1.48	6	429	26.1	0.93	0.47

As for earlier studies, the use of a new methodology and transect locations complicates comparison of results to those from previous studies. At least 5 of the transects do fall within the areas surveyed previously by Cheney et al. (1977) and Tissot et al. (1998), and transect locations appear to provide some coverage of their biotopes II – V (Figures 12 and 15). Data from transects 2A, 40 and 41 provide quantitative data on fish species and abundance in turbid nearshore areas, and the very low values of both are consistent with earlier qualitative observations by Kanayama and Kawamoto (1970) and Cheney et al. (1977), and with quantitative results from the CRAMP RA survey in 2002 (Table 6). One of the transects (18) is well offshore of the Cheney et al. (1977) and Tissot et al. (1998) study areas, and another (35) is well south and is in a unique habitat, so data from these transects are unlikely to be comparable to data from the earlier studies. The lack of a transect in biotope I also complicates comparison of data across these studies, but three transects (16, 16A and 36) are located in biotope V and are relatively close to Cheney et al.'s (1977) transects. Data from these transects thus can be compared to earlier data on the fish community in this biotope.

A total of 18 fish species were observed on quantitative surveys of transects 16, 16A and 36, with an associated average abundance of 700/1000 m^2 (Figure 16c). The number of species is considerably lower than the total observed in biotope V in 1976 (36) and 1996 (39), but the total area surveyed (450 m^2) is smaller than either of the two earlier studies, and species from the qualitative survey are not included but probably would bring the total up closer to the earlier totals. In addition, with only one exception (*Canthigaster jactator*) all of the species observed had been noted previously in either 1976 or 1996 (Figure 16). The abundance of 700/1000 m^2 is much higher than that observed in 1976 (279/1000 m^2) and 1996 (181/1000 m^2), but inspection of Figure 16 shows that one species (*Scarus sordidus*) was responsible for over half of the total number of fish observed and that the abundances of the remaining species mostly fall within the range of abundances seen in earlier studies. While the inclusion of species noted on the qualitative survey also would increase total abundances, the magnitude of the increase probably would be relatively small as abundant species likely would already have been noted on the quantitative survey. Thus, the 2005 data suggest that the fish community in biotope V may not have been significantly different than that found in 1976 and 1996, but fish may have been somewhat more abundant.

B.3.f.ii. Subtidal benthic resources

Nearshore areas around PUHE consist mostly of sandy and muddy sediments, with some areas of hard substrate off the southern portion of the site. Offshore areas have a more varied benthic geomorphology and mostly are overlain with biogenically-structured habitats that form a topographically complex range of substrates (Figure 11). Kawaihae Bay historically was known as the site of one of the best-developed coral reefs in west Hawai‘i, but most of the reef was destroyed in the late 1950s and 1960s during construction of the main basin of Kawaihae Harbor and of a second basin for the small-boat harbor outside of the main harbor. Dredging and blasting during construction introduced significant quantities of rubble and sediment into area waters, and the construction of the harbor itself 'created' Pelekane Bay, which has become a highly effective trap for terrigenous sediments delivered by Makeahua Stream. As a result, benthic habitats around PUHE have changed significantly compared to their condition prior to harbor construction. Corals still are found in association with an extensive consolidated spur- and groove reef system offshore, and scattered coral colonies and limited areas of other hard substrate support attached flora and fauna in nearshore areas, but shallow subtidal areas in Pelekane Bay now consist mostly of areas of mud, silt, and sand (Figure 11), which are inhospitable to corals (Naughton et al. 2001) and support soft-bottom benthic communities that probably were absent or rare prior to harbor construction. Benthic resources around PUHE have been the subject of a number of surveys, usually in association with the surveys of fish and other biota discussed above. However, field surveys mostly have focused on the distribution and abundance of corals and prominent macroinvertebrates such as urchins, with relatively little attention given to benthic algae, molluscs, and crustaceans. Remote sensing (aerial photography and satellite remote sensing) recently has also been used to characterize the spatial distribution of habitat types, particularly coral communities (Figure 11).

The earliest data on benthic resources around PUHE are from Kanayama and Kawamoto (1970). While the focus of their study was on fish populations, some notes were included on corals and other invertebrates in their study area:

> "Coral species in the *Porites*, *Montipora* and *Pocillopora* genera comprised the major portions of the reef. A few scattered colonies of *Fungia scutaria*, a mushroom coral were present. Besides the corals, sea urchins were the most prominent and abundant invertebrates. The sea urchins *Heterocentrotus mammillatus* (slate-pencil urchin), *Echinothrix calamaris*, *E. diadema* and *Diadema paucispina* (three species of long-spined urchins collectively called "wanas"), *Tripneustes gratilla* (short-spined urchin), *Echinometra mathaei* and *E. oblonga*, were very common particularly on the outer half of the reef. Counts of sea urchins at transect stations 6 and 8 in November indicated that there was an average of about 425 slate-pencil urchins, 158 short-spined urchins and 191 long-spined "wanas" per acre of reef. A few individuals of the coral eating starfish *Acanthaster planci* (crown-of-thorns starfish) were seen during the fish counts. Some of these were feeding on the corals, but the damage being inflicted was light. The starfish population was considered as being normal for the reef. Other invertebrates that were seen at the project site reef but only infrequently were *Panulirus japonicus* (spiny lobster), *Polypus marmoratus* (octopus) and *Holothuria atra* (sea cucumber). The Kona crab, *Ranina serrata*, was seen in the sand channel immediately to the south of the project site. The only invertebrates that were collected after the detonations were two specimens of an unidentified species of nudibranchs."

Because all of their surveys were conducted at hard-bottom locations well offshore of PUHE (Figure 14), their results are most relevant to relatively 'clean' offshore reef habitats and are unlikely to be representative of the more turbid soft-bottom areas closer to PUHE.

Cheney et al.'s (1977) survey of marine resources off of PUHE included characterization of benthic habitats (Figure 12) and associated biota. Qualitative sampling within each biotope was performed by recording or collecting benthic epi- and infauna and assessing their relative abundance in a 100 m^2 quadrat. Quantitative assessments of benthic habitat and of corals and other benthic invertebrates were performed along the same line transects in biotope V that were used for fish counts (Figure 12). Mollusks in offshore waters were assessed "by a random sampling of patch reefs and sand deposits within the offshore portion of the site". Excluding mollusks, 67 macroinvertebrate species were identified in offshore biotopes. The total number of mollusk species in offshore biotopes cannot be determined precisely from the data, as observations in intertidal habitats (biotope VI) are included with observations from offshore habitats in a combined species list for littoral habitats (i.e., biotopes I, III, VI). However, 8 mollusk species were observed in the other offshore habitats (II, IV, V), and an additional 27 were observed in littoral habitats, so the number of species found in coastal waters must have been between 8 and 35. Combining this range and the 67 macroinvertebrate species yields a total of 75 to 102 invertebrate species in coastal waters. Cheney et al. (1977) noted that data from the different biotopes showed "striking gradients in diversity and distribution of benthic invertebrates [that typically were] correlated with substrate and water quality factors". Corals were observed to be "under moderate to heavy siltation stress and inshore areas were dominated by opportunistic species". A descriptive summary of the benthic biological resources in each biotope is provided in Table 8; data on habitat types and coral species and cover on transects is given in Table 9 and plotted in Figures 17 and 18. A complete list of the macroinvertebrates observed in each biotope is included in Appendix B.

Table 8. Invertebrate fauna in benthic habitats off of PUHE. Faunal descriptions modified from Cheney et al. (1977).

Biotope	Description	Invertebrate fauna
I	Mixed rubble and silt	Inshore: macroinvertebrates consist of scattered portunid and box crabs, corals not present. Silt substrate perforated with shrimp burrows; infauna consists of isopods and scattered stomatopods, ghost shrimp, small holothurians, and snapping shrimp. Numerous unidentified micromolluscs. Undersides of rocks covered with masses of sabellarid worm tubes, upper surfaces usually bare. Outer regions: Macroinvertebrates more common. Living coral dominated by *Pocillopora damicornis* (20 colonies (5 – 20 cm diameter) in 50 m2 area, many more < 5 cm diameter), *Cyphastrea ocellina* also present. Echinoderms represented by *Echinometra mathaei* in coral rubble and a few *Tripneustes gratilla*. Sand substrate contains "a small infauna of macroinvertebrates made up of alpheid shrimp and annelids (i.e. sabellids)". "Undersurfaces of rocks … encrusted with coralline algae, serpulids, and sabellariids…upper surfaces colonized by vermetids, filamentous algae, and an occasional colony of the hydroid, *Pennaria tiarella*".
II	Sand and silt bottom	Mud dominant inshore with numerous shrimp burrows and tracks from *Terebra crenulata* (crenulated auger). Scattered coral colonies. Infauna in 1 sample "made up completely of annelids (nereids)".
III	Basalt pavement with rubble	*Pocillopora damicornis* dominant coral in shallow areas, *Porites compressa*, *Montipora verrucosa* and *Pocillopora meandrina* found in deeper water around southern edge of biotope. *Leptastrea bottae*, and *Cyphastrea ocellina* (corals), zooanthids, *Athelia edmondsoni* (soft coral) and the sponge *Terpios* encrusting vertical faces of rocks in central portion of biotope. Most live coral disappears toward breakwater. *Echinothrix diadema* most common echinoderm on bare pavement but *Tripneustes gratilla* also often seen. *Echinometra mathaei* usually found in cracks and old coral heads. Contents of single 15 cm diameter coral head included six *E. mathaei* (1 –2 cm diameter), 5 brittle stars (*Ophiocoma brevipes*), 5 small colonies of *P. damicornis* and *Porites* sp., 2 tunicates, many small syllids and serpulids.
IV	Coral in mixed rubble	Biotope "dominated by larger (to 4 m diameter) dead and living coral heads or clumps of colonies with 0.25 to 1 m vertical relief surrounded by a light and loose silt substrate. Smaller coral heads and coral rubble are interspersed in the mud and silt between the larger masses. Many of the coral heads are silted over, particularly those near the breakwater side of the biotope, and there is some evidence of recent death or stress, i.e., bleached but not silted coral heads. Living corals near the breakwater side are predominantly *Pocillopora damicornis* and *P. meandrina*, with *Porites compressa*, *P. lobata*, and *Montipora verrucosa* seen less frequently. Other

Table 8 (cont.). Invertebrate fauna in benthic habitats off of PUHE.

IV (cont.)	Coral in mixed rubble	species are noted in [Appendix B]. Near the sand channels the biotope is characterized by mixed colonies of *Porites*, usually clumped into masses up to 4 m in diameter. Most of the colonies are dead and fragile and are infiltrated with sponges, algae, and a rich infauna like that seen in coral rubble from other biotopes. The Spencer Beach Park portion of the biotope has a lush growth of *Porites compressa* and *P. lobata* with colonies up to 1 m in diameter, and smaller colonies of *Pocillopora meandrina*, *P. damicornis*, *Montipora verrucosa*, and *M. patula*. Both species of *Echinometra* are abundant in the *P. compressa* heads, but *E. oblonga* is more common in shallow water. *Echinothrix diadema* is fairly common around the bases of coral heads, and the slate-pencil urchin, *Heterocentrotus mammilatus*, is frequently seen".
V	Patch reefs	"Individual [coral] colonies and patch reefs ranging from less than 0.5 m to 20 m in width with 0.25 to 3 m of vertical relief. The surfaces of the colonies may break the surface at low tide… There is an apparent deterioration of coral cover and diversity and an increase in silt deposits toward the breakwater side of the biotope which is more or less similar to biotope IV. A large colony of the coral *Porites* (*Synaraea*) sp. was found near the outer edge of the inside transect site (line #1), and two possibly "tumorous" colonies of *Montipora verrucosa* were observed and marked near the center of the biotope. Dead coral heads within the transect area are encrusted with coralline and filamentous algae, bryozoans, hoof shells (*Hipponix pilosus* and *H. barbatus*), and serpulid worms. Boring sponge is common, and scattered bivalves, vermetids, and zoanthids also occur".

Table 9. Coral coverage and species observed at 1 m intervals on 50 m transects on patch reefs (biotope V) adjacent to PUHE (Figure 12). Count is the number of intersections where cover or species was observed, % is the percentage of total habitat (50) or coral species (variable) counts. Modified from Table 5 in Cheney et al. (1977).

	Inner (line #1)		Outer (line #2		Average	
Coverage	Count	%	Count	%	Count	%
Coral substrate	27	54	32	64	29.5	59
Living coral	23	46	21	42	22	44
Mud/sand substrate	23	46	18	36	20.5	41
Totals	50	100	50	100	50	100
Species composition						
Porites compressa	21	50	13	21	17	32
P. lobata	8	19	20	32	14	27
P. (*Synarea*) sp.	3	8	0	0	1.5	3
Pocillopora meandrina	2	5	7	11	4.5	9
P. damicornis	0	0	1	2	0.5	1
Montipora verrucosa	5	12	13	21	9	17
M. patula	0	0	6	9	3	6
Pavona varians	1	2	1	2	1	2
Leptastrea bottae	1	2	0	0	0.5	1
Cyphastrea ocellina	1	2	1	2	1	2
Totals	42	100	62	100	52	100

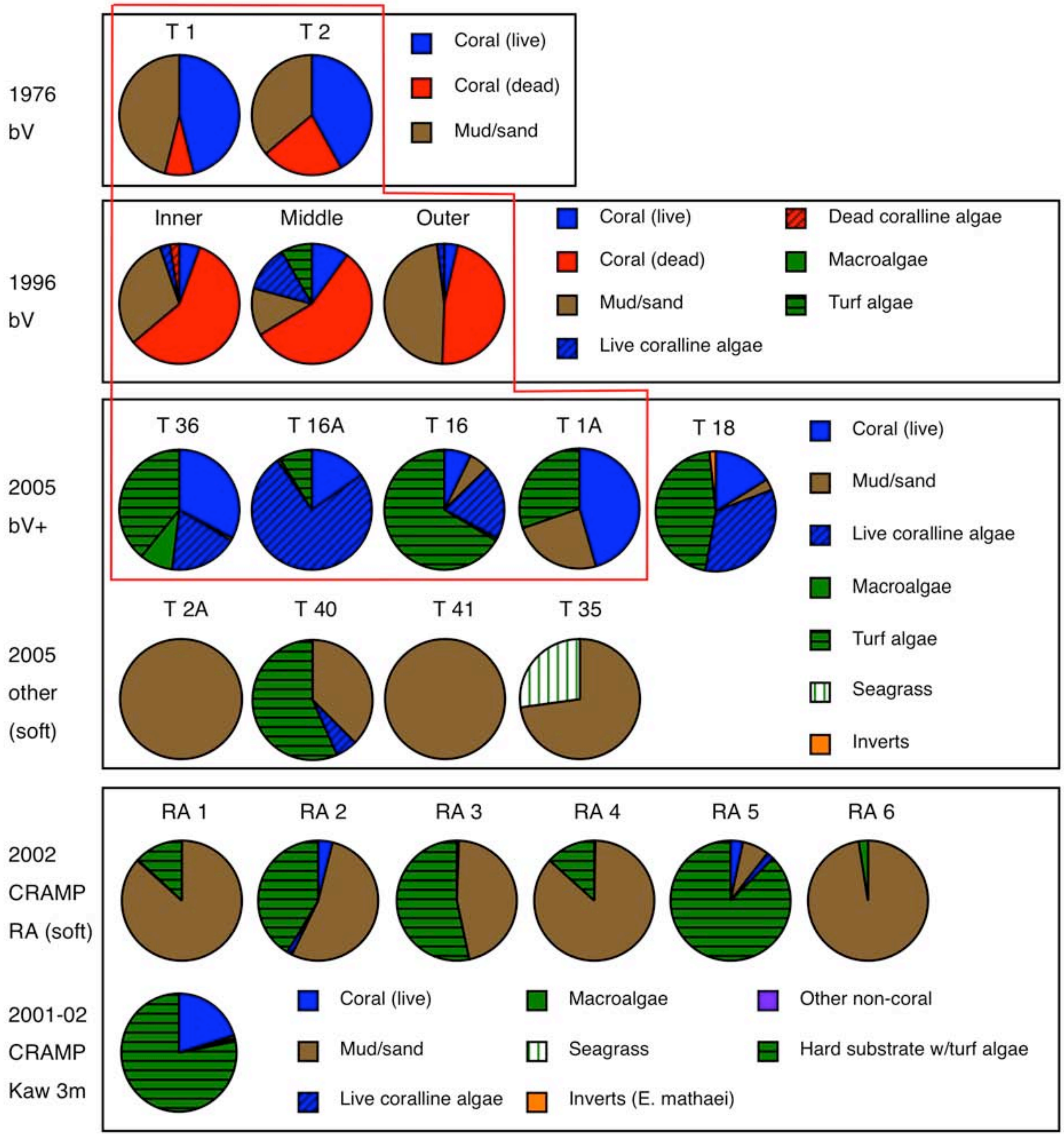


Figure 17. Benthic cover at quantitative survey sites off of PUHE, 1976 - 2005 (see Figures 3, 11 and 12 for transect locations). CRAMP data from their 3 m Kawaihae transect are shown as a possible 'control' for comparison to biotope V (bV) data (transects inside red boundary). While the plots suggest significant changes in benthic cover in biotope V between 1976 and 2005, much of the differences may be due to methodological and classification differences. See text for details.

Ball (1977) surveyed macroscopic benthic algae on 4/10 – 13/1976 in the same study areas surveyed by Cheney et al. (1977) (Figure 12). The survey was performed by snorkeling along the general trajectory shown in Figure 12 and noting species and locations. No quantitative data were obtained, but ten species were observed in subtidal areas (Table 10), only one of which

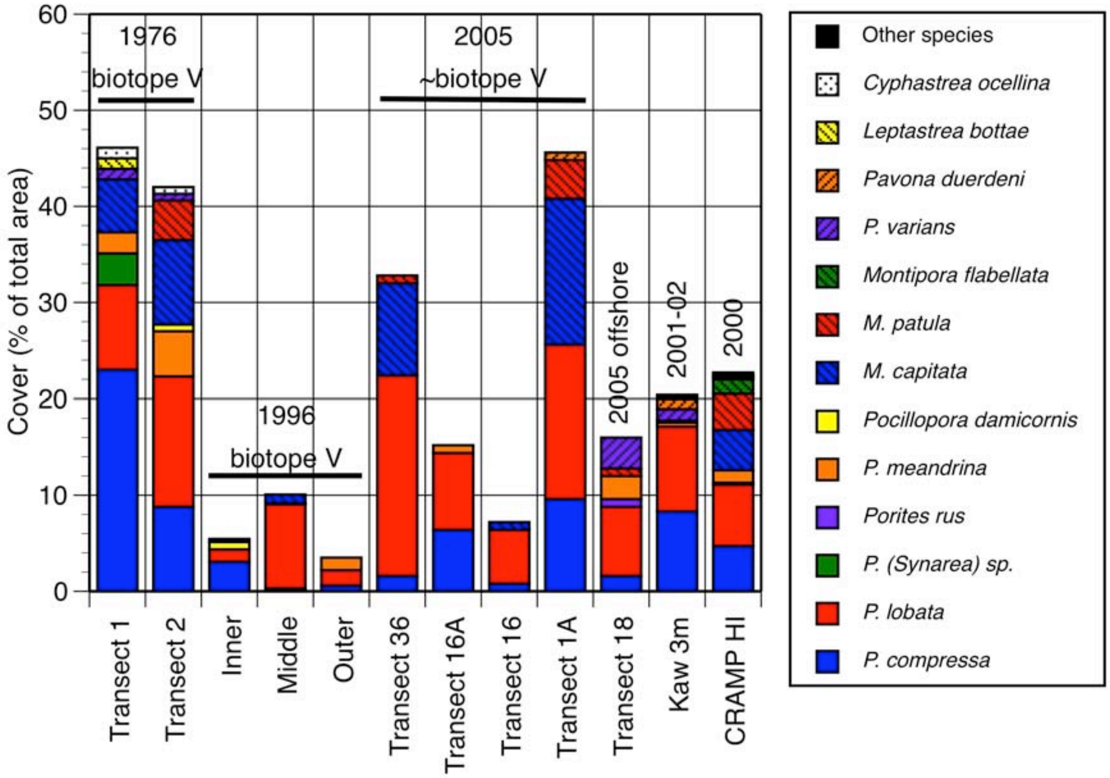


Figure 18. Coral species and cover on quantitative transects in biotope V, 1976 - 2005 (see Figures 3, 11 and 12 for transect locations). Transect 18 and CRAMP data also are shown for comparison. Kaw 3m = 2001-2002 data from CRAMP Kawaihae 3m transect (CRAMP co-PI K. Rodgers, pers. comm. 2006), CRAMP HI = average 3 and 10 m transect data for 28 sites on the islands of Kauai, Oahu, Molokai, Maui, and Hawai‘i (http://cramp.wcc.hawaii.edu/LT_Montoring_files/lt_status_of_the_reefs.htm). 1976 data are from Cheney et al. (1977), 1996 data are from Tissot et al. (1998), 2005 data are from Beets et al. (in review).

(*Biddulphia pulchella*) was considered abundant. Notes on the occurrence and distribution of algae were as follows:

> “Offshore, from the mouth of the embayment out to about 100 m (110 yards), extensive colonies of the diatom *Biddulphia pulchella* were observed amidst the silt and debris, interspersed on occasion with *Enteromorpha* sp., *Ulva fasciata*, *Polysiphonia mollis*, *Grateloupia filicina*, and *Acanthophera spicifera*.
> Further seaward, large mounds of coral rubble were encountered along with isolated live coral heads. In many instances, the coral rubble was covered by moderate growths of the crustose red alga, *Porolithon onkodes*. The live coral heads were relatively clear of macroscopic benthic algae… However, in certain areas the red filamentous algae, *Tolypiocladia* sp., was relatively abundant on coral heads in crevices and patches adjacent to the living coral.
> Of the total biomass of algae observed, the diatom *Biddulphia pulchella* appeared to be present in the largest quantity. The abundance of this species is unusual compared with my previous observations. It may be that its abundance is due to the large quantity of organic and inorganic matter in suspension, and hence increased nutrient loading of the water mass” (Ball 1977).

Overall, algal diversity and density were considered to be low, likely due to the negative effects of turbidity on light availability and of direct sediment deposition on algae. Substratum stability and circulation also were cited as possible factors limiting algal recruitment and growth. Two of the species observed (*Ulva fasciata* and *Enteromorpha* sp.) often are found in areas with elevated nutrient loading, suggesting that nutrient concentrations in the area also may have been elevated.

Table 10. Benthic marine algae observed in coastal waters adjacent to PUHE in April 1976. Modified from Table II in Ball (1977).

Habitat	Species	Abundance(1)	Status(2)
Coral heads, 3-7 m depth	*Tolypiocladia*	Moderate	I
	Porolithon onkodes(3)	Moderate	I
Coral rubble scattered among sediments. 0.3 – 1 m depth	*Cladophora* sp.	Moderate	I
	Ulva fasciata	Moderate	I
	Enteromorpha sp.	Moderate	I?
	Grateloupia filicina	Infrequent	I
	Polysiphonia mollis	Moderate	I
	Acanthophora spicifera	Moderate	X
Forming widespread mats atop bottom sediments (epipelic), 0.3 – 1 m depth	*Biddulphia pulchella*	Abundant	I
Margins of inshore bench from sublittoral fringe to 0.5 m depth	*Amansia glomerata*	Infrequent	I

(1) Infrequent: < 20% cover/m^2, Moderate: 20-60% cover/m^2, Abundant: > 60% cover/m^2.
(2) I = indigenous, X = exotic.
(3) Not listed in Table II in Ball (1977) but discussed in text.

Tissot et al. (1998) surveyed coastal waters adjacent to PUHE in 1996 specifically to assess differences in habitat and benthic biota compared to the conditions observed 20 years previously by Cheney et al. (1977). The areal distribution of benthic habitat types appeared similar (Figure 15), although no quantitative comparisons were made because habitat boundaries were not delineated quantitatively by Cheney et al. (1977). Abundances of algae, corals and epifaunal species were noted qualitatively for each biotope as abundant, common, or rare during swimming surveys, but the details of the survey methodology are not provided. Infaunal macroinvertebrates were identified and enumerated from sediment samples (to 10 cm depth), and the shape, size and position of animal burrows were noted. The occurrence and abundance of macroinvertebrate epifauna, corals, seaweeds, and other substrates were determined quantitatively on the three transects in biotope V (Figure 15) by sampling 10 0.5 m^2 quadrats placed randomly along the transects.

The number of species of algae and benthic invertebrates identified in 1996 was considerably lower than the number observed in 1976, with only 5-6 species of algae observed in non-intertidal habitats (compared to 10 in 1976), and the number of invertebrate species declining from 75 -102 in 1976 to 21 in 1996 (Table 11). Live coral cover in biotope V declined dramatically, from 44% in 1976 to 6.7% in 1996, with a parallel increase in dead coral cover (Table 12, Figures 17 - 19), although the coral species identified and their relative abundance were similar in the two studies (Figure 18). Tissot et al. (1998) concluded that the declines in abundance and diversity most likely were related to “long-term sedimentation stress associated with chronic terrestrial run-off and reduced ocean circulation in Pelekane Bay”. However, as for the fish survey results discussed above, some of the difference in coral cover could be due to other factors. In particular, the reduced cover observed in 1996 may simply have reflected more degraded habitat in the area surveyed by Tissot et al. (1998) compared to the area surveyed by Cheney et al. (1977). Coral cover estimates also may not have been comparable due to fundamental methodological differences in the studies – older studies in Hawaiʻi generally contain higher estimates of coral cover than recent studies (typically 35 – 40% compared to a 2000 average of about 23% for 28 CRAMP sites around the state (http://cramp.wcc.hawaii.edu/LT_Montoring_files/lt_status_of_the_reefs.htm). The number and abundance of organisms observed on transects also seems likely to have been affected by the different locations.

Table 11. Qualitative observations of marine organisms in offshore biotopes in Pelekane Bay (Figure 15) in 1996. Abundance is noted as A (abundant), C (common), or R (rare). Abundance codes with question marks are estimated from Tissot et al. (1998). Modified from Table 3 in Tissot et al. (1998).

PLANTS						
DIVISION	SPECIES	ABUNDANCE				
		I	II	III	IV	V
Phaeophyta	*Padina japonica*					R
Rhodophyta	*Porolithon gardeneri*	R				C
	Porolithon onkodes	R			C	C
	Filamentous red alga (1)	C			C?	
Unspecified	Algal mats (1)	C				
	Turf algae (1)			C?		R?C?
INVERTEBRATES						
PHYLUM	SPECIES	ABUNDANCE				
		I	II	III	IV	V
Cnidaria	*Anthelia edmondsoni*			A		
	Montipora verrucosa					R
	Palythoa tuberculosa			R		
	Pavona varians					R
	Pocillopora damicornis			C	C	R
	Pocillopora meandrina					R
	Porites lobata			C	C	C
	Porites compressa					R
	Zoanthus pacificus			R		
Mollusca	vermetid gastropods					C
Annelida	*Alpheus* burrows	R	C			
	Spirobranchus giganteus					R
Arthropoda	*Alphaeus* spp.	C	A			
	Callapa hepatica	C				
	Grapsus tenuicrustatus			C		
	burrowing isopods	R				
Echinodermata	*Actinopyga mauritiana* (2)					
	Echinometra mathaei			C		R
	Echinometra oblonga			C		
	Echinothrix diadema			C		
	Echinothrix calamari			C		

(1) Not listed in Table 3 in Tissot et al. (1998) but discussed in text.
(2) No abundance data given in Table 3 in Tissot et al. (1998).

Table 12. Abundance of substrate types on patch reefs in 1976 compared to 1996. Values shown are mean percent cover. Differences between years are tested using two-sample t-test, values with an asterisk (*) are significant at $\alpha = 0.05$. Modified from Tissot et al. (1998).

	1976		1996			1976		1996		
Taxa	Inner	Outer	Inner	Middle	Outer	Mean	se	Mean	se	p
Plants										
Turf algae	na	na	0.0	8.3	0.0	na	na	2.8	2.8	na
Encrusting coralline algae	na	na	1.0	12.7	1.9	na	na	5.2	3.7	na
Porolithon onkoides - live	na	na	1.8	0.0	0.0	na	na	0.6	0.6	na
P. onkoides - dead	na	na	2.4	0.0	0.0	na	na	0.8	0.8	na
Corals										
Cyphastrea ocellina	0.9	0.8	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.04*
Leptastrea bottae	0.9	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.50
Montipora patula	0.0	3.8	0.0	0.0	0.0	1.9	1.9	0.0	0.0	0.50
Montipora verrucosa	5.5	8.8	0.3	0.9	0.0	7.2	1.7	0.4	0.3	0.14
Pavona varians	0.9	0.8	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.04*
Pocillopora damicornis	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.3	0.3	0.42
Pocillopora meandrina	2.3	4.6	0.0	0.1	1.3	3.5	1.2	0.4	0.4	0.20
Porites compressa	23.0	8.8	3.1	0.3	0.6	15.9	7.1	1.3	0.9	0.28
Porites lobata	8.7	13.4	1.3	8.8	1.6	11.1	2.4	3.9	2.4	0.13
Porites (*Synaraea*) sp.	3.7	0.0	0.0	0.0	0.0	1.9	1.9	0.0	0.0	0.50
Non-living substratum										
Dead coral	8.1	23.0	59.1	56.4	47.2	15.6	7.5	54.2	3.6	0.07
Sand & Mud	46.0	36.0	31.1	12.8	47.5	41.0	5.0	30.5	10.0	0.42

It is difficult to determine how comparable survey methods were in other areas, but methodological differences might also have affected species lists. For instance, only one of the algal species identified by Cheney et al. (1977) was considered abundant (the diatom *Biddulphia pulchella*, which was considered unusual at that time and was not noted at all by Tissot et al. (1998)), and the other species noted by Cheney et al. (1977) exhibited only moderate abundances or were seen infrequently, suggesting that they could have been missed in Tissot et al.'s (1998) surveys unless the surveys were performed very carefully. Similarly, while Tissot et al. (1998) include only 3 algal species in their species list, 2 of which are encrusting coralline algae, the text of their report discusses 2 to 3 additional species or algal communities (a filamentous red alga in biotope I and possibly IV, algal mats in biotope I, and turf algae in biotope III), all of which appear to have been common. Thus, the apparent decline in algal species may not have been as significant as portrayed in their results. The decline in invertebrate species, particularly in "sponges, flatworms, sipunculans, echiurans, ectoprocts, annelids, arthropods, molluscs and echinoderms" (Tissot et al. 1998) is the most dramatic change noted by Tissot et al. (1998), but also seems likely to have been affected by methodological artifacts. Cheney et al. (1977) observed sponges, echiurans, ectoprocts, annelids, arthropods, and echinoderms in several offshore biotopes, but flatworms and sipunculans were found only in their intertidal habitat (biotope VI), which was not surveyed at all by Tissot et al. (1998), and a significant fraction of the molluscs and of some of the other groups may also have been found only in intertidal areas. The most robust evidence of change in 1996 appears to have been in coral rubble and soft sediment areas: "In and amongst coral rubble [Cheney et al. (1977)] found numerous species of

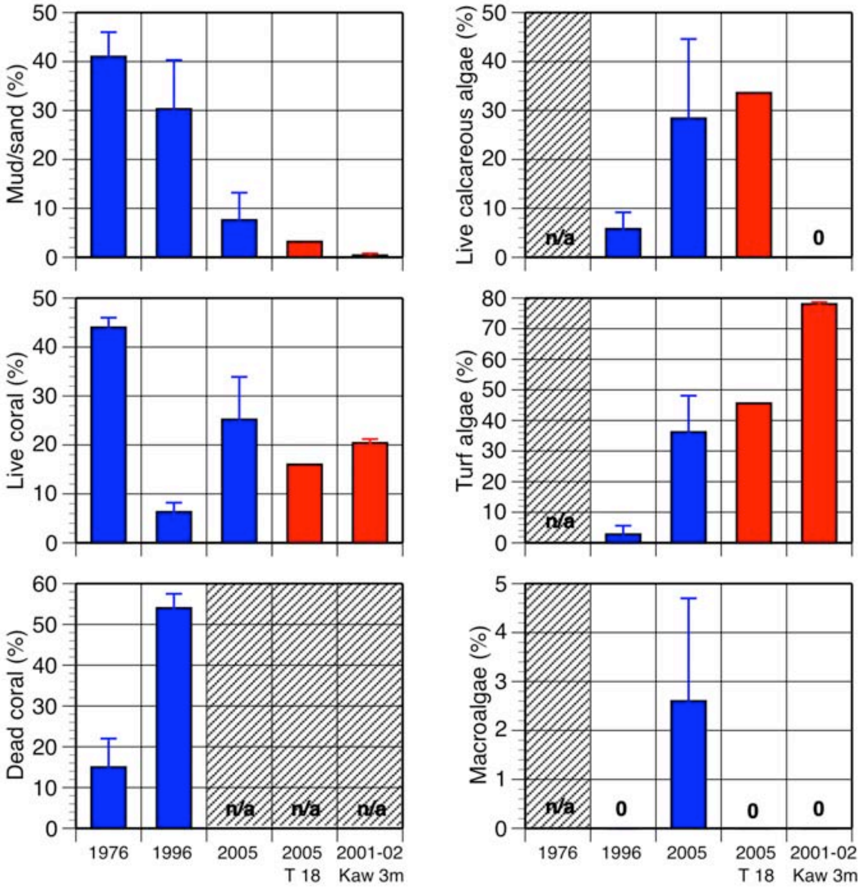


Figure 19. Average percent cover of individual benthic substrate types on biotope V transects. Error bars are one standard error. Shaded years have no comparable data. Data from an offshore site surveyed in 2005 (2005 T 18) and from the CRAMP 3 m long-term monitoring site outside of Kawaihae harbor (2001-02 Kaw 3m) also are show for comparison as possible 'control' sites. Statistical comparisons between years are not performed because differences in transect locations and classification methodologies probably are at least as significant as temporal changes in producing observed differences. 1976 data are from Cheney et al. (1977), 1996 data are from Tissot et al. (1998), 2005 data are from Beets et al. (in review) transects 1A, 16, 16A, and 36, and 2001 CRAMP data are from K. Rodgers, CRAMP co-PI, pers. comm. 2006.

polychaete worms, crustaceans, gastropods, sea cucumbers and sea urchins. During surveys in 1996, these same coral rubble areas were largely bare, with occasional *Alpheus* shrimp burrows, vermetid gastropods, shore crabs, and several unidentifiable worm burrows. Moreover, the infauna, which consisted of several species of polychaetes, and *Alpheus* and Callianassid shrimp burrows in 1976, were greatly reduced in 1996. Although several unidentifiable worm burrows and *Alpheus* shrimp burrows were commonly seen during this study, repeated samples of sediment throughout the Bay contained few macroscopic organisms. Anoxic conditions were often encountered within several centimeters of the surface, perhaps in response to chronic accumulations of sediment" (Tissot et al. 1998). These observations suggest that the soft sediment habitats may have degraded during the 20 years between the studies, although the lack of data on shorter term fluctuations in habitat properties and the associated flora and fauna makes generalizations somewhat problematic.

CRAMP personnel surveyed benthic resources in Pelekane Bay in 2002 using 6 transects in primarily soft-bottom habitats around the mouth of the bay and in the area just south of the small-boat harbor (Figure 5). Transects were surveyed once using Rapid Assessment Techniques (RAT) (http://cramp.wcc.hawaii.edu/Rapid_Assessment_Files/rapid_assessment.htm). The most seaward sites (1, 4, 6) all had zero relief (and zero fish), and substrate consisted of greater than 85% mud and less than 0.3% coral. The greatest coral cover was found at the two nearshore sites (2 and 5) which had 4 and 3.2% cover respectively, but coral species richness and diversity were very low at all sites compared to values at an offshore hard-bottom CRAMP monitoring site (Tables 13 and 14, Figures 17 and 18). Analysis of a single sample of soft-bottom sediment showed very high organic and detrital content and low carbonate content compared to sediment collected at the offshore site (Table 15). The soft-bottom sample also contained a much larger proportion of small particles (92% less than 250 µm) than the hard-bottom sample (only 9% less than 250µm) (Table 16).

Table 13. Benthic cover on CRAMP Rapid Assessment (RA) transects in Pelekane Bay. Transect surveys were performed on 3/20/2002. Data from 2001-2002 surveys of the CRAMP Kawaihae 3m transect (Kaw 3m) also are shown for comparison. All values are as % cover. Data from K. Rodgers, CRAMP co-PI, pers. comm. (2006).

Category	RA 1	RA 2	RA 3	RA 4	RA 5	RA 6	Kaw 3m
Calcareous algae	0.2	1.4	0	0	2.2	0	0
Macroalgae	0	0	0	0	0	2.4	0
Mud	86.6	53.4	46.2	86.6	7.2	97.6	0
Sand	0	0	0	0	0	0	0.4
Sub(turf)[1]	13	41.4	53.4	13.2	87.2	0	78.0
Coral	0	4[2]	0.6[3]	0.2[4]	3.2[5]	0	20.4[6]
Total[7]	99.8	100.2	100.2	100.0	99.8	100.0	98.8

1. Non-coral hard substrate, colonized by turf algae.
2. 3% *Porites lobata*, 1% 1 other species by subtraction and species richness in Table 14 (only 6 coral species categories listed in data provided: *Montipora flabellata*, *M. patula*, *M. capitata*, *Pocillopora meandrina*, *Porites compressa*, and *P. lobata*).
3. 0.6% 1 other species from species richness in Table 14 – all 6 species listed in data provided are zeros.
4. 0.2% *P. lobata.*
5. 3.2% *P. lobata.*
6. 8.8% *P lobata*, 8.3% *P. compressa*, 1.2 % *Pavona varians*, 1.0% *P. duerdeni*, 0.44% *P. meandrina*, 0.18% *M. patula*, 0.15% *Porites evermanni* 0.04% *Leptastrea purpurea*, 0.2% unknown coral.
7. Totals from data as given. Small deviations from 100% are due to rounding errors, except Kaw 3m total, which does not include data from two additional categories: *Echinometra mathaei* (0.60%) and other/non-coral (0.46%), which would bring total to 99.9%.

Table 14. Coral species richness, diversity (Shannon-Weaver H') and rugosity on CRAMP Rapid Assessment (RA) transects in Pelekane Bay. Data from 2001-2002 surveys of the CRAMP Kawaihae 3m transect (Kaw 3m) also are shown for comparison. Data from K. Rodgers, CRAMP co-PI, pers. comm. (2006).

Category	RA 1	RA 2	RA 3	RA 4	RA 5	RA 6	Kaw 3m
Richness[1]	0	2	1	1	1	0	8
Diversity	0	0.56	0	0	0	0	1.34
Rugosity[2]	1.00	1.22	1.16	1.00	1.68	1.00	1.81

1. Number of coral species
2. Ratio of draped chain length to transect length (1.00 = completely flat)

Table 15. Sediment composition in Pelekane Bay on 3/20/2002. Only one sediment sample was analyzed from the CRAMP RA area. Data from the 3/27/02 survey of the CRAMP Kawaihae 3m transect (Kaw 3m) also are shown for comparison. All values are as % of total mass. Data from K. Rodgers, CRAMP co-PI, pers. comm. (2006).

Category	RA	Kaw 3m
Loss on ignition at 500°C (organics)	23.61	3.7
Loss on ignition at 1000°C (carbonates)	10.01	93.12
Remaining (usually terrestrial mineral detritus)	66.38	3.18

Table 16. Grain size in sediments in Pelekane Bay, 3/20/2002. Only one sediment sample was analyzed from the CRAMP RA area. Data from the 3/27/02 survey of the CRAMP Kawaihae 3m transect (Kaw 3m) also are shown for comparison. All values are as % of total mass. Data from K. Rodgers, CRAMP co-PI, pers. comm. (2006).

Category	RA	Kaw 3m
Medium sand (250 – 500 µm)	3.4	85.39
Fine sand (125 – 250 µm)	4.11	5.91
Very fine sand (63 – 125 µm)	41.58	8.04
Silt (< 63 µm)	50.91	0.66
Total	100.0	100.00

Beets et al. (in review) quantified benthic cover and coral and benthic macroinvertebrate species on 9 transects offshore of PUHE (Figure 11). Benthic surveys were performed using the point-intercept method with a 1 m^2 quadrat with a 10-cm grid placed randomly within successive 5 x 5 m portions of each 5 x 25 m transect, and 25 of the 81 possible intercepts randomly selected for counting. Transect locations were selected randomly within benthic habitat strata (colonized hard bottom, uncolonized hard bottom, and unconsolidated sediment). The locations selected appear to provide some coverage of Cheney et al's (1977) biotopes II, III, IV, and V, but do not include data from biotope I, and several of the transects are near boundaries between biotopes, so it is not possible to relate Beets et al.'s (in review) results directly to earlier data on the extent and characteristics of each of the biotopes. However, the transects in soft bottom habitats provide data on the types and extent of substrates in those areas that look quite similar to the CRAMP RA data (Figure 17), and four of the transects are located in the general area of the biotope V transects surveyed by Cheney et al. (1977) and Tissot et al. (1998) (Figure 11), and thus provide an opportunity for comparison to those earlier studies. The types and extents of substrates present in 2005 in biotope V generally are different from those found in 1996 and in 1976, with less mud and more coralline algae and turf algae than in 1996 or 1976 (Figures 17 and 19), and live coral cover appearing higher in 2005 than in 1996, but lower than reported in 1976 (Figure 18). Some of the differences may reflect temporal changes in the benthic community, but the large variability in the extent of substrate types and coral cover on the four 'replicate' 2005 transects (Figures 17 and 18) shows that relatively small differences in transect locations can produce large differences in substrate area estimates, making it impossible to detect temporal changes in biotope V using these data alone. However, it is interesting to note that the average of the 2005 biotope V transects is rather similar to results from transect 18, and to data from the 3 m CRAMP transect off of Kawaihae harbor (Figure 19), suggesting that obvious sediment and turbidity impacts on benthic resources (e.g., coral mortality – Naughton et al. 2001) are restricted mostly to areas closer to Pelekane Beach.

Final data are not yet available, but one ongoing study will provide additional data on macroalgal species and distributions in marine habitats in and adjacent to the site. Cheryl Squair at the University of Hawaiʻi is conducting a rapid assessment of algae in intertidal and shallow subtidal habitats around PUHE and other Pacific National Parks - preliminary surveys in 2005 did not identify any alien algae in PUHE, although poor visibility hampered survey efforts. However, the algal community generally appeared to be in poor health with low diversity, likely due to the restricted circulation in Pelekane Bay (C. Squair, pers. comm. 2005).

Two recent studies have used remote sensing to map benthic habitat and associated biotopes around PUHE. NOAA's Biogeography Program (http://ccma.nos.noaa.gov/about/biogeography/) analyzed satellite images and aerial color photos obtained in 2000 to determine the distribution of coral communities and other habitats throughout the main Hawaiian islands (Figure 11c). The USGS produced a benthic habitat map specifically for waters adjacent to PUHE using aerial photos and LIDAR bathymetry obtained in 2000, supplemented by field data from underwater video and still photographs collected in 2004 and by field checks of classification accuracy in 2005 (Figure 11b). Both of the maps show generally similar distributions of coral reef and soft-bottom habitats off of PUHE and the habitats identified in the remote sensing products match those expected from previous surveys by Cheney et al. (1977), Tissot et al. (1998), Beets et al. (in review), and by the CRAMP RA surveys in 2002. The relatively coarse resolution available from remote sensing data (typically 1 - 4 m per pixel), the delineation of features as polygons with areas typically greater than 1 acre (NOAA) or 100 m^2 (USGS), and the limited field verification used for the NOAA map make these products most useful for assessing the general distribution of biotopes compared to other areas. The USGS classification scheme did allow for classification of "small" features when warranted (e.g., a 2 m diameter coral head in an otherwise uncolonized area), and underwater video and still photographs obtained by the USGS could be used to obtain additional insight into habitat distribution and quality.

B.3.g. Kawaihae Harbor

Biological resources in Kawaihae Harbor are not considered specifically in this report, as resources inside the main basin are physically separated from PUHE's coastal waters by the harbor breakwater and landfill. Resources associated with the breakwall itself and with waters in the area of the small boat harbor outside of the main basin are discussed above as they affect PUHE's coastal waters and intertidal resources.

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 site waters. However, there is significant potential for non-point source pollution due to intermittent discharges of water and sediment from Makeahua stream and possibly from harbor lands to the north (i.e. leaching of fill and windblown dust). Runoff may also contain contaminants derived from the highway immediately inland of the site. Pathogens may be elevated intermittently in anchialine and coastal waters due to runoff inputs from upslope fecal sources and from local sources (pet waste), and due to high turbidity limiting UV inactivation of pathogens. Activities within the site, such as waste disposal via the on-site septic leach field, also could affect site groundwater, or could affect surface water resources directly. Sedimentation from non-point sources could affect site resources if sediment from the coral fill areas reaches site waters, or if harbor maintenance (e.g. dredging) or planned expansion results in sediment deposition in site waters. Airborne pollutants, including dust, also can be deposited in PUHE, and light and noise pollution may impact biological resources.

C.1.a.i. Surface runoff

While most freshwater inputs to PUHE coastal waters occur via groundwater discharges, occasional high-runoff events produce flow in the lower reaches of Makeahua Stream and Pohaukole Gulch and result in significant discharges of water, sediment, and associated pollutants to coastal waters. Some direct runoff from site lands probably reaches coastal waters during occasional intense rain events, but there are no significant paved areas along the coastal margin of the site, so runoff likely would contain primarily contaminants derived from the ground surface. Runoff from the highway inland of the site may represent a significant non-point-source pollutant issue, as traffic is heavy and runoff from the highway probably drains directly into Makeahua Stream and Pohaukole Gulch, or directly on to other site lands, where it either contributes to direct runoff or infiltrates to groundwater.

C.1.a.ii. Groundwater contamination

Because of the high permeability of soils and rocks along the west Hawaiʻi coast, the majority of the freshwater in the area occurs as groundwater (Oki et al. 1999). Rainfall in the PUHE area is greater inland than along the coast, so most natural groundwater recharge occurs inland of the site, and groundwater should flow in a generally seaward direction through the site and into coastal waters (Oki et al. 1999). Groundwater in PUHE thus will be affected by activities both in, and inland of, the site, and groundwater pollutants ultimately will pass through PUHE's anchialine/estuarine habitats, and probably through intertidal areas enroute to discharging into coastal waters. Groundwater is an important resource in PUHE, as historically it was a critical resource for native Hawaiians living in the region, and because it plays a major role in determining water quality in anchialine habitats, and to a lesser degree in coastal tidepools and 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 petroleum products. It also can include pharmaceutical compounds and their byproducts. Because of the difficulty and expense of analyzing water samples for industrial, agricultural, and pharmaceutical contaminants, these analyses are performed only rarely, and the effects of many contaminants 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 site may occur due to infiltration of wastewater from cesspools and septic leach fields (including the leach field recently installed in the site), fertilizer, herbicide and pesticide use, stormwater runoff from developed areas, including the highway adjacent to the site, and improper disposal or spills of toxic substances. The impacts of these contaminants on PUHE ecosystems will depend on the type and extent of contamination and the vulnerability of receiving ecosystems. While dilution should disperse most groundwater contaminants to some degree as groundwater flows downslope, dilution may be less effective than expected if contaminated recharge does not mix extensively with underlying uncontaminated water during transport, and if lateral mixing is slow, resulting in relatively narrow contaminant plumes flowing downslope on top of uncontaminated groundwater. Monitoring wells or sampling at springs or discharge points along the coast 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. Herbicide use

Maintenance of site grounds historically has included extensive use of herbicides on plants growing around cultural sites, along trails, and around the anchialine pool in Makeahua Stream (Pratt 1998). In particular, the herbicide Rodeo® was used starting in 1996 around the anchialine pool to eradicate an alien pickleweed (Pratt 1998). Detailed data on chemicals used in the site are available since 1985 from entries recorded in the site's pesticide use log, but these data were not reviewed for this report. The effects of these chemicals on water resources in the site are not known (Else 2004), but may be significant if toxic compounds persist in dissolved forms or in association with sediments or biota in site waters.

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

There are no perennial streams or significant areas of surface runoff in the site, but windy conditions and dumping of trash in and around the site probably result in significant garbage inputs to anchialine habitats and coastal waters. In 1976, Cheney et al. (1977) observed that "an abundance of litter in the form of car bodies, boats, engine blocks, tires, bottles, cans, and wire may be seen on the bottom and along the shoreline". Present-day conditions are not known, but visitor activities in the site and in Spencer Beach Park to the south probably continue to contribute to garbage in the site. Some garbage also may reach PUHE's intertidal areas and adjacent coastal waters from offshore sources, including boats and related activities in Kawaihae

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. No data are available on whether animal waste is a problem in the site, but if site trails or open areas are frequented by dog owners, pet waste might be a problem. Animal waste probably would be most common around high-use areas, particularly if dogs are not leashed. Impacts on PUHE's ecosystems due to animal wastes probably are minor, but aesthetic impacts could be significant, and wastes may carry pathogens that could adversely affect the quality of coastal waters for recreational use.

C.1.a.iv. Sedimentation

While there are no perennial streams or other significant sources of regular surface runoff in PUHE, significant areas of the watershed upslope of the site are degraded and vulnerable to erosion (Haight 1998; Stewart 2001). As a result, the occasional runoff events that do occur in Makeahua Stream and Pohaukole Gulch probably deposit abnormally large quantities of sediment in coastal waters. Modification of the local coastline by the addition of Kawaihae Harbor to the north has resulted in poor circulation in Pelekane Bay, and a significant fraction of the sediment deposited during runoff events is retained in the bay. Sediment accumulation near the mouth of Makeahua Stream appears to have resulted in net accretion of land around the stream mouth and shoaling of the bay, as evidenced by historical changes in the local coastline (Figure 3) and by the bar visible at low tide off the beach during a site visit in 2004 (Figure 8a). Accumulated sediments probably have buried the Hale o Kapuni heiau, which now seems likely to be under the accreted portion of Pelekane beach instead of offshore as it was prior to harbor construction. In contrast, high runoff events probably scour stream channels, resulting in a temporary loss of sediments from the estuarine portions of Makeahua Stream and Pohaukole Gulch. Sediments in these areas probably are resupplied during low-runoff periods from biological sources, both in the waters themselves and from adjacent terrestrial vegetation. Airborne dust also may be a significant source of sediments to waters in and around the site - winds in the area frequently are strong, and arid conditions and land use practices have resulted in large areas of exposed soil, promoting significant dust transport throughout the year. In particular, a quarry inland of the site historically has been noted as a major dust source, with dust plumes observed up to a mile offshore (Harbors Division 1985), and stockpiled dredge material in Kawaihae harbor also is vulnerable to wind transport. Other sediment sources include biological sources in coastal waters, which contribute to biogenic sands in subtidal and intertidal areas, and possibly winnowing of fill material from behind the Kawaihae Harbor revetment north of the site. Tidal waves and large storm surf may occasionally deposit significant quantities of offshore sediments in tidepools, estuarine areas, and in intertidal and supratidal areas in the site, and construction activities, such as dredging in Kawaihae Harbor, could mobilize significant quantities of sediment that might affect site waters. For instance, explosive excavation of the Kawaihae small-boat harbor basin in 1969 resulted in the deposition of large quantities of rubble and sediment in adjacent waters, which include the coastal waters immediately adjacent to PUHE. Future construction-related sediment issues should be much smaller if activities are conducted according to established guidelines for prevention of sediment mobilization and transport, but poor project planning or implementation, or unusual events such as heavy rainfall or winter storm conditions could result in significant sediment inputs. For example, a construction-related sediment runoff event in 2000 at the Hokulia development project in Kona affected reefs 3 km away (http://www.hawaii.gov/dlnr/chair/pio/HtmlNR/00-70.htm).

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

Air pollution may impact site water resources via the deposition of particulate contaminants in site waters, as noted above, or via the dissolution of contaminant gases in site waters. While development in the area doubtless affects air quality, air quality overall in west Hawaiʻi is relatively good, and the site probably receives only very modest inputs of most anthropogenic airborne contaminants. Significant local anthropogenic sources may include vehicles entering and leaving PUHE and Spencer Beach Park, boats and other vehicles and sources associated with Kawaihae Harbor north of the site, and vehicles traveling on the highway immediately inland of the coastal parcel of the site. One significant local air pollutant probably is dust from a quarry inland of the site, and from stockpiled dredge spoils on the landfill areas in Kawaihae harbor. Dust clouds from these sources have been observed up to a mile offshore (Harbor Division 1985). Dust mitigation measures on harbor lands have included a coconut tree windbreak and a small amount of naupaka groundcover, both of which apparently have not been effective (Harbor Division 1985). Some contaminants also may be derived from emissions from Kilauea volcano, although they probably are quite minor given the physical distance between the site and the source. Volcanic emissions do include a number of constituents that could affect PUHE's coastal resources, including compounds that increase the acidity of waters and toxic constituents such as mercury (Brock and Kam 1997). However, VOGNET monitoring along the Kona coast has shown that a relatively clean layer of air normally is present near sea level, 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 are minor.

Noise pollution might affect the suitability of site waters and wetlands for use by dolphins, whales, birds, and other organisms sensitive to noise. The most significant noise sources probably are larger boats transiting to and from the main harbor basin, and small boats traveling to and from the small-boat harbor just offshore of PUHE, but no data are available on the magnitude or possible impacts of noise pollution in the area. Impacts from noise pollution may increase when the Fast Ferry system starts providing service to Kawaihae harbor, currently scheduled for 2009.

Light pollution 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 site, but seems likely to be a minor issue unless lighting around the site parking area and visitor center impacts nearby coastal waters.

C.1.a.iv. Kawaihae Harbor

The presence of a boat harbor immediately adjacent to site waters represents a potentially significant source of non-point source pollutants. The main harbor basin consists of 3 different sections: the north basin, the south basin, and the deep draft harbor. The north basin (4.0 acres) contains 9 Tahiti style moorings, a launch ramp, and a comfort station. The deep draft harbor includes 23 offshore moorings, 2 Tahitian style moorings, and a loading pier. The south basin (7.75 acres) has no facilities (http://www.hawaii.gov/dlnr/dbor/hawaiiharbors/kawaihae.htm). A small-boat harbor is located outside of the main harbor basin just offshore from PUHE. The deep-draft harbor currently caters primarily to interisland barge traffic, which is the main source of goods for the Kohala region, but plans are being developed to accommodate an interisland "Fast Ferry" system and increased military use as well. Local residents use the small boat harbor facilities for recreation and small business activities.

Nutrients, metals, petroleum products, marine debris, offal from fish cleaning, and other pollutants all may be discharged in association with boating operations, either in nearshore areas during launching and retrieval, or as boats transit coastal waters. Table 17 summarizes the environmental impacts of some pollutants commonly associated with boating.

Table 17. Environmental impacts of boating pollutants. 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 amounts of 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 * Plastics degrade very slowly * 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	* Accumulate 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 by decreasing or increasing pH respectively	* 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)	* Still 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 marine plants and 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 in marine	* 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 marine plants and 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 sediments near the discharge of water * Sediment-bound contaminants released to water if disturbed	* May reduce amounts of oxygen in affected waters * 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 (eutrophication) * (N) can be toxic in higher concentrations

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

Water quality affects biological resources in many ways. Dissolved nutrients can stimulate plant growth, while toxic substances can inhibit growth of plants and other organisms. Physical and chemical parameters such as temperature, pH, turbidity, and dissolved oxygen levels also can inhibit or promote the growth of different classes of organisms. In the following sections, water quality in PUHE's coastal resources is assessed first with respect to existing State of Hawai‘i water quality standards, then with respect to observed or potential effects of water quality on associated ecosystems (flora, fauna, and habitat), and finally 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 site 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. Allowable concentrations for some toxic contaminants are specified, and narrative and numeric criteria are provided for individual classes of water resources within ‘inland’ and ‘marine’ categories, and for various levels of protection. Relevant water quality standards are included in Appendix F with major points summarized below.

‘Inland’ waters relevant to PUHE include the anchialine/estuarine pools in Makeahua Stream and Pohaukole Gulch, and wetlands associated with the pools. PUHE's inland waters currently are designated Class 2 (waters within National Parks would be Class 1a, but these areas are not currently within the site), and are subject to narrative criteria that specify their protection "for recreational purposes, the support and propagation of aquatic life, agricultural and industrial water supplies, shipping, and navigation". Uses to be protected include those "compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters". Class 2 waters may receive wastewater discharges that have received "the best degree of treatment or control compatible with the criteria established for this class", except for treated sewage, which is not permitted. Industrial discharges into estuaries are not permitted except for stormwater discharges "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", and discharges "covered by a National Pollutant Discharge Elimination System general permit" (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). Class 1 waters receive a much higher level of protection ("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)" which should be considered in light of the possible future addition of these areas to the site. Specific criteria applicable to inland waters around PUHE include those for anchialine pools and possibly estuaries (during periods when the sand berm at the mouth of Makeahua Stream is breached), and those for coastal wetlands.

'Marine' waters in and adjacent to PUHE include intertidal areas and coastal waters and associated benthic habitats. Separate criteria are provided for coastal waters, embayments, sandy and rocky intertidal areas, and soft bottom communities. The coastal waters adjacent to PUHE (Pelekane Bay) are not specifically listed as an embayment in the DOH standards, and they would not appear to qualify as an embayment under the DOH criterion (ratio of total volume to cross-sectional entrance area ≥ 700 (Department of Health 2004)). However, several structurally similar coastal areas (e.g., Puako Bay) are listed as embayments, so water quality standards for both embayments and open coastal waters are considered here. Open coastal waters in and adjacent to PUHE are designated Class A by the State of Hawai'i (Department of Health 2004). If Pelekane Bay is considered an embayment, it's classification would be uncertain as it is not listed specifically in either the Class A or Class AA lists.

Class A coastal waters are managed similarly to Class 2 inland waters, with "the objective … that their use for recreational purposes and aesthetic enjoyment be protected" (Department of Health 2004). All other uses are permitted, with the stipulation that they be compatible with "the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters", and that waters 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". Kawaihae Harbor, immediately north of the site, is considered an embayment and also is designated Class A, as are marine waters adjacent to Spencer Beach Park, just south of PUHE. In addition to narrative criteria applicable to all Hawaiian waters, coastal waters off PUHE 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. The criteria for nutrients include adjustments for salinity to reflect the effects of ubiquitous groundwater inputs to coastal waters in this area. Coastal waters just south of Spencer Beach Park are designated Class AA, and are managed to "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".

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 coastal water resources in and adjacent to PUHE are excerpted in Appendix F and discussed in the following sections as they relate to specific resources.

Although the water quality criteria outlined above are intended to maintain relatively high levels of water quality in PUHE's water resources, data suitable for assessment of water quality relative to numeric standards are very limited. Existing data compilations in the PUHE "Horizon" report (National Park Service 2000) and in a recent USGS data compilation (Wolff unpubl. 2005) contain some data, but they are from a number of different 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, and data generally are insufficient to address the salinity-dependent criteria unique to the Kona coast. However, combining these data with additional data from published reports and ongoing studies does provide some insights into water quality in PUHE, and into the degree to which site waters comply with narrative criteria.

C.2.a.i.Groundwater

Groundwater flow

Groundwater flow has not been studied in PUHE, but flow likely is complex due to the highly heterogeneous permeability of the lavas making up the Kona coast. The overall permeability of extruded lavas is high (Oki et al. 1999), but groundwater flow 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 Hawaiian pahoehoe flows, also 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 case for many kilometers. Barriers that restrict or divert groundwater flow also may occur in the form of dikes and other subsurface features. For instance, the watershed upslope of PUHE is made up primarily of flows from the Kohala volcano, but the site itself is situated on ancient (~0.27 million years old) flows from the younger Mauna Kea volcano, and Mauna Kea flows lap onto the Kohala volcano flows along the southern margin of the watershed (Richmond et al., in prep.), creating the potential for complex subsurface geology and groundwater flow. Construction of Kawaihae Harbor also probably altered groundwater flow in nearshore areas north of, and possibly in, the site. Thus, while the overall direction of groundwater transport through PUHE should be seaward, the details of groundwater transport and the fate of associated contaminants are less predictable.

The magnitude of groundwater flow through the site probably is low compared to most other areas around the island due to the very low rainfall in most of the contributing watershed. Groundwater heads near the coast increase inland at about 2’/mile (Davis and Yamanaga 1974; 1998 – 2006 head data for well 6147-01 at http://nwis.waterdata.usgs.gov/hi/nwis/gwlevels/), so maximum groundwater heads within the site probably are less than 1’. Some of the observed head actually may be due to groundwater expansion due to higher groundwater temperatures compared to other areas; Epp and Halunen (1979) observed elevated temperatures in a well upslope of and south of the site that they attributed to residual volcanic heat, and both early western visitors and recent investigators noted that water discharging along the shoreline near PUHE was unusually warm. Warm groundwater discharging at a coastal spring south of the site and possibly at an inland location near Pelekane reputedly were used for bathing and were thought to have medicinal properties (Greene 1993). Some perched groundwater also may be present in the site; test holes drilled to a depth of approximately 36 feet in the upper portion of the site (elevation approximately 127 feet) encountered possible groundwater at the bottom of one of the holes. Groundwater could not be assessed in the other hole due to hole collapse (Pacific Geotechnical Engineers, Inc. 2000).

Most of the groundwater flow through PUHE is derived from recharge at much higher elevations, where rainfall is greatest. No studies have been performed on the impacts of upslope withdrawals on groundwater flow through PUHE, but a study for Kaloko-Honokohau National Historical Park (KAHO), on the Kona coast south of PUHE, showed that upslope well development could have reduced groundwater flow through that park by nearly 50% between 1978 and 1997. While there do not appear to be any significant withdrawals in the lower portion of the PUHE watershed, significant amounts of surface water that ultimately should contribute to recharge are diverted for human use upslope of the watershed, and groundwater is pumped from wells just south of PUHE's watershed, potentially reducing groundwater flow through the site. Reductions in groundwater flow reduce groundwater discharge to coastal waters, increasing the salinity of brackish groundwater near the coast, and reduce the dilution of contaminant inputs by reducing groundwater volume and flow velocity. Artificial recharge, for instance due to irrigation or disposal of waste water via leach fields or dry wells, increases groundwater flow if the recharge water is obtained outside the contributing watershed. If local groundwater is utilized for irrigation or other uses, local flow will be altered as water is removed in one area and added in another. Local flow also may be altered by construction activities that increase or decrease the permeability of soils and rocks subject to infiltration and groundwater flow. For instance, extensive landfilling associated with the construction of Kawaihae harbor probably altered local groundwater flow significantly, and may have obliterated a historical brackish pool/well that was the namesake of the area (Kawaihae means "water of wrath" reputedly due to area residents fighting over water from this pool (Kelly 1974)). No data are available to directly assess long-term changes in groundwater flow in the PUHE area, but coastal salinities off of Spencer Beach Park, just south of PUHE, have increased significantly over the last 16 years (see Coastal Waters below). Average salinities during this period have increased from about 27.5 ppt to about 33.5 ppt, suggesting a corresponding decline in groundwater contributions from 20% of the water sampled in 1990 to only about 4% in 2006. While some of the reduction in groundwater inputs may be associated with natural long-term fluctuations in local climate, it seems likely that surface water diversions and groundwater withdrawals associated with growth in the town of Kamuela (Waimea) upslope of the site, and in coastal areas around the site also are significant. Over longer time scales, it also has been suggested that the historical loss of forest at lower elevations (due to sandalwood harvesting in from the early 1800's to about 1845, and impacts of cattle grazing starting in 1793) reduced infiltration and groundwater flows in the watershed (Kelly 1974).

Groundwater quality

There are no groundwater monitoring locations in PUHE and only very limited data are available from nearby areas (Figure 6). While water quality at these sites may not be completely representative of groundwater quality in the PUHE watershed, hydrologic conditions and upslope land use generally appear similar to those upslope of PUHE, so water quality also seems likely to be similar. As noted above, a temperature profile was obtained in well 6147-01 on 8/27/74 by Epp and Halunen (1979). Chlorinity in the same well (labeled "16" by Davis and Yamanaga (1973) and located slightly to the north on their map) was reported to be about 250 mg Cl/l, equivalent to about 1.3% seawater. Chlorinity at a second well (labeled "14") downslope of well 16 was reported to be 325 mg/l, or about 1.7% seawater (Davis and Yamanaga 1973). This second well probably is either well 6148-01 or 6148-02 (Figure 6), both of which also have significant amounts of temperature, specific conductivity and chlorinity time-series data (Figure 20). The USGS water quality database also includes some flow data for well 6148-01, but only 4 data points are available, all are from a very limited time period (2/2002 – 8/2002), and all are zeros. The lack of data from 1982 – 1999 at this site may indicate that the well was not being used, so the zero flow values may be associated with initial non-pumped sampling of the wall after a period of disuses, but they also may simply be bad data points. The closest groundwater nutrient data are from a coastal well (MK4) over 1 km south of the site, where nutrients were only analyzed twice, on 5/17/1972 and 8/22/1974. Chlorinity in these samples showed that the samples contained about 9% and 23% seawater respectively. Based on these values, fresh groundwater upslope of this site probably contained about 1000 µM silicate, 100 – 250 µM nitrate, and about 5 µM phosphate (Figure 21). These values are elevated slightly compared to

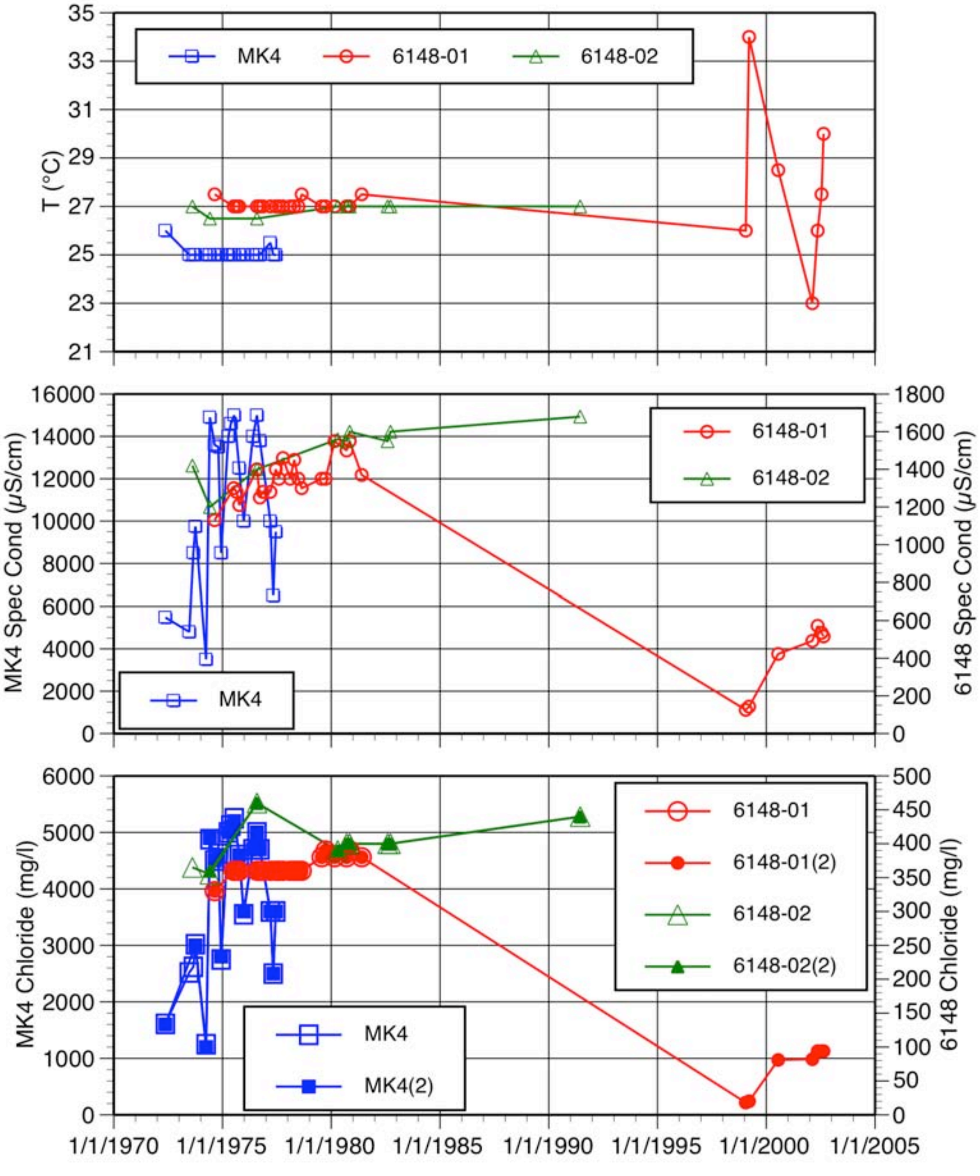


Figure 20. Water quality data from wells near the PUHE watershed. Note difference in scales in bottom two panels between Well MK4 data (left side) and Wells 6148-01 and 6148–02 data (right side). Second set of chloride data in bottom panel is from replicate measurements using a different analytical method.

values in uncontaminated (presumably) groundwater upslope of KAHO (~820, 70, and 3.5 µM respectively; Hoover and Gold 2005). Water from this well is used primarily for irrigation on the Mauna Kea resort, and fertilizer application to resort grounds and repeated infiltration of pumped water back into the aquifer may have increased nitrate and silicate concentrations locally, but the degree to which the increased values represent contamination versus natural differences cannot be ascertained with the available data.

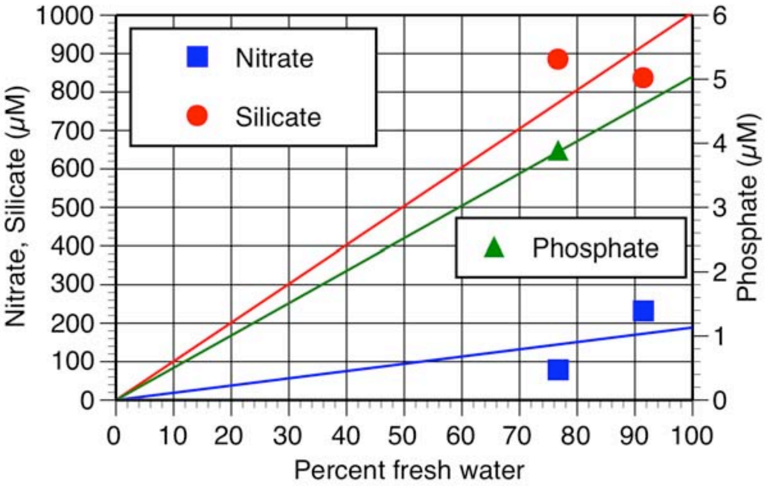


Figure 21. Nitrate, silicate and phosphate in two samples from well MK4. Samples were collected on 5/17/1972 and 8/22/1974. Intercepts of regression lines at 100% fresh water provide estimates of concentrations in fresh groundwater assuming that concentrations vary solely due to dilution with seawater and that concentrations in seawater are negligible. Percent fresh water is calculated from chlorinity based on seawater of 35 ppt salinity containing 19,400 mg Cl/l.

One fairly extensive dataset that offers some insight into the quality of groundwater in PUHE is available from State of Hawai‘i Department of Health (DOH) monitoring of coastal water quality at site 1225 off of Spencer Beach Park, just south of PUHE (Figure 22). Some parameters have records starting as far back as 1973, but the greatest number of parameters were monitored from about 1990 to 1997 (Figure 23). Plotting the nutrient data against salinity shows that nitrate, silicate and phosphate follow generally linear relationships consistent with dilution of high-nutrient groundwater by low-nutrient seawater (Figure 24). Regressions suggest a groundwater endmember containing about 100 – 150 µM nitrate, 500 – 600 µM silicate, and ~1.5 µM phosphate, although forcing the phosphate regression through zero at a salinity of 35 (a reasonable expectation for offshore seawater) produces an intercept closer to 2.5 µM. These values are fairly similar to the values predicted from well MK4 and in KAHO groundwater, suggesting that groundwater in the area may not have been contaminated significantly by human activities during the period of monitoring (~1990 – 1997).

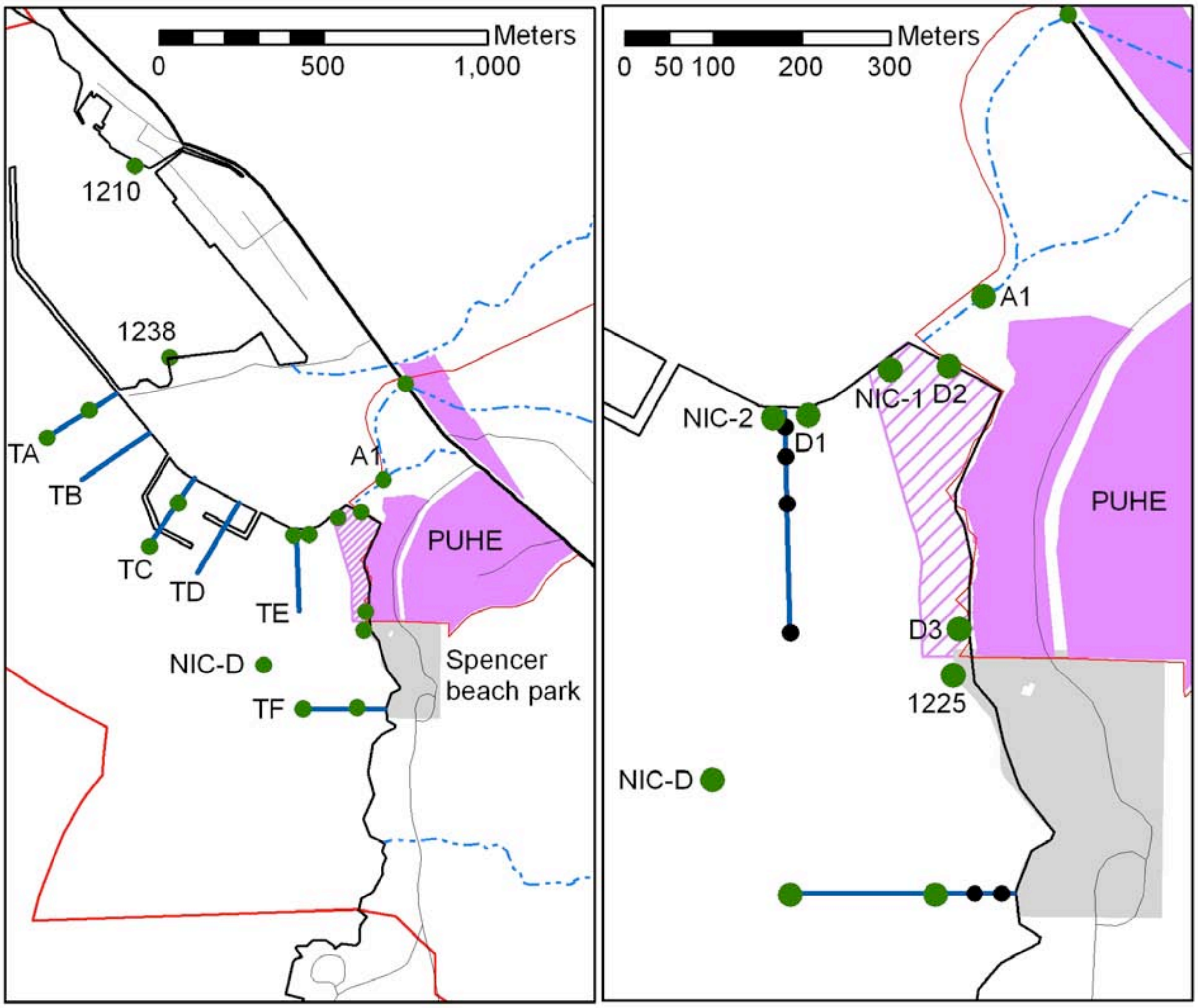


Figure 22. Coastal water quality sampling sites (green dots) around PUHE. Blue lines are transects used by Ocean Research Consulting & Analysis, Ltd. (1978) for biological surveys. Approximate extent of coastal waters generally associated with the park (e.g. http://www.nps.gov/puhe/planyourvisit/maps.htm) is shown by purple hatched area.

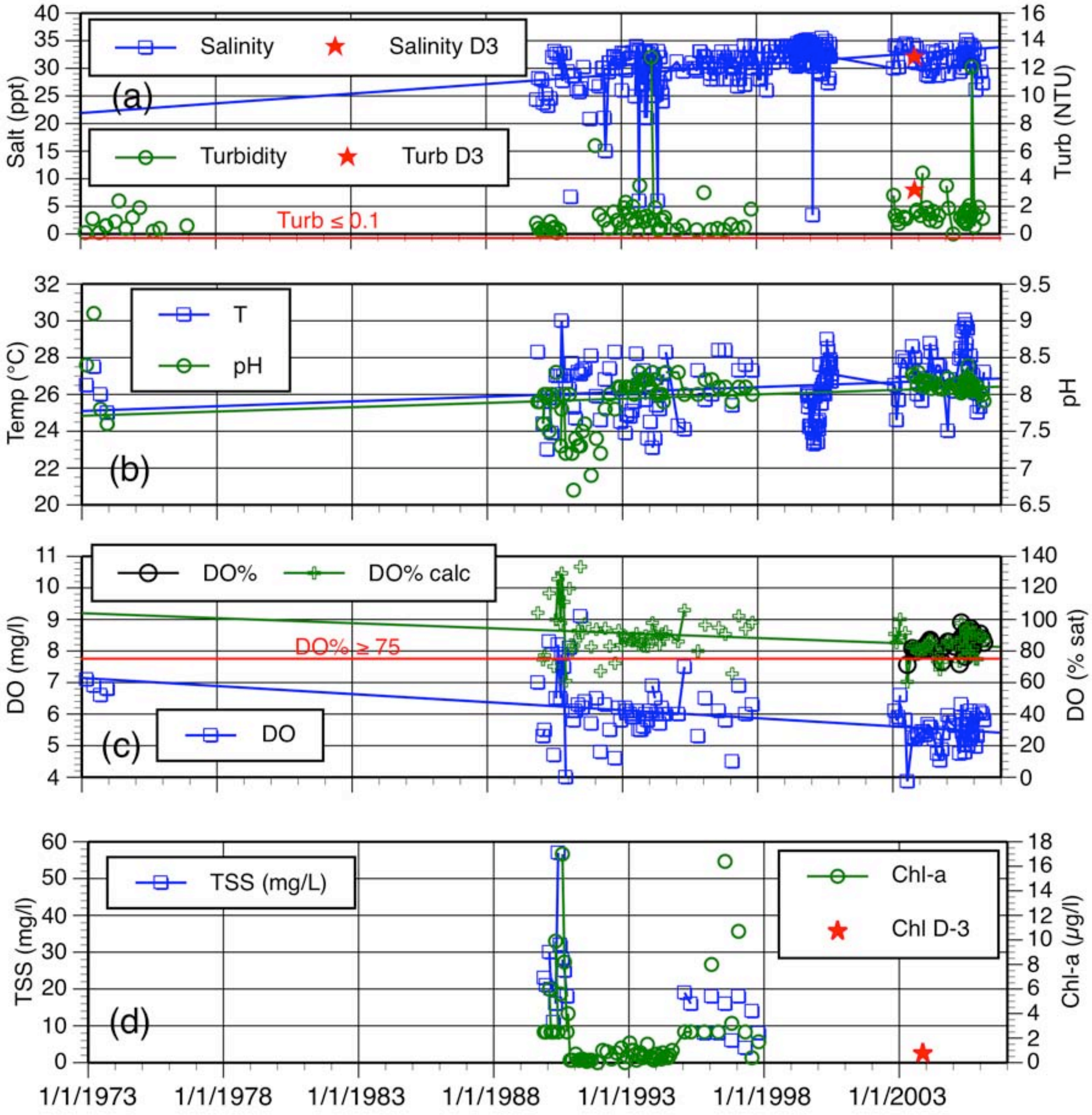


Figure 23. Water quality data from DOH site 1225 off of Spencer Beach Park. Data from the November 2004 sampling at site D3 also are shown as red stars, and DOH water quality standards are shown as red lines where appropriate. Linear fits are shown for statistically significant regressions:

Salinity = 21.9 + 0.35(Year -1973), $R^2 = 0.12$ $p < 0.001$;
Temperature = 25.1 + 0.052(Year -1973), $R^2 = 0.05$, $p = 0.005$;
pH = 7.71 + 0.012(Year -1973), $R^2 = 0.08$, $p = 0.005$;
Dissolved oxygen (mg/l) = 7.15 - 0.051(Year -1973), $R^2 = 0.23$, $p < 0.001$;
DO (% saturation, calculated) = 104 - 0.63(Year -1973), $R^2 = 0.10$, $p = 0.001$.

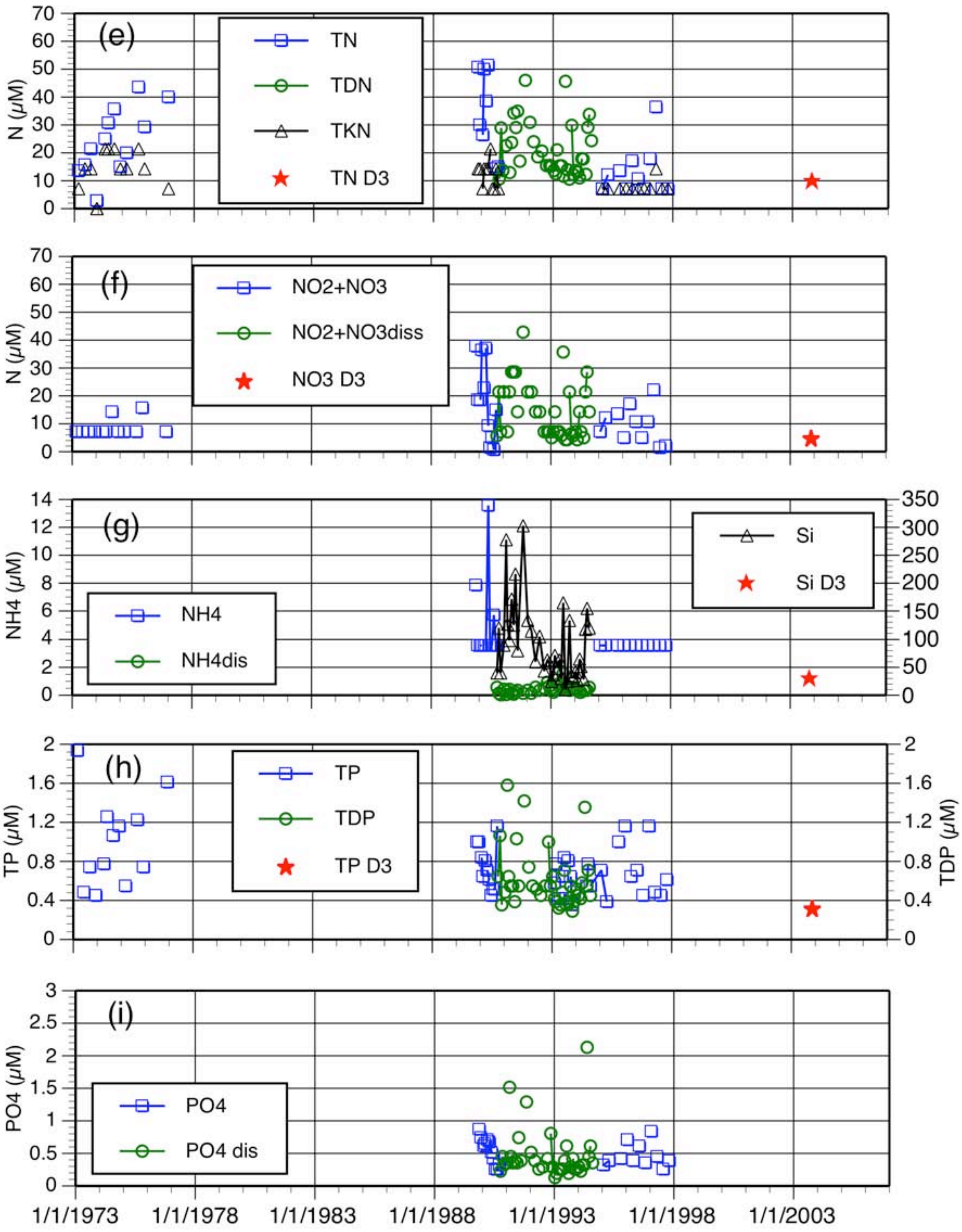


Figure 23 (cont.). Water quality data from DOH site 1225 off of Spencer Beach Park. Regressions are not shown for these parameters due to the relatively short periods of record and sparse sampling. Data from the November 2003 sampling at site D3 also are shown as red stars.

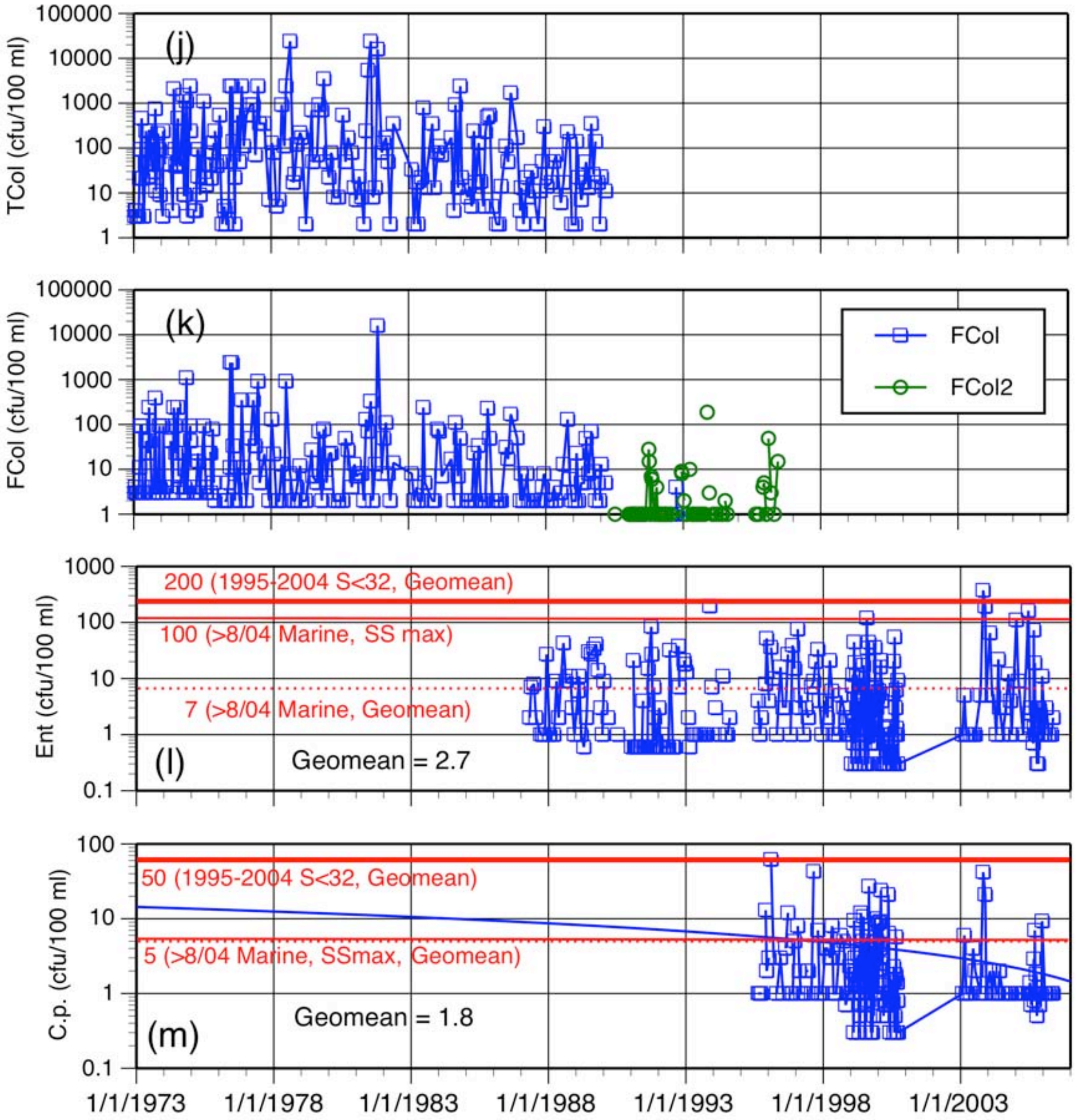


Figure 23 (cont.). Bacterial water quality data from DOH site 1225 off of Spencer Beach Park. Log scales are used to show full range of variability. Linear regressions are not significant except for *Clostridium perfringens* = 14.4 - 0.38(Year-1973), $R^2 = 0.02$, $p = 0.05$. DOH water quality standards are shown as red lines where appropriate.

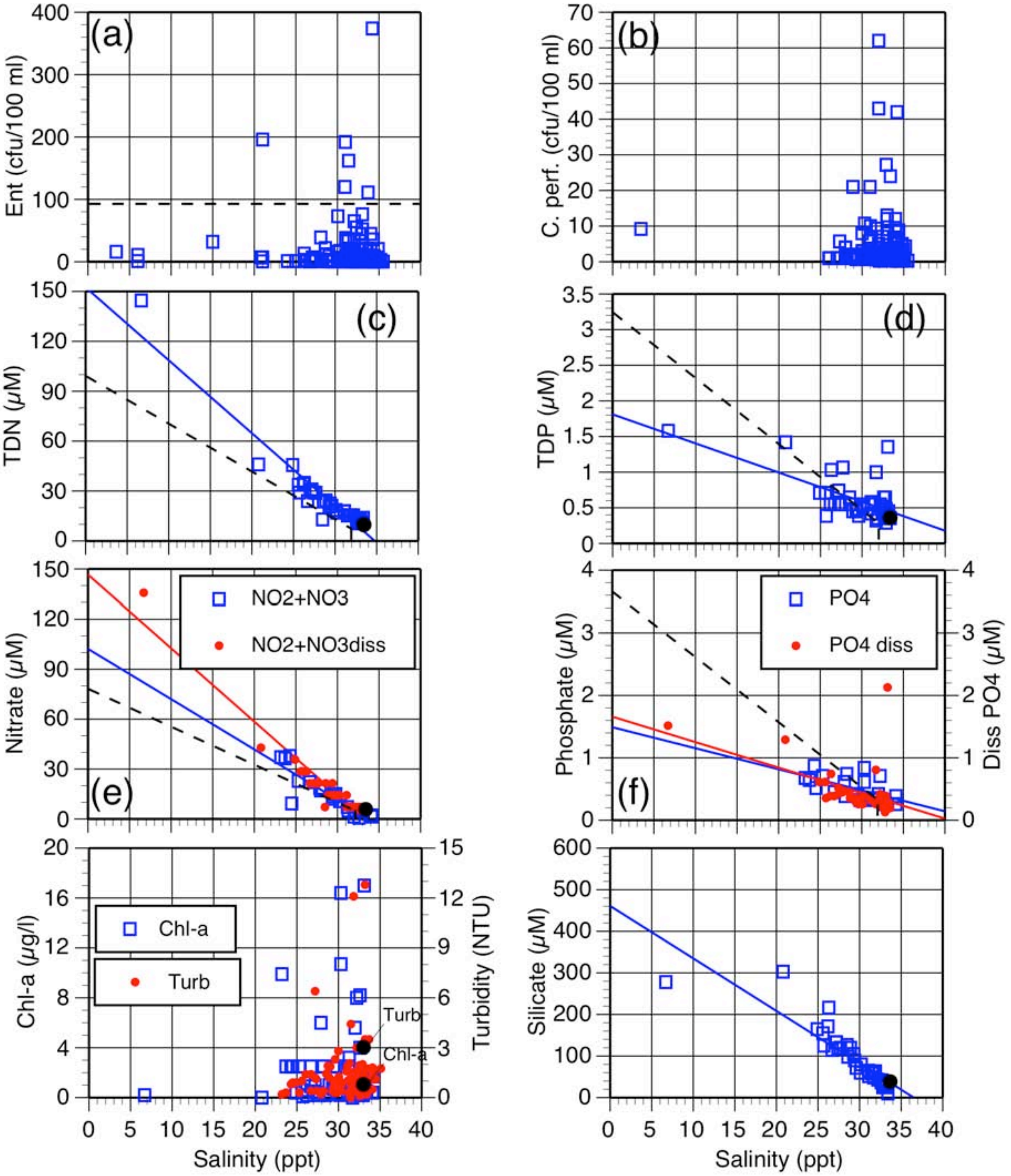


Figure 24. Water quality data from DOH site 1225 off of Spencer Beach Park. Data are from T. Teruya, Hawaiʻi DOH, pers. comm. 2006. DOH standards are shown as dashed black lines where appropriate. Linear regressions are (S = salinity in ppt):

TDN = -4.4(S) +152 (R^2 = 0.91)
TDP = -0.041(S) +1.81 (R^2 = 0.41)
NO2+NO3 = -3.0(S) + 102 (R^2 = 0.79)
NO2+NO3diss = -4.4(S) +147 (R^2 = 0.93)
PO4 = -0.034(S) + 1.49 (R^2 = 0.35)
Silicate = -12.6(S) +461 (R^2 = 0.79).

C.2.a.ii. Anchialine/estuarine habitat

Because anchialine systems exist in areas of brackish groundwater, and are influenced by tidal fluctuations, water quality varies considerably, particularly with respect to salinity and nutrients (Brock and Kam 1997). There are no numeric criteria for anchialine pools, but they 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). Published compilations of anchialine pools along the Kona coast have not included any pools in PUHE except for Maciolek and Brock (1974), who included the brackish waters inland of the beach bar in Makeahua Stream in their survey and noted that salinity in the pool varied from 8 –15 ppt (salinity ranges in their results represent either vertical stratification or lateral variations within pools, but the source of the variability is not specified for this pool). Their survey showed that anchialine habitat is scarce around PUHE, as the only other pool identified in North Kohala was about 5 miles north of PUHE, and the nearest pool south of PUHE was similarly distant (Maciolek and Brock 1974). The lack of anchialine habitat in North Kohala was ascribed to the relatively steep slopes and older lavas present in this area compared to the southern portions of the island. Water quality in the anchialine pool at the mouth of Makeahua Stream also was measured on 6/30/1998 (Table 18). The enterococci measurement exceeded the single-sample State of Hawaiʻi criterion, but not by a large amount, and enterococci are known to persist in Hawaiian soils and thus may not be a reliable indicator of fecal contamination. Measurements of ammonia, nitrate, and dissolved phosphorus all met DOH criteria, despite the fact that the ammonia and nitrate measurements were performed on unfiltered samples. The chlorophyll-a concentration measured is quite high, but not surprising for an estuarine system, and nutrient concentrations overall are consistent with expectations for an estuarine system with inputs of relatively high nutrient groundwater, with low inorganic nutrients due to biological uptake, modest dissolved ammonia, and somewhat elevated total phosphorus and nitrogen due to high levels of dissolved organic N and P and to N and P in particulate organic matter. Although no salinity measurement was made, salinity can be estimated from the

Table 18. Water quality in the anchialine pool at the mouth of Makeahua Stream on 6/30/1998. Data are from Wolff (unpubl.). Standards are from Department of Health (2004).

Parameter	Filt/Unfilt	Value	Units	Standard
Enterococci	n/a	120	cfu/100 ml	≤89
Fecal coliform	n/a	87	cfu/100 ml	n/a
Chlorophyll-a	n/a	19.93	µg/l	≤2
Ammonia	Unfilt	0.26	µM	≤0.4*
Nitrate	Unfilt	0.20	µM	≤0.6*
Total nitrogen in SS	n/a	21.35	µM	n/a
Phosphate	Filt	0.12	µM	n/a
Phosphorus	Filt	0.62	µM	≤0.8
Phosphorus	Unfilt	2.34	µM	n/a
Silicate	Filt	311	µM	n/a

* Standards are for dissolved species (filtered samples). Concentrations in unfiltered samples may be higher due to contributions from particles.

silicate value and an expected groundwater concentration of 500 – 600 µM (Figure 24), suggesting that salinity was approximately 13 – 17 ppt, possibly slightly higher than that measured by Maciolek and Brock (1974). No water quality data are available for the small anchialine pool upstream of the access road in Pohaukole Gulch.

C.2.a.iii. Wetlands

There are no numeric criteria for water quality in wetlands, and no water quality data for wetlands in PUHE.

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

Intertidal rocky shoreline

Rocky intertidal areas along PUHE's coastline are designated Class II by the State of Hawaiʻi and are subject to specific criteria only for deposition of flood-borne sediment. These criteria are related to water quality through the potential presence of 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 PUHE's rocky intertidal areas, but intertidal areas surveyed in December 2004 generally were free of significant deposits of sediments, despite turbid conditions in coastal waters (D. Hoover, pers. obs. 2004). Occasional large runoff events from Makeahua Stream seem likely to result in significant deposition of sediments in intertidal areas which probably violate water quality standards, but no data are available to assess this possibility. Some observations of water quality in rocky intertidal areas are available from Cheney et al. (1977), who noted that temperatures generally ranged from 25.0 – 28.5°C, and that warm (to 29.5°C) freshwater springs discharged in the rocky intertidal, primarily in the area adjacent to Spencer Beach Park. Corresponding salinities in intertidal areas ranged from 3.0 to 25.0 ppt. Ball (1977) noted that there was a persistent freshwater lens adjacent to the rocky shelf along the southern portion of the site shoreline, and observed that "algal diversity and density along the rocky edges of the shore were conspicuously low compared to adjacent areas" with generally eutrophic species along the breakwater. He attributed the generally depauperate flora primarily to reduced light availability due to high turbidity and to the direct effects of sedimentation on the algae, but the presence of eutrophic species along the breakwater also suggests that nutrients may have been elevated in that area, possibly due either to nutrients in groundwater discharging in the area, or to nutrients remobilized from sediments deposited in Pelekane Bay.

Intertidal sand beaches

Sand beaches in PUHE are designated Class II by the State of Hawaiʻi and are subject to specific criteria relating to deposition of flood-borne sediment similar to those noted above for rocky intertidal areas. Although no data are available for evaluation of these criteria on PUHE's beaches, significant sediment deposition on the beach area fronting Pelekane probably does occur during flood events given its proximity to Makeahua Stream. However, no data are available to determine whether this represents a significant water quality issue. One investigator did note that water in the sandy intertidal area appeared to be less turbid than water in adjacent areas with predominantly mud bottom (Cheney et al. 1977). This phenomenon may have been due to trapping of fine sediments in the interstices of sandy sediments, reducing resuspension and turbidity in overlying water.

C.2.a.v. Coastal waters

Planktonic and pelagic resources

While there are very few quantitative data to assess coastal water quality off of PUHE, coastal water quality clearly is affected by sediments deposited in Pelekane Bay, and by brackish groundwater discharging along the shoreline and possibly from offshore subtidal locations. Coastal water quality also may be affected by contaminants from boats and individuals using Kawaihae Harbor and Spencer Beach Park, by occasional direct runoff from site grounds, and by trash from a variety of sources, but no data are available for quantitative assessment of impacts associated with these sources. In general, the persistent discharge of brackish ground water to nearshore waters along the Kona coast suggests that this will be a significant factor in PUHE as it is in other areas in west Hawaiʻi, and the effects of sediments on turbidity and benthic resources is obvious and clearly plays a major role in structuring water column and benthic communities in Pelekane Bay. In contrast, contamination from boats and people in the water is episodic and localized, and should be diluted rapidly, so contamination from these sources seems unlikely to affect site waters significantly. Occasional direct runoff from site grounds probably impacts nearshore water quality for short periods following high rainfall events, but impacts seem likely to be minor compared to the effects of occasional large discharges from Makeahua Stream, and the chronic effects of sediment resuspension in Pelekane Bay on turbidity and benthic resources.

- Groundwater discharge

Groundwater discharge is the main pathway by which freshwater reaches the ocean in west Hawaiʻi (Oki et al. 1999). Groundwater discharges in the PUHE area are important culturally and historically as brackish water from coastal pools and wells was used for drinking water and other purposes (Greene 1993). Groundwater discharges have not been quantified in the PUHE area, but a modeling study for KAHO, south of PUHE, showed that groundwater flow through KAHO may have been reduced by as much as 50% between 1978 and 1997 due to upslope withdrawals, so groundwater development seems likely to be impacting groundwater flow through PUHE also. PUHE is known to be an area of significant groundwater discharge: although Fischer et al. (1966) did not survey the Kawaihae area specifically, they did observe cold temperature anomalies indicative of freshwater discharges in infrared aerial photographs of coastal areas both north and south of the site, and Adams et al. (1969) noted a cold water anomaly due west of Puʻukohola heiau in an infrared image. The observation of a low-temperature anomaly is somewhat surprising, as anecdotal and other quantitative observations generally have noted unusually warm groundwater discharging in the PUHE area (e.g., Kelly 1974; Cheney et al. 1977). In-water surveys have suggested that the greatest groundwater inputs occur along the rocky shoreline bounding the southern portion of the site. Diffuse groundwater discharges make water-quality monitoring difficult, as the combination of spatially and temporally variable groundwater inputs and similarly variable mixing in coastal waters can produce dramatic variability in nearshore water quality.

Both the quantity and quality of groundwater reaching PUHE coastal waters are affected by natural and human activities that affect recharge within and upslope of the site (i.e. withdrawals and additions, see *Groundwater* above), and water quality also can be affected by processes occurring in the brackish anchialine pools in Makeahua Stream and Pohaukole Gulch. Groundwater passing through these features is chemically altered by biogeochemical processes in the pools and exchanges heat and gases with the atmosphere. As a result, the quality of groundwater reaching coastal waters may vary from that entering the site. In addition to variability due to spatial heterogeneity in upslope processes (contaminant inputs and reactions in subaerial pools and ponds), groundwater quantity and quality probably both vary temporally, on seasonal, annual and longer time scales due to changes in natural recharge and human impacts (e.g., deforestation in the watershed), and on short time scales, such as those associated with storm events and tidal cycles. Basal groundwater heads in PUHE likely are small, with water levels inside the site probably less than 1' above mean sea level (Oki et al. 1999), so large rainfall events probably result in significant changes in groundwater heads and associated discharge. Oki et al. (1999) noted that groundwater flows near the Kona coast vary significantly on short time scales due to tidal effects, with flows actually reversing and flowing inland during high tides.

- Water quality

Water quality data for coastal waters around PUHE are limited. Most of the available data are from one site off of Spencer Beach Park, just south of PUHE, and from the small boat harbor area along the south side of the Kawaihae Harbor breakwater, with only a very few data points available from nearshore areas adjacent to PUHE. The waters of Pelekane Bay are considered class A by the State of Hawaiʻi Department of Health (see above), and are listed as impaired in the 2004 State 303(d) list for excessive turbidity (Koch et al. 2004). No quantitative basis is given for the listing, but nearby waters off of Spencer Beach Park also are listed for turbidity and chlorophyll-a based on extensive monitoring and numeric criteria (see below).

Neighbor Island Consultants (1974) made turbidity measurements in surface and bottom water samples at a number of sites offshore of PUHE on 20 cruises between 6/9/1973 and 6/6/1974, including a few at a site just off of Pelekane Beach (Figure 22). Surface water turbidities from this site ranged between 2.9 and 14 FTU (Formazin turbidity units), while values in the area of the small boat harbor typically were on the order of 1 FTU with a few higher values to 8.5 FTU, and values at a site about 400 m off of Spencer Beach Park ranged from 0.27 to 0.45 FTU. Formazin turbidity units should be generally comparable to nephelometric turbidity units (NTU); current DOH standards are based on the geometric mean of multiple samples but would generally require turbidities to be less than about 1 – 2 NTU in nearshore waters and 0.1 NTU in offshore waters (Department of Health 2004). Cheney et al. (1977) also observed that turbidity in Pelekane Bay increased with onshore wind speed and wave height, with higher values in nearshore areas than at offshore sites. Another data set collected by Ocean Research Consultants (1978) includes temperature, nitrate, and phosphate data from sites in the small boat harbor area, off of Spencer Beach Park, and off of the harbor breakwall north of the small boat harbor (Figure

22). All of these sites are sufficiently distant from PUHE that they are unlikely to reflect nearshore water quality, but they provide some idea of surrounding water quality (Table 19, Figure 25).

Table 19. Water quality data from six coastal sites around PUHE (inner = I and outer = O sites on transects TA, TC, and TF in Figure 19, Surface = S, Bottom = B). Samples were collected from April 12 – 14, 1978 during daily maximum high and minimum low tides. Data from Ocean Research Consulting and Analysis (1978).

Site	Depth	Offshore (m)	Tide	T (°C)	S (ppt)	PO4 (µM)	NO2+NO3 (µM)
TA/O	S	250	Hi	25.3	32.23	0.39	0.46
TA/O	S	250	Lo	25.2	34.08	0.19	0.55
TA/I	S	100	Hi	25.3	33.86	0.28	0.76
TA/I	S	100	Lo	25.8	34.23	0.23	0.67
TA/O	B	250	Hi	24.6	33.90	0.58	0.77
TA/O	B	250	Lo	24.9	33.40	0.21	0.62
TA/I	B	100	Hi	25.3	34.14	0.54	0.63
TA/I	B	100	Lo	25.6	32.25	0.18	0.95
TC/O	S	250	Hi	25.4	32.14	0.80	1.26
TC/O	S	250	Lo	25.4	34.25	0.23	0.75
TC/I	S	100	Hi	25.3	33.42	0.69	1.57
TC/I	S	100	Lo	25.1	34.19	0.24	0.06
TC/O	B	250	Hi	24.5	33.20	0.77	0.54
TC/O	B	250	Lo	25.3	34.23	0.21	0.62
TC/I	B	100	Hi	24.7	34.04	0.56	0.12
TC/I	B	100	Lo	24.6	33.20	0.29	0.05
TF/O	S	250	Hi	25.7	30.00	1.52	6.26
TF/O	S	250	Lo	25.7	33.82	0.32	1.24
TF/I	S	100	Hi	25.5	30.98	1.33	7.37
TF/I	S	100	Lo	26.6	32.05	0.68	3.29
TF/O	B	250	Hi	25.0	34.04	0.77	0.93
TF/O	B	250	Lo	25.1	34.17	0.30	0.97
TF/I	B	100	Hi	25.0	33.73	0.77	1.47
TF/I	B	100	Lo	25.4	34.14	0.30	1.09

The most useful data set from the PUHE area is from long-term DOH monitoring of a nearshore site off of Spencer Beach Park, just south of the PUHE site boundary (Figure 22). Water quality at this site should be relatively comparable to water quality in nearshore waters adjacent to PUHE, although the similarity probably declines significantly toward the head of Pelekane Bay, where the effects of discharges from Makeahua Stream and sediment resuspension are most pronounced. Data from the DOH Spencer Beach Park site are particularly useful because they can be used both to assess temporal changes in water quality and water quality relative to existing standards. Although the time series data contain gaps, many parameters exhibit significant variability, and periods of measurement differ for different parameters (Figure 23), inspection of the data and linear regression analyses suggest significant temporal trends for

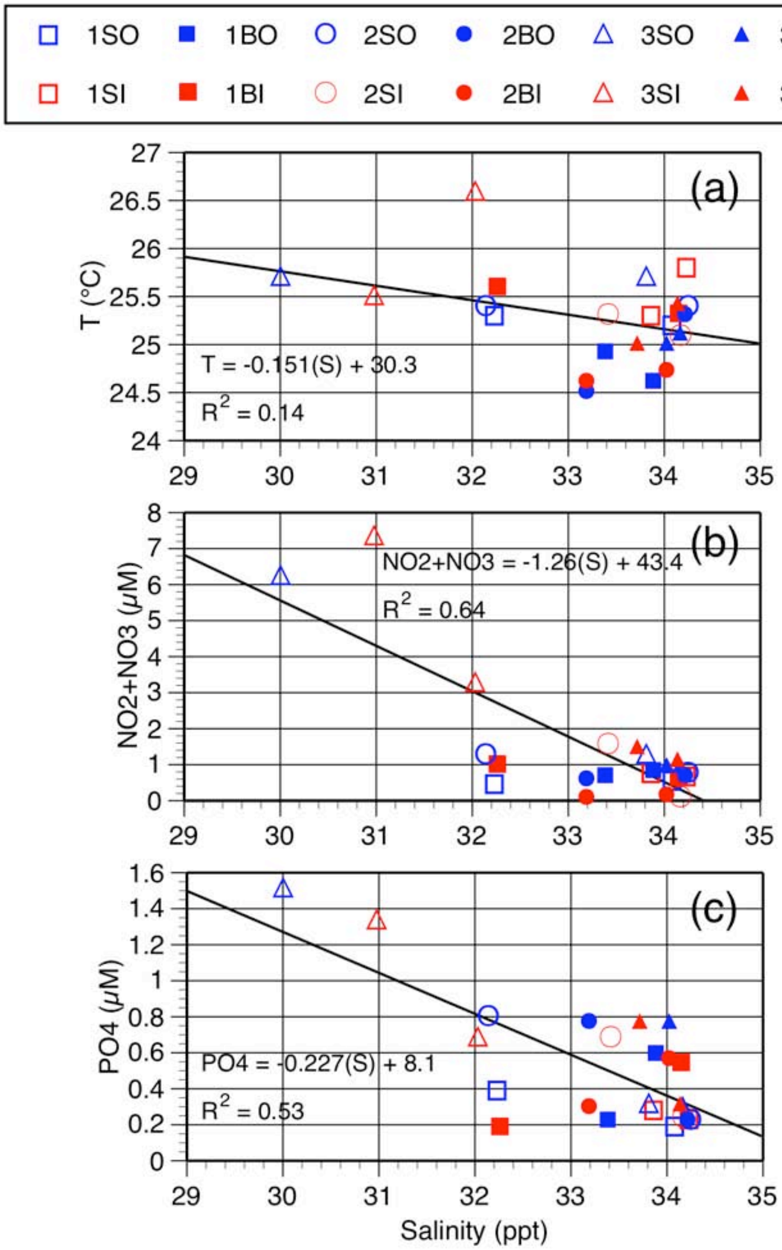


Figure 25. Water quality data from samples collected at six sites around PUHE from April 12 - 14, 1978. Samples were collected at inner (I = 100 m from shore) and outer (O = 250 m from shore) locations on three transects: 1 = Outer reef, Deep-draft harbor, 2 = Small boat harbor (Project Tugboat) site, 3 = Spencer beach park (transects TA, TC, and TF in Figure 22). Samples were collected at the surface (S) and near the bottom (B) at high tide and at low tide. Linear regressions are for all data combined. Data are from Ocean Research Consulting and Analysis, Ltd. (1978).

several parameters. In particular, salinity increased significantly from 1990 to 2006, with most of the increase from 1990 to 2000. Several factors may have contributed to the increase, including climate effects on rainfall and infiltration in the watershed, but the increase does coincide with significant population growth in the town of Waimea, upslope of the site, suggesting that increasing diversions of fresh water and groundwater withdrawals may have reduced groundwater discharges along the coast. The pH increase over the same period probably reflects the decline in the proportion of groundwater in samples, as the pH of brackish groundwater normally is significantly lower than seawater. Dissolved oxygen also shows a statistically significant decline from 1990 to 2006. This change seems most likely to be related to the balance between oxygen demand in coastal waters and local mixing processes as they affect replenishment by atmospheric oxygen. One possible scenario is that the completion of the small boat harbor outside of the main harbor reduced circulation/mixing in Pelekane Bay and adjacent waters further compared to the circulation characterizing the area when the main harbor was built in 1959, resulting in increased accumulation of sediments in the area and an associated increase in oxygen consumption due to remineralization of organic matter in sediments. Reduced circulation simultaneously would inhibit replenishment of oxygen in the water column from the overlying air, and a reduction in circulation and mixing might also explain the temperature increase over the same period. A reduction in groundwater discharge could also affect the temperature record, but data are not available to characterize the temperature of groundwater discharging in the Spencer Beach Park area, and plotting temperature versus salinity in the DOH samples (data not shown) does not show a clear relationship that would indicate a major temperature difference in groundwater and coastal seawater.

Other parameters mostly have shorter records, typically from about 1990 to 1997, and thus are not as useful for detecting long-term trends in water quality. Most of the nutrient parameters (Figure 23e-i) appear to decline over this time period, but plotting against salinity shows that most produce linear relationships (Figure 24), suggesting that dilution (i.e., a change in the proportions of groundwater and seawater in the sample) is most important in controlling nutrient concentrations. The declines in the time series thus seem likely to reflect reductions in groundwater discharge, rather than changes in groundwater quality. Chlorophyll-a values are quite high early in the record (~1989-90), low from 1991-94, with a few higher values occurring again in 1996 and 1997. These data are difficult to interpret because chlorophyll-a values can change rapidly in response to local conditions, especially wind and wave conditions that control mixing in the water column. Because groundwater inputs and remineralization of sediments in Pelekane Bay both should provide a steady supply of nutrients to coastal waters, chlorophyll-a levels can be expected to be relatively high in the area, and occasional very high values should be expected when calm conditions promote phytoplankton blooms. Bacterial data are available over longer time periods than any other water quality parameters, but the highly variable nature of these parameters makes them difficult to analyze for trends. *C. perfringens* is probably the most specific indicator of fecal contamination currently in use, and linear regression analysis does show a statistically significant decline from 1995 – 2006 (Figure 23m), suggesting that fecal contamination may have declined over this period. The source of the contamination is not known, but might be related to restrooms in Spencer Beach Park if they use an on-site waste disposal system.

Comparing available data to water quality standards shows that Spencer Beach Park waters generally are not in compliance with DOH standards. Ammonia, chlorophyll-a, and turbidity all consistently exceed the DOH standards (Table 20), as do total dissolved nitrogen (TDN), dissolved nitrate-plus-nitrite (NO3+NO2), total dissolved phosphorus (TDP), and dissolved phosphate (PO4) in 'marine' samples (salinities greater than 32 ppt) (Table 21). Some parameters that are affected significantly by freshwater inputs require more extensive sampling and calculations to assess compliance; although the samples collected by DOH cannot be used to assess compliance with the standards established by DOH directly, they can be used in a semi-quantitative assessment. Standards for TDN, NO3+NO2, TDP, and PO4 in samples with salinities less than 32 depend on sample salinity; plotting against salinity shows that TDN and NO2+NO3 probably both exceed DOH standards, while TDP and PO4 are more scattered but mostly are within the DOH standards (Figure 24c-f). Overall, the Spencer Beach Park data suggest that coastal waters adjacent to PUHE probably do not comply with DOH water quality standards, with potentially elevated levels of dissolved nitrogen, turbidity, and chlorophyll-a, and reduced dissolved oxygen levels. Bacterial indicators also may be elevated, although the persistence of enterococci in Hawaiian soils may contribute to elevated counts, and while *C. perfringens* is a relatively specific indicator of fecal contamination, its utility for quantifying associated human health risks has not yet been established.

Table 20. DOH Spencer Beach Park data and DOH standards for parameters applicable to samples of all salinities.

Parameter	Units	Criterion	Data available	n	Median	Max
NH4	µg N/l	2.50	11/89 – 10/97	61	8	190
Chl-a	µg/l	0.30	11/89 – 10/97	61	0.8	17
Turb	ntu	0.10	3/73 – 5/06	99	1	12.8

Table 21. DOH Spencer Beach Park data and DOH standards for marine samples (salinities greater than 32 ppt).

Parameter	Units	Criterion	Data available	n	Median	Max	Compliant?
TDN	µg N/l	100.00	10/94-5/98	13	175	216	No
NO3+NO2	µg N/l	4.50	6/94 – 10/01	19	70	100	No
TDP	µg P/l	12.50	10/94-5/98	13	14	42	No
PO4	µg P/l	5.00	6/94 – 10/01	19	8	66	No

Parameter	Units	Criterion	Data available	n	Compliant?
pH	n/a	±0.5 units from ambient (1)	3/73 – 5/06	102	Mostly – 2 low values < 7, 1 value (9.1) probably bad data point (2)
Dissolved Oxygen	% sat	≥75% saturation	11/89 – 5/06	102	Mostly – 13 values < 75%
Temperature	°C	±1°C from ambient	3/73 – 5/06	153	Probably (3)
Salinity	ppt	±10% from ambient	11/89 – 5/06	247	Probably (4)

(1) except where freshwater influence depresses pH to 7.0 minimum.
(2) Assume ambient pH ~8.1, so acceptable range is ~7.0 – 8.6.
(3) No ‘ambient’ temperature available for comparison, but no thermal pollution sources known in area.
(4) No ‘ambient’ salinity available for comparison, but no anthropogenic sources of low or high salinity known in area.

On November 3, 2003 DOH sampled nearshore waters at three sites around PUHE: site D1 off the harbor breakwall about 150 m from the mouth of Makeahua Stream, site D2 just off of Pelekane Beach, and site D3 just north of DOH site 1225 off of Spencer Beach Park (Figure 22, Table 22). Water quality data from site D3 is quite similar to data from DOH site 1225 (Tables 20 and 21, Figure 24), but data from site D1 shows somewhat poorer water quality than observed at more distant sites in and adjacent to the small boat harbor (Table 19 sites TC/O and TC/I), and water quality at site D2 was similar to or poorer than quality at site D1. Water quality at both D1 and D2 was significantly poorer than at site D3, supporting the expectation that nearshore waters adjacent to PUHE typically will have lower water quality than is observed at DOH site 1225, and that water quality is poorest in the area at the head of Pelekane Bay and improves with distance from the mouth of Makeahua Stream.

Table 22. Water quality in Pelekane area samples collected in November 2003. DO = dissolved oxygen, TSS = total suspended solids. Data from Department of Health (2003).

Parameter	Small Boat Harbor (D1)	Pelekane Beach (D2)	Spencer Boundary (D3)
Temperature (°C)	27.48	28.05	27.84
Salinity (ppt)	33.58	31.04	33.46
DO (mg/l)	5.44	5.66	6.12
DO (% sat)	84.0	87.1	95.6
Turbidity (Hach)	9.15	26.5	3.18
pH	8.11	8.15	8.19
TSS (mg/l)	30	28	6
Chl-a (µg/l)	3.76	3.19	0.85
Total N (µM)	16.7	24.9	9.8
NO3 (µM)	6.3	14.5	4.9
Total P (µM)	0.65	1.3	0.32
Si (µM)	26.0	50.8	27.5

Significant amounts of data are available from two DOH monitoring sites inside Kawaihae Harbor (Figure 22, sites 1210 and 1238), but because water inside Kawaihae Harbor is physically isolated from water in Pelekane Bay, water quality at these sites is unlikely to correlate significantly with water quality in Pelekane Bay and these sites are not considered further here. Some data also are available from other sites further from the site, especially to the south (National Park Service 2001), but data from these sites generally are limited to salinity and bacteriological measurements.

Overall, despite the lack of quantitative data from waters immediately adjacent to PUHE, it is clear that water quality in this area is degraded significantly due to turbidity associated with the predominantly muddy sediments in nearshore areas, and it seems likely that these waters also exhibit higher nutrient, chlorophyll-a, and possibly bacterial concentrations than would have been found prior to the construction of Kawaihae harbor. Sediment deposition in site waters probably is due primarily to storm runoff inputs, but may be augmented by dust derived from upslope areas and from dredged material stockpiled behind the Kawaihae harbor breakwall north of the site. Terrestrial sediment inputs to nearshore waters probably are significantly higher than normal due to excessive erosion in the watershed associated with recent and historical land-use activities (timber harvest and cattle grazing) and possibly due to contributions from a quarry located just inland of the site. While some reductions in sediment delivery might be achieved by applying control measures such as best management practices in the watershed and on nearby harbor lands, dramatic improvements in site water quality seem unlikely unless circulation in Pelekane Bay also is improved, facilitating export of sediments from the bay.

C.2.a.vi. Subtidal benthic resources

Reef flats and reef communities

PUHE’s reef communities are designated Class II by the State of Hawai‘i and are protected for “all uses compatible with the protection and propagation of fish, shellfish, and wildlife” (Department of Health 2004). There are no numeric water quality standards specific to reef flats and reef communities, but there are criteria relating to sediment deposition and to the quality of sediments in reef communities. Sediment deposition is limited by the criterion that “episodic deposits of flood-borne sediment shall not occur in quantities exceeding equivalent thicknesses [of two millimeters (0.08 inch) on living coral surfaces and five millimeters (0.20 inch) on other hard surfaces] for longer than twenty-four hours after a heavy rainstorm” (Department of Health 2004). While no data are available to assess compliance with this criterion, the historical accumulation of terrigenous sediment in the Pelekane Bay area suggests that this criterion probably is exceeded on a regular basis following runoff events. Sediment quality in reef flats and communities is maintained by criteria specifying that the redox potential in surface sediments exceed 100 millivolts and that “no more than fifty percent of the grain size distribution of sand patches shall be smaller than 0.125 millimeters in diameter” (Department of Health 2004). While no data are available to evaluate the redox criterion directly, analysis of sediment from Pelekane Bay in 2002 showed very high organic content (Table 15), which suggests that redox potentials in sediments probably are quite low, and the generally fine-grained character of the sediments trapped in the Pelekane Bay area (>92% less than 0.125 mm; Table 16) suggests that the grain size criterion probably also is violated. It is worth noting that while DOH criteria are focused on terrigenous sediment delivered by storm runoff, other sediment sources also may be important in Pelekane Bay. In particular, sediment from wind-borne dust from coral fill in Kawaihae Harbor and from particles winnowed from fill by wave action may contribute to the sediment load affecting reef communities. While narrative criteria for reef flats and communities stipulate that “no action shall be undertaken which would substantially risk damage, impairment, or alteration of … biological characteristics”, harbor development impacts can be exempted where no feasible alternatives exist and where approval is obtained from the State of Hawai‘i Director of Health (Department of Health 2004).

Soft bottom communities

Soft bottom communities in PUHE’s coastal waters are designated Class II by the State of Hawai‘i. Numeric criteria are defined only for within-sediment redox potential (not less than –100 millivolts in the upper 10 cm), but narrative criteria specify similar levels of protection to those discussed above for reef communities. Extensive areas of sandy/silty sediments are present in nearshore waters, particularly in the area directly off of the mouth of Makeahua Stream. No data are available to directly assess compliance with the numeric or narrative criteria in these soft-bottom communities, but the sediment organic content and grain-size distribution data discussed above (Tables 15 and 16) do suggest that the criteria probably are violated in some areas, particularly near the mouth of Makeahua Stream where water circulation is poor and fine sediments accumulate. Observations of anoxic conditions at shallow sediment depths and changes in the soft-bottom community between 1976 and 1996 (Tissot et al. 1998) also suggest that the redox criterion is violated in these areas.

C.2.b. Ecosystem effects

C.2.b.i. Groundwater/Anchialine Pools

Although groundwater contains biological resources, data generally are not available on the relationships between groundwater ecosystems and groundwater quality. Anchialine pools are surface expressions of groundwater, so anchialine ecosystems have the potential to provide insights into water quality effects on both anchialine and groundwater ecosystems. However, PUHE's anchialine resources are unusual in that they are intermittent compared to 'classic' anchialine pools, and the associated ecosystems probably are affected significantly by periodic flushing during high runoff events, and by subsequent reestablishment of estuarine/anchialine conditions. Ecosystem attributes in PUHE's anchialine pools thus may not be straightforward indicators of groundwater quality effects. Regardless, there are no significant amounts of biological data for PUHE's anchialine/estuarine systems, so it is not possible to perform a rigorous or even a semi-quantitative assessment of water quality effects on PUHE's anchialine ecosystems. However, some insight can be gained into possible linkages between water quality and ecosystem structure and function by considering more typical anchialine and estuarine systems.

Anchialine ecosystems persist over a relatively wide range of water quality conditions. In natural systems, water quality differences are due primarily to differences in the relative proportions of groundwater and seawater in pools, but anchialine systems also appear to be tolerant of additions of anthropogenic nutrients, at least where water residence times are short (Brock and Kam 1997). Tolerance to other contaminants is not well known. Oil and grease pollution in one anchialine pool near Honokohau Harbor, south of PUHE, did result in the disappearance of endemic shrimp from the pool, but these pollutants probably would not be transported effectively through groundwater due to sorption of contaminants to solid surfaces. However, these types of pollutants could reach PUHE's anchialine systems in runoff from the highway adjacent to the site. Accelerated sedimentation can be a significant concern in anchialine pools as it reduces water exchange between pools and groundwater and can lead to premature pool senescence (Brock and Kam 1997). Salinity in PUHE's anchialine pools probably changes significantly throughout the year and from year to year depending on local climate and physical isolation of the pools (due to the presence or absence of the sand berm at the mouth of Makeahua Stream), and longer-term changes also seem likely if streamflow and groundwater discharges have declined due to historical changes in the hydrologic cycle in the watershed. Natural and anthropogenic nutrient and contaminant effects on the pools seem likely to be similar to those expected in typical anchialine pools, and there probably is some sediment accumulation from in-pool sources and from surrounding vegetation (and possibly from dust deposition) while the pools are isolated. As noted above, high-runoff events probably scour fine sediments from the stream channels and anchialine/estuarine pools, limiting the potential for long-term sediment accumulation, although some net accumulation might occur during smaller runoff events. Nutrient impacts probably depend primarily on water residence time. Brock and Kam (1997) and (Nance 2000) argue that even relatively large changes in nutrient concentrations are unlikely to affect anchialine ecosystems because nutrients normally are present in pools at relatively high concentrations and thus are not limiting to photosynthesis. However, some anchialine systems may be more susceptible than others: mixing diagrams in Brock and Kam (1997) show significant nutrient depletion in many pools, with a few having very low nutrient concentrations, so additions to low-nutrient pools might stimulate plant production and impact pool ecosystems. The anchialine pool in Pohaukole Gulch is relatively small (D. Hoover pers. obs. 2004), so water residence times normally would be expected to be short, making it less likely that nutrients would be depleted. However, water residence times will increase if groundwater flow through the site is slowed, and when sediments and debris in the pool impede groundwater flow through the pool. The pool in Makeahua Stream is relatively large, so residence time probably is fairly long, increasing the potential for nutrient depletion.

There appear to be no major sources of urban or industrial contamination upslope of the site, but residential, agricultural, and light industrial development around the site could result in the introduction of a variety of chemical contaminants to groundwater, and historical activities in the site may have resulted in residual contamination. For instance, concrete waste in Pohaukole Gulch from the batching plant previously located in the site may be affecting water quality in the downstream anchialine pools. No testing has been performed to determine whether contaminants are present and in what quantities, so there is no way to assess the potential impacts of urban and industrial contaminants on biological resources in groundwater and anchialine pools in the site, but in general, the relatively sparse development upslope suggests that inputs at this time probably are small and relatively dispersed. Historical and ongoing activities within the site, such as the use of herbicides, also may have resulted in some contaminant inputs, but no data are available to assess possible impacts in this area.

In many areas the most widespread and serious impacts on anchialine ecosystems are associated with the accidental or deliberate introduction of alien fish (Brock 1985). The anchialine pool in Makeahua Stream contained alien fish in 1976 (*Tilapia* spp; Cheney et al. 1977), but because the pools are subject to periodic flushing by storm runoff, and the pool at the mouth of Makeahua Stream normally is connected directly to coastal waters after large runoff events, the factors controlling species introduction and persistence are different than for typical anchialine pools. These factors seem likely to produce a rather different 'characteristic' ecosystem than that found in typical anchialine pools, and may reduce the potential for establishing dominant populations of alien fish. Terrestrial aliens, such as ants and spiders, also may impact anchialine fauna (Foote 2005), but the extent to which they may be a factor in PUHE's anchialine systems is not known.

C.2.b.ii. Wetlands

No water quality data are available for wetland areas, and there are no data on aquatic ecosystems in wetland areas except for plants (e.g., Macneil and Hemmes 1977, Pratt and Abbott 1996, Pratt 1998). PUHE's wetlands mostly are associated with the riparian zone around Makeahua Stream, and any water quality-related issues thus would be associated primarily with groundwater discharging through the stream channel into the anchialine pool/estuarine reach at the mouth of the stream. Toxic contaminants in groundwater can accumulate in sediments in wetland areas, resulting in potential impacts on wetland flora and fauna, but no data are available on groundwater or sediment quality to assess possible impacts on PUHE's wetland flora or fauna.

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

No chemical water quality data are available for rocky and sandy intertidal areas. While there was no evidence of significant sediment accumulation in intertidal areas during a site visit in December 2004 (D. Hoover, pers. obs. 2004), intertidal areas in the site clearly are affected by the high turbidity water commonly found in this area, and additional impacts due to dissolved contaminants also seem possible. The most likely source of contaminants affecting rocky and sandy intertidal areas would be groundwater discharging to tidepools or through rocky or sandy substrates, and increased nutrient levels in nearshore waters due to remineralization of sediments in Pelekane Bay. Increased nutrients could enhance algal growth in intertidal areas; for instance *Ulva* sp. often is locally abundant around coastal groundwater seeps, and Ball (1977) noted that 'eutrophic' algal species were common in the rocky intertidal area along the harbor breakwater. Sessile flora and fauna could accumulate pollutants if these were present in groundwater, resulting in pollutant transfer to higher trophic levels, such as waterbirds and turtles. No testing has been conducted in these areas, and while rocky and sandy intertidal areas in Hawaiʻi normally should be relatively insensitive to contaminant inputs due to the short residence time of groundwater and seawater along Hawaiʻi's coasts, the poor circulation in Pelekane Bay may increase the risk of contaminant accumulation in this area. For instance, moderate increases in nearshore nutrient concentrations normally should not have significant impacts on coastal ecosystems because even pristine groundwater already contains relatively high nutrient concentrations, but the increased residence time of water in Pelekane Bay probably results in greater nutrient uptake by coastal biota than in other areas, making the area more susceptible to anthropogenic nutrient additions.

C.2.b.iv. Coastal waters

Planktonic and pelagic

The response of planktonic and pelagic organisms to aquatic pollutants generally depends on both pollutant concentration and duration of exposure. Because the biggest potential source of contaminants to coastal waters in west Hawaiʻi normally is groundwater, ecosystem impacts depend to a large degree on the balance between groundwater supply and dilution in receiving waters. Groundwater is less dense than seawater, and in the absence of mixing by wind and waves, groundwater floats on seawater, forming laterally extensive but relatively thin surface layers. If calm conditions allow a layer 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 can grow rapidly in response to the nutrients contributed by groundwater. The presence of toxic contaminants under these conditions could result in significant effects on phytoplankton populations due to increased concentrations and exposure times, and contaminants and effects could be transferred to higher trophic levels. Calm conditions most often are found in enclosed bays or harbors (and in fishponds and anchialine pools), but they are extremely rare in open coastal settings in Hawaiʻi. As a result, although groundwater inputs commonly result in obvious changes in coastal water quality in the immediate area of discharges, there normally is relatively little impact on planktonic and pelagic biota (Dollar and Atkinson 1992; Dollar and Andrews 1997). In PUHE, groundwater discharges produce a noticeable surface layer of brackish water off of rocky intertidal areas in the southern portion of the site and reduce nearshore salinities in Pelekane Bay. While no data are available to assess possible impacts on planktonic and pelagic organisms, shallow depths and relatively sluggish circulation in Pelekane Bay probably slow dilution and increase the possibility of impacts on flora and fauna in this area. Sediments accumulated in Pelekane Bay also may increase the potential for pollutant transfer to biota, as sediment-bound contaminants may be remobilized to dissolved phases after sediments are deposited in coastal waters, either via desorption reactions or via biogeochemical transformations. Cyclic resuspension of sediment particles, which probably is common in Pelekane Bay, also increases the potential for contaminant release over time.

Subtidal benthic

Most of the groundwater discharge around PUHE probably occurs near the coastline, but because groundwater is more buoyant than seawater, groundwater floats and thus usually has little effect on subtidal benthos. However, some groundwater probably does discharge subtidally through rocky and sandy substrates, so flora and fauna in these areas may be affected by groundwater quality. Nearshore waters around PUHE also are quite shallow, so groundwater discharged along the shore may be mixed through the water column and impact benthos before being exported offshore. Surveys of nearshore benthic resources generally have concluded that they were impacted most significantly by sediments, both due to direct burial and to reduced light due to high turbidity (Cheney et al. 1977; Tissot et al. 1998; Beets et al. in review), but no studies have been conducted on possible chemical contaminant impacts.

C.2.c. Human health effects

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

C.2.c.i. Groundwater

Groundwater in the site 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 site's anchialine pools. Potential human health effects in this area are discussed briefly below.

C.2.c.ii. Anchialine pools

Anchialine pools historically have been used for a variety of purposes that may have human health implications. Bathing in pools can 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), and harvesting of cultivated or natural pool resources carries a risk of ingestion of toxins accumulated by the organisms. There have been no analyses of water quality in PUHE's anchialine pools or of organism tissues that would allow assessment of this risk, but the relatively degraded appearance of PUHE's pools probably makes them unattractive for contact recreation or harvesting of associated flora or fauna. Visitation to the pools also probably is very low, particularly the one in Pohaukole Gulch, so the risk of human health issues overall probably also is quite low.

C.2.c.iii. Wetlands

There are no data on the frequency with which visitors or park personnel utilize wetlands or vegetation from the riparian areas around Makeahua Stream in ways that might promote pathogen transfer, but this type of interaction seems likely to be very rare and human health risks very small. While some wetland organisms probably have the potential to accumulate toxic contaminants, upslope contaminant inputs seem likely to be small, and it seems unlikely that there is significant consumption of flora or fauna from these areas.

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

Bacterial contamination might be present in tidepools due either to the presence of contaminated groundwater or to direct contamination, but PUHE's tidepools are very small and the residence time of water in pools should be low, so the risk of human health effects also seems very small. Health effects related to consumption of contaminated organisms are possible, but probably are negligible. The most likely pathway for consumption of contaminated intertidal organisms probably is through shellfish, particularly native limpets, or opihi. However, there is no significant evidence of contamination by toxics in the site in general, intertidal habitat in PUHE is not particularly suitable for opihi, and opihi generally occur at low densities in accessible areas of the Kona coast due to heavy harvesting pressure. Thus, opihi probably do not represent a significant food resource in the site and the risk of a human health issue due to consumption of contaminated organisms seems very small.

C.2.c.v. 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. There is significant visitor use of the beach area immediately south of PUHE, and boats frequently are found offshore transiting to and from the small boat harbor. Circulation in Pelekane Bay is sluggish, so dilution is poor compared to most coastal areas in west Hawai'i, increasing the potential for human health issues in the Pelekane Bay area. However, visitor contact with nearshore waters adjacent to PUHE seems likely to be minimal due to their generally unattractive condition, so the risk of human health issues seems small.

Fishing does occur in coastal waters off PUHE, and carries some risk of consumption of contaminated organisms. Strong currents and rapid mixing and dilution normally minimize the residence time and adverse effects of contaminants in Hawaiian coastal waters, reducing the potential for contamination of fish and other pelagic organisms. However, the residence times of waters in Pelekane Bay and inside Kawaihae Harbor are relatively long, and both areas contain boats and other sources of potential contaminants, as well as significant areas of soft sediments that may contain or accumulate contaminants, so fish and other marine resources in the area could accumulate contaminants from these sources. The human health risk associated with these sources is not known, but some contaminants common in boat harbors (e.g. heavy metals) can bioaccumulate and can result in human health risks.

Subtidal benthic

Some of the subtidal benthic resources in waters off of PUHE probably are harvested for consumption (e.g., octopus, lobster, sea urchins and snails are heavily fished in many areas in Hawaiʻi). There are no data on contaminants in subtidal benthic resources adjacent to PUHE, but the relatively poor water quality in the area suggests that there may be associated human health risks. As for pelagic resources, the most credible concern probably would be boating- or sediment-derived contaminants accumulating in benthic organisms in the Pelekane Bay area, but the magnitude of this threat cannot be assessed without data on the occurrence and distribution of contaminants and the frequency with which contaminated organisms are harvested and consumed.

C.3. List of impairments

Pelekane Bay is listed as impaired due to excessive turbidity in the State of Hawaiʻi's most recent 303(d) list (Koch et al. 2004). No quantitative basis is given for the listing, but adjacent waters off of Spencer Beach Park also are listed for turbidity and chlorophyll-a based on extensive monitoring and numeric criteria, and data reviewed in this report suggest that the waters of Pelekane Bay probably are even more impaired with respect to dissolved nitrogen and chlorophyll-a, and potentially for dissolved oxygen.

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

At present none of PUHE's water bodies are monitored sufficiently to establish compliance with water quality standards or to assess accurately the condition of associated ecosystems relative to water quality. There are no groundwater data, and for all practical purposes, no data from anchialine pools. There also are virtually no data from nearshore coastal waters adjacent to the site, although there are some historical data from offshore areas around the small boat harbor, and there is a substantial (and ongoing) time series of water quality data from a nearshore monitoring site just south of PUHE.

While the relatively sparse development upslope of the site suggests that groundwater contamination may not be a major concern, groundwater quality affects water quality in PUHE's anchialine pools and in nearshore waters around the site, so groundwater quality data are essential for managing resources in these areas. Groundwater flow also is an uncharacterized but key factor that affects the salinity and residence time of groundwater in the site and thus of water quality in the site's anchialine pools and coastal waters. While PUHE's anchialine pools are unique in some respects compared to the anchialine pools commonly found in other areas of the Kona coast, anchialine habitat in the region is rare so they may be important biogeographically, and anchialine pools in general are threatened by development throughout the state, making conservation a priority (cf., Wiegner et al. 2006). The unique nature of PUHE’s anchialine pools also makes them potentially valuable opportunities to understand the processes controlling the associated anchialine/estuarine ecosystems as they undergo cyclic resetting by runoff events. Coastal waters adjacent to the site are poorly mixed and heavily impacted by sediments accumulated in Pelekane Bay. Based on data from the adjacent Spencer Beach Park monitoring site, water quality in Pelekane Bay probably does not meet State of Hawai‘i standards, due both to the effects of groundwater discharging in the area and to the direct and indirect effects of sediments trapped in the bay. Water quality monitoring in nearshore waters around PUHE will be essential to any future remediation efforts, both to determine the relative importance of the many factors affecting water quality, and to document the effectiveness of remediation.

D. ISSUES AND THREATS TO COASTAL RESOURCES

D.1. Coastal development

D.1.a. Population and land use

Population growth and coastal development are major issues in west Hawaiʻi and pose potentially significant threats to PUHE's coastal resources. From 1990 to 2000, population in the State grew by 9%, and recent data show that Hawaiʻi County (i.e., the island of Hawaiʻi) had the highest growth rate in the State (Table 23). Growth-driven changes in land use are expanding urban areas at the expense of conservation and agricultural lands in many areas in west Hawaiʻi, but monitoring and protection of coastal resources has not kept pace with development. A recent review of coastal monitoring data for developments in west Hawaiʻi concluded that existing standards and monitoring programs were insufficient to protect coastal resources, and that enforcement was lacking (Wiegner et al. 2006).

Table 23. Population change by county in the State of Hawaiʻi (Gima 2005).

	July 1, 2004	July 1, 2003	% Change
Hawaii County	162,971	158,735	2.7
Honolulu County	899,593	893,358	0.7
Kalawao County (Kalaupapa)	126	130	-3.1
Kauai County	61,929	60,736	2.0
Maui County	138,221	135,796	1.8
State of Hawaii (total)	1,262,840	1,248,755	1.1

Land use changes that have impacted PUHE's resources include historical changes in the upslope watershed caused by sandalwood harvesting/deforestation and cattle ranching, both of which had major impacts on streamflow and groundwater hydrology, and on erosion and sediment transport to Kawaihae Bay. More recent impacts have been associated primarily with population growth and associated surface and groundwater use on the Waimea plain and in the town of Waimea (Kamuela), and with urban development around the site, including the construction of Kawaihae Harbor in 1959, the associated operation of a quarry immediately inland of the site, expansion of the harbor in 1969-1970, and construction of the small boat harbor in the late 1990s. Harbor construction in particular had catastrophic impacts on coastal resources in the area, as it destroyed a large area of coral reef and drastically altered nearshore circulation, degrading habitat in Pelekane Bay (Naughton et al. 2001). Harbor construction also destroyed at least one coastal fishpond, and altered groundwater hydrology in the area. Additional harbor modifications have been proposed to accommodate the new Hawaiʻi Superferry (Leideman 2005), but new impacts on PUHE resources probably will be associated primarily with increased visitor and vehicle traffic in the area, as the proposed modifications will occur within the existing harbor, and ferries will not discharge waste to ocean waters. Some additional risk of alien species introductions will occur with the increased vessel, vehicle, and human traffic. While major new developments have not yet occurred in agricultural lands upslope of the site, development trends in west Hawaiʻi suggest that it is only a matter of time. Upslope developments can contaminate groundwater that subsequently flows downslope to the site, and coastal developments may impact nearby PUHE resources via increases in sediment, nutrient, and other chemical pollutants, introduction of alien species, alteration of habitat around the site and thus of the potential for dispersal and colonization of species in the site, and through increased visitor use and associated impacts. Development within PUHE, such as the new visitor facility and associated septic system, and restoration activities around the anchialine pond and in coastal areas, also may impact resources

While new developments obviously have significant potential to impact site resources, population growth also will increase the impacts of existing developments. For instance, there is a growing need for cargo services in Kawaihae Harbor, with attendant increases in vehicle and boat traffic and associated infrastructure. As a result, the US Army Corps of Engineers and the State of Hawaiʻi have proposed a number of modifications to deepen and expand the harbor, including construction of an entrance channel, a "rubble mound" breakwater, and deepening of the harbor basin (Tetra Tech 2004). Increased usage and the proposed modifications will have a variety of potential consequences for PUHE's water resources. Increased usage likely will increase impacts in a number of areas, including nutrient and chemical pollutant loading to site 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. Increased harbor usage (due both to increasing demand for harbor services and to the new 'Fast Ferry', scheduled to start operations in 2009) also is likely to result in additional development in the harbor. Development probably would include construction of facilities on fill areas immediately north of PUHE with attendant increases in pollutants from that area, including atmospheric emissions, trash, and potentially pollutant leaching through fill into Makeahua Stream and Pelekane Bay. However, development might also reduce dust emissions from the area as existing bare ground surfaces are paved and landscaped. One recent development that may affect site resources is the decision to increase military training in the Pohakuloa training area (PTA), upslope of the site, with convoys of military vehicles associated with the Stryker Brigade Combat Team (SBCT) arriving at Kawaihae Harbor and traveling between the harbor and PTA, passing PUHE as they leave the harbor (Tetra Tech 2004).

Increased resident and visitor populations also will result in increased site visitation, with attendant impacts on site coastal water resources. Visitation is associated with impacts like increased garbage and animal waste and direct inputs of contaminants to site waters. Visitors also may take items from tidepools and other accessible areas. For instance, because corals in intertidal areas are conspicuous and can be taken easily without swimming, they often are removed as ornamental curios by visitors (Parrish et al. 1990). Native edible limpets are heavily harvested from intertidal areas along the Kona coast, and cowries and other large shelled and unshelled (octopus) mollusks also may be collected for food 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 stresses waterbirds, making PUHE's already limited and degraded habitat even less suitable for bird use (cf., Morin 1998). Recreational fishing in coastal waters adjacent to the site may be impacting fish populations, and impacts likely will increase in the future, but neither the site nor the State of Hawaiʻi collects recreational catch or effort data suitable for assessing the effects of recreational fishing on these resources. Increased resident and visitor populations also will increase visitor use of Spencer Beach Park, with attendant impacts on PUHE due to incidental visitation (i.e., visitors entering PUHE from Spencer Beach Park), and via impacts on coastal waters adjacent to Spencer Beach Park that then affect PUHE coastal resources.

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

No surface water resources are utilized in the PUHE area, but developments adjacent to and upslope of the site affect groundwater flow and quality via groundwater pumping and wastewater disposal, and via increases in impervious surfaces (e.g., roads, parking areas, and buildings) that enhance surface water runoff and alter infiltration patterns. Oki et al. (1999) modeled groundwater flow in KAHO, south of PUHE, and showed that groundwater withdrawals had a negligible effect on flow through KAHO in 1978, but that by 1997 there was sufficient pumping capacity to reduce groundwater flow through the site by 47%. Pumping in the PUHE watershed may be lower than in the KAHO watershed, but sustainable yield probably also is lower given the very low rainfall in the area. Surface water diversions and groundwater pumping in the Waimea area probably have reduced flows in Makeahua Stream and groundwater flows through the site, and pumping doubtless will increase as population and development increase in the area. Development probably has resulted in significant local impacts on groundwater recharge patterns and groundwater hydrology and quality, as impervious surfaces and storm runoff collection systems redistribute runoff into specific infiltration areas, wastewater disposal primarily is through cesspools and septic systems that produce localized inputs of contaminated water at multiple points in the watershed. Construction of Kawaihae Harbor also likely resulted in major changes in groundwater flow and discharge to coastal waters around the harbor. Groundwater inputs inside PUHE also may affect PUHE's coastal resources, for instance due to irrigation or infiltration of waste water from the septic system installed with the new visitor facilities. Changes in groundwater withdrawals and recharge thus could have significant impacts on PUHE's coastal water resources, particularly its anchialine pools and nearshore waters.

D.1.c. Erosion

Excessive erosion in the Pelekane watershed is a major factor affecting the degradation of water quality and biological resources in Pelekane Bay. Historical and present-day land use practices have increased erosion from the watershed, dramatically increasing the supply of sediment to Pelekane Bay. Important historical land use changes that increased erosion include overgrazing due to cattle introduced in the late 1700s, and widespread deforestation due to sandalwood harvesting in the early 1800's. Present-day land use in the watershed primarily is associated with cattle grazing; although best-management practices (BMP's) have been implemented in some areas to reduce erosion losses, significant areas of the watershed have been damaged by grazing and wildfires and still are vulnerable to erosion during storms (Haight 1998; Stewart 2001).

D.1.d. Site maintenance

Maintaining archaeological and cultural resources in PUHE historically has required extensive removal and disposal of vegetation and application of herbicides (see section C.1.a.iii Herbicide use). Currently, a significant amount of plant waste is disposed of in at least one on-site debris pile that may be impacting adjacent anchialine resources in Makeahua Stream and Pohaukole Gulch (D. Hoover, pers. obs. 2004). Potential impacts of vegetation management chemicals on coastal water resources are difficult to assess due to the variety of chemicals used, the lack of data on actual contaminant inputs and reactivity in PUHE's unique environment, and the lack of data on the sensitivity of biological resources to specific contaminants, but the potential for contaminant transport in groundwater to anchialine pools, wetlands, and intertidal areas, and the potential for contaminant retention and remobilization from sediments in Pelekane Bay suggests that these activities could represent a threat to PUHE's coastal resources.

D.2. Nuisance species

Invasive species are a major concern in Hawaiʻi due to the unusual vulnerability of Hawaiian ecosystems to alien introductions, particularly terrestrial ecosystems. Hawaiian marine ecosystems may be somewhat more resistant to alien introductions than terrestrial systems due to their lower degree of endemism (Eldredge and Carlton 2002), but few areas have been surveyed extensively for invasives and the vulnerability of specific ecosystems probably varies. Because PUHE'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), and the occurrence and extent of tumors may be related to water quality in certain areas of the main Hawaiian Islands (Dr. Larry Basch, Senior Scientist-Advisor, NPS PICRP, pers. comm. 2005). Coral diseases also recently have been documented in Hawaiʻi, including on Kona reefs, and are believed to be caused by pathogenic microbes or fungi (Dr. Larry Basch, pers. comm. 2005). PUHE may be particularly vulnerable to invasive species due to its proximity to Kawaihae Harbor, as invasive species commonly are transported on the hulls and in the ballast water of ships, and in cargo. Alien species that have been noted in association with PUHE's coastal resources include the snapper *Lutjanus fulvus* (listed as *L. vaigensis* in Kanayama and Kawamoto 1970, Cheney et al. 1977, and Tissot et al. 1998 and as *L. fulvus* in Beets et al. in review), the peacock grouper *Cephalopholus argus* (Beets et al. in review), *Tilapia* spp. in the anchialine pool in Makeahua Stream (Cheney et al. 1977; C. Stewart, Marine and Coastal Solutions International, Inc., pers. obs. 2003), the pickleweed *Batis maritima* around the anchialine pool (but apparently eradicated in 1996) (Pratt 1998), and the alga *Acanthophera spicifera* in coastal waters (Ball 1977).

D.2.a. Terrestrial plants and animals

Alien plants are a significant problem in PUHE, as they are in most developed coastal areas in Hawaiʻi (Pratt 1998). Of particular concern are alien species in PUHE's wetlands that may displace native species (e.g. the alien pickleweed *Batis maritima*).

Mongooses, rats, mice, goats, domestic and feral cats and dogs, and chickens all have either been seen in the site or are known to be established in the area (Morin 1998; DeVerse and DiDonato 2004; DeVerse and DiDonato 2005). Herbivores can impact native plants in PUHE's wetland, anchialine pool, fishpond, and coastal strand communities. Predators prey on herbivores, represent a significant hazard to birds, and may harass native animals, such as turtles and monk seals. Invasive insects and spiders also may impact biological resources; alien ants have been observed to prey on native anchialine crustaceans at low tide, and alien spiders prey on native insects (Foote 2005).

D.2.b. Algae

Alien and invasive algae are considered a major threat to coral reef ecosystems in Hawai‘i (Davidson et al. 2005). Invasive algae have had significant impacts on reef ecosystems on Oahu, but appear to be less established on the other Hawaiian islands. In a 2000 survey of several sites along the Kona coast, only one site found to have an invasive species (*Acanthophora spicifera*) (http://www.hawaii.edu/ssri/hcri/rbi/hawaii/honokohau_bay.htm; Smith et al. 2002). The same species was found to be abundant inside Kaloko pond in KAHO in 2000 (Marine Research Consultants 2000), and was observed in PUHE’s coastal waters in 1976 (Ball 1977). The risk of introductions is relatively high due to PUHE’s proximity to Kawaihae harbor; an ongoing algal survey should provide data on the current status of PUHE’s algal community in 2006 (C. Squair, survey manager, UH Manoa, pers. comm. 2005).

D.2.c. Fish and aquatic invertebrates

Introduced fish and invertebrates could have significant impacts on brackish and marine ecosystems in and adjacent to PUHE. Invasive fish (*Tilapia* spp.) have been noted on at least two occasions in PUHE’s main anchialine pool (Cheney et al. 1977; C. Stewart, Marine and Coastal Solutions International, Inc., pers. obs. 2003) – the presence of alien fish in anchialine habitats 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. Introduced shrimp and prawns also may compete with or prey on native shrimp, altering the ecological balance in anchialine environments. However, the degree to which these phenomena would impact PUHE’s anchialine systems is uncertain because the pools are flushed periodically by fresh water, and the pool at the mouth of Makeahua Stream is connected seasonally with Pelekane Bay, potentially ‘resetting’ pool ecosystems on a regular basis.

Alien fish and invertebrates also could have significant impacts on coastal ecosystems in and adjacent to PUHE. No data are available on alien invertebrates, but introduced fish such as the peacock grouper or roi (*Cephalopholis argus*), black tail snapper (to‘au-*Lutjanus fulvus,* also known as *L. vaigiensis*), and blue-striped snapper (ta‘ape-*Lutjanus kasmira*) commonly are found in coastal waters off west Hawai‘i. Of these, to‘au is known to have been established in PUHE coastal waters since at least 1969 (Kanayama and Kawamoto 1970, Cheney et al. 1977, Tissot et al. 1998), roi was noted in 2005 (Beets et al. in review), and ta‘ape seems likely to be found in clearer offshore areas as well. Parrish et al. (1990) suggested that roi and to‘au might have relatively insignificant effects on the natural community structure in KAHO’s coastal waters, but that ta‘ape might produce significant impacts due to their “piscivorous habits and extreme abundance achieved over a short time in many areas”. Hoover (1993) noted that ta‘ape are suspected of displacing “valuable shallow-water food fishes such as weke and kumu [goatfishes]”. These and other fishes will be part of long-term community monitoring efforts by

NPS Pacific Islands Coral Reef Program staff in future studies (Dr. Larry Basch, Senior Scientist-Advisor, NPS PICRP, pers. comm. 2005).

D.3. Physical impacts

Significant physical impacts to PUHE's coastal resources by visitors are unlikely as most water-related resources are robust and visitor activities are focused on archaeological and cultural resources, with relatively little attention paid to anchialine pools or intertidal areas. There is very little visitor activity in Pelekane Bay, and if it still exists, Hale o Kapuni probably is buried and thus relatively immune to further damage.

In coastal waters adjacent to the site, some impacts to benthic resources might occur in association with diving, fishing, and boating. Fishing and diving also may have some minor impacts on benthic substrates, but a study at a popular nearby SCUBA diving site (Kealakekua Bay) showed no significant physical effects due to diving activity (Tissot and Hallacher 2000), and no significant impacts were observed in an area frequented by aquarium fishermen in KAHO (Tissot and Hallacher 2003). Boating may have significant local impacts where boat groundings occur, but boats using the small boat harbor are unlikely to enter nearshore waters adjacent to PUHE, and benthic substrate in shallow areas mostly is sand, mud, and silt, with some areas of mostly dead coral or sparsely colonized basalt, so groundings in these areas probably would have minimal impacts on benthic substrate and ecosystems. The most significant physical impacts to coastal water resources in and around the site probably occur in association with very rare but potentially highly destructive earthquakes and tidal waves.

D.4. Global change

D.4.a. Sea level rise

Apple and MacDonald (1966) documented the effects of historical sea level rise in PUHO, about 70 km (45 miles) south of PUHE, noting that many cultural resources and man-made coastal features, such as bait cups, net-tanning tubs, and playing boards, were submerged and unusable for their original purpose. Recent data show that sea levels in Hawai‘i have continued to rise: from 1946 to 2002, sea level at Hilo (Figure 1) rose an average of 0.34 cm per year (0.13 in/y), likely due both to global sea level rise and local subsidence of the island (Hapke et al. 2005). Global sea level almost certainly will continue to rise due to global climate change, and the island of Hawai‘i will continue to sink as the mass of the growing volcanic edifice depresses the underlying oceanic crust. As a result, PUHE's intertidal resources will continue to slowly be inundated, with the intertidal zone moving further inshore. One result will be that nearshore mixohaline resources, such as tidepools, will become more saline, some intertidal resources will become permanently subtidal, and the anchialine habitat in Makeahua Stream and Pohaukole Gulch might expand and move inland. However, these changes will take place slowly and probably will not affect the overall condition of the resources significantly. PUHE's beach probably will not be inundated at the same rate as other areas, because sediment supply from Makeahua Stream probably will continue to infill the bay and promote beach advance, offsetting the effects of sea level rise. However, cultural resources in or just above intertidal areas, such as the Royal Courtyard, may be affected, and rising sea level may impact the mechanisms affecting the maintenance of the sand berm normally present at the mouth of Makeahua Stream, altering the frequency and degree of connection between the anchialine pool in Makeahua Stream and Pelekane Bay.

D.4.b. Climate change

Global climate change also may impact PUHE's 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 upslope rainfall and groundwater recharge, affecting groundwater flow through the site. Changes in the frequency and intensity of storms also could affect the direction and intensity of wave energy reaching PUHE's shoreline, affecting the distribution of sand along the coast, potentially adding to or eroding the beach at the head of Pelekane Bay, and likely altering the distribution, abundance, and diversity of organisms in nearshore areas subject to storm disturbance. Increased temperature also correlates 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 and around PUHE, because other nutrients (usually nitrogen or phosphorus) usually are more limiting and CO_2 probably already is 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 (i.e., the biominerals secreted by many marine organisms, including corals and calcifying marine algae), and may also inhibit organisms' ability to secrete biominerals in the first place. Increasing CO_2 thus may affect PUHE's aquatic communities in anchialine pools and nearshore intertidal areas, which are areas of very active photosynthesis and carbonate synthesis, and in subtidal areas 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. Effects are likely to be less important in areas of soft sediments, where respiration in sediments probably elevates CO_2 in overlying waters. 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 and collecting of marine organisms is allowed in intertidal areas and coastal waters around PUHE, so harvesting may represent a threat to resources in these areas. Traditional harvesting for opihi (*Cellana* sp.), pipipi (*Nerita* sp.), a‘ama (a crab, *Grapsus grapsus*), wana (*Centrechinus paucispinus* - collected seasonally for their edible gonads), and limu (algae) may occur along the shoreline and in tidepools, although no data are available and PUHE's intertidal zone does not contain particularly good opihi habitat. Subtidal harvesting of octopus, lobster and food fish probably does impact local populations (cf., Doty 1969, Kanayama and Kawamoto 1970, Cheney et al. 1977). Hook-and-line fishermen have been observed fishing from the shoreline, and gill nets were used around the time of Cheney et al.'s (1977) survey. Spearfishing also was noted to be common around the time of Cheney et al.'s (1977) survey, although catch rates were noted as being low compared to catches from areas north and south of the site (Cheney et al. 1977).

D.6. SCUBA/Snorkeling

Coastal waters adjacent to PUHE are turbid and unattractive for SCUBA or snorkeling, so impacts in these areas probably are negligible.

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

E.1. Summary

Table 24 summarizes existing and potential problems in PUHE's coastal water resources based on available data and our best professional judgement. Brief rationales for the classifications assigned to each of the resources and relevant stressors are provided below.

Table 24. Degraded and potentially degraded coastal water resources in and adjacent to PUHE.

Stressor	Ground-water	Anchialine Pools	Wetlands	Intertidal	Coastal Waters
Water Quality					
Nutrients	OK	OK	OK	PP	PP
Fecal bacteria	OK	OK	OK	OK	PP
Dissolved oxygen	OK	OK	OK	OK	PP
Metal contamination	OK	PP	PP	OK	PP
Toxic compounds	PP	PP	PP	OK	PP
Sediment	na	PP	PP	PP	EP
Increased temperature	OK	OK	OK	OK	PP
Increasing CO2	OK	PP	OK	PP	OK
Water Quantity					
Changing GW flux	OK	PP	PP	OK	PP
Population Effects					
Fish/shellfish harvest	na	OK	OK	PP	PP
Invasive species	PP	PP	EP	PP	PP
Physical impacts	na	OK	OK	OK	OK
Behavioral impacts	na	OK	OK	PP	PP
Habitat Disruption					
Sea level rise	OK	OK	OK	PP	PP
Sound pollution	na	OK	OK	OK	PP
Light pollution	na	OK	PP	PP	PP

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

E.1.a. Surface water

Surface water is not included as a resource in Table 24 because there are no perennial streams or other fresh surface water bodies in the site. Makeahua Stream and Pohaukole Gulch pass through or are adjacent to site lands and converge before discharging into Pelekane Bay, but both streams are intermittent in their lower reaches and no data are available for water quality or biological resources associated with freshwater flows in these streams.

E.1.b. Groundwater

Coastal water quality data and anecdotal information and observations show that significant amounts of groundwater do discharge along PUHE's coastline, but no data are available to assess the quality of groundwater in the site itself. Data from one long-term coastal water quality monitoring site just south of PUHE suggest that the quality of groundwater in the area is relatively similar to uncontaminated groundwater in other areas in west Hawai‘i, but that groundwater flows have declined significantly over at least the last 16 years. The absence of obvious nutrient contamination in nearby groundwater and the lack of major contaminant sources in the watershed suggests that the risk of groundwater contamination in the site is fairly low. However, waste water from the septic leach field recently installed in the site may impact site groundwater, and groundwater may provide important habitat for hypogeal anchialine organisms, so toxic contaminants may be a concern. Invasive species that could displace endemic hypogeal species also could be an issue, and groundwater contributes significantly to water in the anchialine pools in Makeahua Stream and Pohaukole Gulch, and affects water quality in intertidal and nearshore areas, so groundwater quantity and quality are concerns in those areas.

E.1.c. Anchialine pools

Anchialine pools are rare, and associated ecosystems are poorly understood. The two major pools in the stream channels in the site can be considered anchialine due to their generally brackish condition, but both are unusual compared to ‘typical’ anchialine pools in that they are subject to occasional flushing by high runoff events, and the pool in Makeahua Stream is seasonally connected to Pelekane Bay when high runoff events erode the sand berm at the mouth of the stream. Data either are not available or are insufficient to assess water quality or biological conditions in these pools. Anchialine pools are affected significantly by groundwater quality, but because the probability of groundwater contamination seems low, groundwater contaminants seem unlikely to be a major issue for the site's pools. However, excess sediment (due to enhanced erosion in the watershed) may affect pool ecosystems, and the lack of chemical and biological data suggests that it is prudent to leave open the possibility that contamination by metals and toxic compounds could be an issue, particularly given the presence of numerous potential sources in and around Kawaihae harbor to the north and associated with the highway immediately inland of the site, and the presence of significant quantities of waste concrete around the pool in Pohaukole Gulch. Pool ecosystems also may be impacted by changes in groundwater flow due to upslope development. While anchialine ecosystems in general 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 and to changes in atmospheric CO_2. Anchialine pools have been impacted significantly by coastal development throughout the state (Wiegner et al. 2006), despite the fact that pools provide habitat for some rare and candidate endangered species, such as the orange-black damselfly (*Megalagrion xanthophelas*), which may be vulnerable to changes in habitat and to predation by alien species, such as orb-weaver spiders (Foote 2005).

E.1.d. Wetlands

PUHE's wetlands primarily are associated with the large anchialine/estuarine pool in Makeahua Stream. Wetlands are rare in west Hawai'i, so PUHE's wetlands provide potentially important habitat for insects, plants, and transient birds. No water quality data are available for PUHE's wetland habitat, but there is no obvious indication of water quality issues in groundwater, which supplies most of the freshwater to the system, or of water quality impacts on existing biota. However, wetlands are subject to flooding and sediment loading during storm runoff events and can accumulate metals and toxic compounds, so problems could exist in these areas given the excessive erosion occurring in the watershed and the proximity of potential contaminant sources associated with the harbor and the highway adjacent to the site. Wetlands also may be susceptible to salinity changes associated with changing groundwater flux. Alien species that displace native species are a concern - efforts to eradicate *B. maritima* appear to have been successful, but continued monitoring is needed to prevent reestablishment, and other alien species still are present and may be affecting wetland function. Light pollution may be an issue for wetland fauna if lighting associated with the harbor reaches the wetland area.

E.1.e. Intertidal

Biological resources in PUHE's intertidal have received only cursory study, but available data and a site visit suggest that the generally poor water quality in Pelekane Bay probably is impacting the intertidal community. The degree to which specific water quality factors are impacting intertidal resources is not known, but it seems likely that elevated nutrient concentrations (due to enhanced groundwater residence time and nutrient release from sediments, and possibly due to nutrient inputs from the on-site septic leach field) and excessive sediment loads are issues. Increasing atmospheric CO_2 levels also may affect calcifying organisms in intertidal areas. No data are available on the degree to which recreational harvesting of intertidal organisms may be impacting this resource, but harvesting does affect resources in many areas and the proximity of PUHE's intertidal zone to high-use areas in Spencer Beach Park suggests that this could be an issue. Intertidal zones also may provide habitat for green sea turtles (*Chelonia mydas*), and for threatened hawksbill turtles (*Eretmochelys imbricata*) and endangered Hawaiian monk seals (*Monachus schauislandi*), creating potential behavioral impacts due to visitor activities in these areas. Intertidal areas also may be vulnerable to sea level rise, and to light pollution from harbor or site sources.

E.1.f. Coastal waters

Coastal waters include both pelagic habitat and a variety of benthic habitats, from subtidal sediments to coral communities, that support resident and transient fish, reptiles, mammals, invertebrates, and other organisms, including turtles, sharks, and threatened humpback whales (*Megaptera novaeangliae*) that seasonally are found offshore of the site. Studies that have addressed pelagic and benthic biological resources generally have concluded that they are degraded significantly in nearshore areas, with conditions improving rapidly in more offshore waters. The principal factor responsible for the degraded conditions appears to be sediment deposited in Pelekane Bay by Makeahua Stream, which is retained in the bay due to sluggish circulation. Sediments may impact coastal resources in several ways, including via the direct effects of sediment loading on biota, via nutrient, metal, and toxic compound release from sediments, and via increased turbidity, which affects biota directly and also enhances survival of fecal bacteria by reducing ultraviolet penetration into the water. Groundwater discharging to Pelekane Bay also affects water quality, and the effects of groundwater additions (e.g., decreased salinities and increased nutrient concentrations) may be increased by the extended residence time of nearshore waters in Pelekane Bay. However, the effects of increased residence times may have been offset to some degree by recent (over at least the last 16 years) reductions in groundwater discharge to coastal waters. Contaminant inputs from the highway adjacent to the site, from the new visitor facilities, and from sources in the small boat harbor offshore of the site are possible concerns. Fecal bacteria potentially may be an issue based on monitoring at an adjacent coastal site off of Spencer Beach Park, but data from that site may be confounded by the persistence of enterococcus in Hawaiian soils. At least three alien fish species are established around the site, and stressors such as sound and light pollution and behavioral impacts due to visitor activities (e.g. wading, swimming, snorkeling, SCUBA diving, and boating) have not been addressed but may be significant for organisms like turtles and sharks that frequent the bay. 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. Alien species introductions are a particular concern at this site because of its proximity to Kawaihae harbor, where vessel hulls and ballast water provide regular opportunities for alien species introductions, and vessel traffic is expected to increase in the near future.

E.2. Recommendations

Although data are sparse, it seems clear that many of PUHE's coastal water resources are degraded (Table 24). However, data are insufficient in all areas to determine the degree to which site resources actually are impacted, and many areas where impacts are likely have no data at all. As a result, there are significant and fundamental information needs for the site related to most of the known and potential problems in Table 24. These are listed below, followed by recommended courses of action for other known impacts and issues. Some of the information needs will be addressed by studies currently planned for the site and by "Vital Signs" monitoring planned under the NPS Inventory and Monitoring Program. Ongoing and planned studies are noted where appropriate, but details of Vital Signs monitoring are not yet available, so the relevance of those activities to the issues identified below cannot be determined at this time. It should be noted that for all of the recommended water quality studies, the potential for strong vertical stratification and water quality gradients (due to groundwater floating on underlying seawater and to benthic impacts on water quality in shallow areas) 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.

Despite the lack of quantitative data, coastal waters in PUHE clearly are degraded significantly compared to adjacent coastal areas and likely compared to historical conditions. One obvious factor degrading coastal waters is the large quantity of terrigenous sediment in nearshore waters, which maintains turbid conditions and has prevented recovery of the coral reef ecosystem that existed prior to construction of Kawaihae harbor. The most effective solution to this problem would be removal of the harbor, which would allow sediment reaching nearshore site waters to be transported along- and offshore as it was prior to harbor construction. More practical approaches might include sediment removal from Pelekane Bay or reduction of sediment delivery to the bay. Unfortunately, while the complete lack of data on sediment sources and magnitudes makes it difficult to determine the potential for remediation, these approaches seem unlikely to have a significant impact on coastal water quality and ecosystem structure under the current conditions of drastically reduced circulation in the bay. Management of site lands and adjacent harbor lands to minimize dust might benefit site waters and would enhance the visitor experience in the terrestrial portion of the site as well, although there are cultural considerations that favor maintaining PUHE's terrain in a relatively unvegetated, and thus dust-prone, state (Pratt 1998). Similarly, the complete lack of water quality data prevent accurate assessment of the condition of affected site resources; a basic program of water quality monitoring thus is needed to provide baseline data for management of site resources. Overall, priority should be given to characterizing the sediment supply to coastal waters, the fate of sediment after delivery, and the short- and long-term impacts of the sediment on water quality and coastal biota. Other high-priority work should include characterizing groundwater fluxes through the site, which appear to have declined dramatically over at least the last 16 years, characterizing the unique anchialine/estuarine system in the lower reaches of Makeahua Stream, and investigating the factors responsible for the persistent presence of sharks in Pelekane Bay.

E.2.a. Information needs

E.2.a.i. Water quality

Surface water runoff and quality

1. Characterize storm-water runoff quantity and quality in Makeahua Stream. Automated monitoring and sampling equipment will be required, as storm runoff events in Hawaiʻi are unpredictable and short-lived and thus cannot be sampled effectively using manual methods. An automated sampling device was installed in 2005 under the Highway 270 bridge over Makeahua Stream (C. Stewart, Marine and Coastal Solutions International, Inc., pers. comm. 2005) that could provide the necessary samples if it still is in operation and available. Monitoring should include automated recording of stream level as a proxy for stream flow during storm events and *in-situ* turbidity measurements, and sample analysis should focus on determination of total suspended solids in storm runoff samples

to estimate the total sediment load introduced to Pelekane Bay during each event. Turbidity also should be determined on each sample to obtain the data needed to estimate suspended sediment concentrations from *in-situ* turbidity measurements. Sediment properties should be characterized using analyses of grain size and sediment composition, particularly organic carbon and nitrogen. Dissolved inorganic nutrients (nitrate, ammonia and phosphate) and dissolved silica also should be analyzed to estimate dissolved nutrient loads to the bay but on only a subset of samples. Analyses of other dissolved and particulate contaminants (metals, pesticides, etc.) also could be included as appropriate. Sampling should be performed on samples from at least four runoff events to assess variability in water and sediment quality between events.

2. Continuously monitor stream level and turbidity at the sampling site used in item 1 above to obtain a multi-year record of streamflow frequency and intensity and associated fluxes of suspended sediment and associated nutrients and contaminants to Pelekane Bay.

Groundwater supply and quality

1. Conduct a preliminary assessment of groundwater dynamics and quality in the site. Water quality parameters should include T, S, DO, and dissolved inorganic nutrients. Additional parameters can be analyzed (e.g., degradation products of chemicals and herbicides used in the site, and contaminants likely to be introduced upslope of the site) if appropriate, but "Total" N and P probably can be omitted, as the analyses are expensive and the resulting data provide little insight into ecosystem processes. Use the resulting information and available data on hydrology and groundwater development in the upslope watershed to estimate the potential impacts of groundwater development on flow through the site (cf., Oki 1999), and to assess the sensitivity of anchialine and coastal systems to variations in groundwater supply and groundwater quality (cf., Brock and Kam 1997). Monitoring of groundwater dynamics will require at least one but preferably more monitoring wells in the site; well numbers and siting should be based on consultation with experts in groundwater hydrology and should consider the potential impacts of on-site wastewater disposal (from the septic leach field) on groundwater flow and quality. Data from one or more wells in upslope areas also may be needed to assess changes in groundwater quality in the site relative to uncontaminated upslope water, and the effects of existing and planned development in the area immediately upslope of the site. Some aspects of groundwater quality also can be inferred from brackish coastal water samples (see below).

2. Monitor groundwater dynamics and groundwater quality in the site on roughly a weekly basis for at least a year to characterize variability associated with the various factors that may impact groundwater discharge (seasonal changes in upslope recharge, intermittent storms, etc.). A short-term (1-2 day) intensive monitoring program also is needed to characterize tidal effects on groundwater flow and quality to facilitate the design and interpretation of the results of the longer-term monitoring program.

Water quality in anchialine pools

1. Perform an initial survey of water quality in the two anchialine pools in the site. While Brock and Kam (1997) argue that anchialine pool ecosystems are relatively insensitive to changes in water quality, there are no baseline data for site pools with which to assess current conditions or future changes. In addition, because anchialine pools are subaerial exposures of groundwater, water quality measurements in anchialine pools potentially can be used to supplement groundwater quality data from monitoring wells. Analyses probably could be limited to basic water quality parameters (T, S, dissolved inorganic nutrients, chlorophyll-*a*), although additional parameters (e.g., the toxic contaminants noted above for groundwater) could be analyzed if needed. Priority should be given to characterizing the large pool/estuarine reach in Makeahua Stream, but some basic characterization of the small pool in Pohaukole Gulch should be included. Data should be collected on temporal and spatial scales appropriate to characterizing ecosystem processes in the pools, specifically the seasonal and event-scale changes in ecosystem structure and function associated with periodic flushing during high-runoff events and connection with, and isolation from Pelekane Bay due to the removal and restoration of the sand berm at the mouth of Makeahua Stream.

2. Perform limited analyses of pool water and sediment samples for toxic contaminants to assess the potential for contaminant release from sediments or delivery via groundwater. Sampling of fish or other organism tissue also may be appropriate for some contaminants.

3. Establish long-term monitoring of water quality in the Makeahua Stream pool. Monthly sampling probably would be appropriate, but the sampling interval, locations, and parameters measured should be determined based on the results of items 1 and 2 above. Some basic monitoring of the pool in Pohaukole Gulch also would be useful if the associated ecosystem is found to be of interest.

Water quality in coastal waters

1. Characterize the locations and intensity of groundwater inputs to coastal waters. Sampling simultaneously with DOH sampling at their Spencer Beach Park site would facilitate interpretation of both datasets.

2. Characterize coastal circulation in Pelekane Bay and offshore to determine both the residence time of pollutants delivered to the bay, and the potential for contaminant inputs from the small boat harbor and from the deep-draft harbor.

3. Characterize surface water quality in Pelekane Bay at a nearshore site off of the mouth of Makeahua Stream and at at least one and preferably more offshore sites along an onshore-offshore water-quality (e.g., turbidity, salinity) gradient. Sampling should be coordinated with sampling for item 1 above to facilitate data interpretation. Baseline data on water quality in offshore waters that are relatively unaffected by brackish water inputs also should be obtained to provide an appropriate context for interpretation of the effects of groundwater inputs on nearshore waters.

4. Conduct long-term monitoring of water quality at a nearshore site in Pelekane Bay off of the mouth of Makeahua Stream. Monitoring should be coordinated with DOH monitoring at their Spencer Beach Park site to allow comparison of water quality between the sites, and with monitoring of water quality in the anchialine/estuarine portion of Makeahua Stream, to support characterization of the interaction between groundwater discharges and transformation in the lower reaches of the stream and nearshore water quality and ecosystems function. Monitoring should include bacterial indicators in addition to basic water quality parameters. Monitoring also should include event-based sampling following storm-runoff inputs to assess stormwater impacts on coastal waters and the timescales of recovery following storm events.

E.2.a.ii. Biological resources

Anchialine pools and associated wetlands

1. Map, describe, and document the biological status of the anchialine pools in the site.

2. Inventory wetland areas to document habitat and plant species. Consider using the Hawaiʻi-specific wetland classification system currently being developed through the State of Hawaiʻi Department of Land and Natural Resources.

3. Characterize ecosystem structure and function in the anchialine pool in Makeahua Stream to evaluate the impacts of changing groundwater inputs and seasonal flushing by freshwater, and seasonal removal and restoration of the sand berm at the mouth of Makeahua Stream, and of alien species in the pools (if present). If appropriate, include an assessment of the feasibility and benefits of removing alien species from one or both pools.

4. Conduct long-term monitoring of anchialine biota and ecosystem status in the Makeahua Stream pool, including rare and endangered species as appropriate. Monitoring is needed both to support assessment of basic ecosystem function and to determine the long-term effects of any restoration efforts, including early warning of any new alien species introductions. Anchialine pools in the site may be important biogeographically and may provide habitat for rare and endangered species. Monitoring should be designed based on the results of item 1 and 2 above and the results of studies characterizing pool response to groundwater dynamics and seasonal flushing by freshwater, and seasonal removal and restoration of the sand berm at the mouth of Makeahua Stream.

5. Assess the feasibility and benefits of eradicating alien plants from site wetlands. An alien pickleweed (*Batis maritima*) previously was eradicated from wetland areas around the pool in Makeahua Stream, but other alien species may be impacting wetland function. Wetlands are rare in west Hawaiʻi and PUHE's wetlands provide potentially important habitat for native species, including some rare and candidate endangered species. PUHE's wetlands also provide a unique opportunity for educating visitors on the importance of wetlands in the west Hawaiʻi ecosystem and their role in Hawaiian culture.

Intertidal areas

1. Perform a quantitative survey of biological resources in rocky intertidal zones in the site. Only one significant intertidal survey has been performed in the site (in 1976 - Cheney et al. 1977), and quantitative methods were not used so baseline data are not available to assess the current status of intertidal resources, or to assess future trends in resource condition. Some data on algal species and abundance should be forthcoming from a rapid assessment project that conducted initial fieldwork in November and December of 2005, with additional fieldwork scheduled for summer 2006 (C. Squair, project manager, UH Manoa, pers. comm. 2006).

Coastal waters

1. Establish a long-term monitoring program on permanent transects to assess benthic community structure and condition. Monitoring should be designed to detect long-term changes in ecosystem health, including potential effects of development and recreation in the area (e.g., effects of boating and diving, introduction of alien species and coral bleaching and disease), and of any remediation efforts directed at removing sediment in Pelekane Bay or reducing sediment inputs from the watershed. The number and location of transects and the monitoring interval an methods should be determined in consultation with soft-bottom and coral reef ecologists familiar with Hawaiian ecosystems, but should use transect locations used by previous investigators where possible. Monitoring should be designed to provide data compatible with data being collected by the WHAP and CRAMP programs at nearby sites.

2. Use the results of the studies above to develop an integrated assessment of ecosystem function in Pelekane Bay and the costs and benefits of removing accumulated sediments from the bay and of reducing new sediment inputs to the bay.

3. Consider performing an initial assessment of sea turtle numbers, size, and condition in waters adjacent to the site. The study should be complementary to ongoing work in KAHO and to other monitoring in west Hawaiʻi being conducted by NMFS. If appropriate, this assessment could be coordinated with a planned herpetological inventory of west Hawaiʻi parks (F. Klasner, Ecologist, NPS Pacific Islands Area Network Inventory and Monitoring Program, pers. comm. 2006).

4. Consider performing an assessment of shark populations and activity in nearshore waters in Pelekane Bay. Such a study would complement efforts to understand ecosystem processes in the bay, basic shark biology, and shark behavior, and would fit well with the historical presence and cultural implications of Hale o Kapuni heiau. The study should be developed in conjunction with the water quality and ecosystem studies recommended above, and in consultation with shark biologists and community ecologists.

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

1. Obtain quantitative or at least semi-quantitative data on recreational fishing catch and effort in waters adjacent to the site, including intertidal areas.

2. Obtain quantitative or at least semi-quantitative data on recreational snorkeling and SCUBA activity in and around the site.

3. Characterize boating activity in Pelekane Bay and boating traffic to and from the small-boat harbor offshore of PUHE.

4. Consider performing a preliminary assessment of underwater noise pollution in coastal waters adjacent to the site and the potential for impacts to biological resources.

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

1. If justified by studies above, pursue options to reduce the existing sediment inventory in Pelekane Bay and/or to reduce sediments delivered to the bay during high runoff events.
2. If justified by studies above, remove alien fish from anchialine pools.
3. If determined to be feasible and beneficial, eradicate invasive wetland plants from around the anchialine pool in Makeahua Stream.
4. Perform regular monitoring for invasive algae in intertidal and subtidal areas around the site.
5. If appropriate, increase public education regarding fishing regulations in and around the site
6. Collaborate with researchers working in the site to maximize the relevance of ongoing and planned studies to site needs for basic, robust data on water quality and aquatic biological resources in the site.
7. Expand site interpretive materials to include information on site water resources and their vulnerability to development in and around the site. Include information on culturally significant coastal water resources, such as brackish springs (both for their use as water sources and for the putative healing properties of high-temperature springs in the area) and salt pans and fish ponds that were present in the area prior to harbor construction (Greene 1993).
8. Coordinate with appropriate State agencies to provide informational materials to boaters using the small-boat harbor to minimize pollutant releases and impacts to coastal water resources.

9. Collaborate with the State of Hawaiʻi and others to enhance the level of resource protection and conservation of adjacent and upslope lands, and of coastal waters, including Pelekane Bay.

LITERATURE CITED

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

Armstrong, R. W., Ed. (1983). Atlas of Hawaii. Honolulu, University of Hawaii Press.

Beets, J., E. Brown and A. Friedlander (in review). Inventory of marine vertebrate species and fish-habitat utilization patterns in coastal waters off four National Parks in Hawai'i, National Park Service Inventory and Monitoring Program.

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.

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.

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.

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.

Cheney, D. P., D. E. Hemmes and R. Nolan (1977). The physiography and marine fauna of inshore and intertidal areas in the Puukohola Heiau National Historical Site, Cooperative National Park Resource Studies Unit.

Daniel, R. and D. Minton (2004). Marine Report, National Park Service**:** 127.

Davidson, K., M. Hamnett and C. Minato (2005). Hawaii Coral Reef Initiative Research Program: West Hawaii Projects, Social Science Research Institute, University of Hawaii**:** 12.

Department of Health (2003). Non potable water chemistry report. Honolulu, State of Hawaii Department of Health.

Department of Health (2004). Hawaii administrative rules: Water quality standards. Honolulu, State of Hawaii Department of Health**:** 61.

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

DeVerse, K. and E. DiDonato (2004). Draft Water Quality Report, National Park Service**:** 69.

DeVerse, K. and E. DiDonato (2005). Water Quality Report, Inventory and Monitoring Program Pacific Island Network Monitoring Plan**:** 104.

Dollar, S. and C. Andrews (1997). Algal blooms off West Maui: Assessing causal linkages between land and the coastal 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.

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, National Park Service**:** 15.

Fischer, W., D. A. Davis and T. M. Sousa (1966). Fresh-water springs of Hawaii from infrared images. Washington D.C., U.S. Geological Survey.

Foote, D. (2005). Inventory of anchialine pools in Hawaii's National Parks., U.S. Geological Survey.

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

Haight, P. (1998). Sediment management plan: Pelekane watershed, Island of Hawaii, prepared for Mauna Kea Soil and Water Conservation District.

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**:** 24.

Harbors Division, D. (1985). Development of Kawaihae small boat harbor, Kawaihae, Hawaii, Hawaii, State of Hawaii**:** 96.

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.

Hoover, J. P. (1993). Hawaii's fishes: A guide for snorkelers, divers and aquarists. Honolulu, Hawaii, Mutual Publishing.

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

Kanayama, R. K. and P. Y. Kawamoto (1970). Project Tugboat - fish and wildlife studies. Honolulu, HI, Division of Fish and Game, State of Hawaii Department of Land and Natural Resources**:** 41 p.

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 pCO2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment." Journal of Geophysical Research **110**(C09S07).

Leideman, M. (2005). Ferry deal gives state $2.3M a year. Honolulu Advertiser. Honolulu.

Maciolek, J. A. and R. E. Brock (1974). Aquatic survey of the Kona coast ponds 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.

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

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.

National Park Service (1999). Baseline water quality data inventory and analysis: Puuhonua o Honaunau National Historical Park, United States Department of the Interior, National Park Service, Water Resources Division.

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.

National Park Service (2001). Baseline water quality data inventory and analysis: Puukohola Heiau National Historic Site, United States Department of the Interior, National Park Service, Water Resources Division.

Naughton, J. and P. L. Jokiel (2001). Coral reef mitigation and restoration techniques employed in the Pacific Islands: I. Overview. Oceans 2001 MTS/IEEE Proceedings, Escondido, California, Holland Publications.

Neighbor Island Consultants (1974). Summary Report for Kawaihae water quality and current studies. Honolulu, Hawai'i, U.S. Army Engineer Division.

Oceanic Institute, students and staff (1992). Evaluation of anchialine fishponds Hele 'I Palala at Pu'uhonua O Honaunau National Historical Park, The Oceanic Institute**:** 23 pp.

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.

Pacific Geotechnical Engineers Inc. (2000). Consultation letter: Proposed septic tank and leaching field, Pu'ukohola Heiau National Historic Site. Honolulu, Hawaii.

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.

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.

Richmond, B. M., A. E. Gibbs and S. A. Cochran (in preparation 2006). Geologic Resource Evaluation, Pu'ukohola National Historic Site, Part I: Geology and coastal landforms, U.S. Geological Survey.

Ryan, S. (2003). The "clean air" layer at sea level along the Kona Coast, Mauna Loa Observatory.

Sale, R. F. and R. Dybdahl (1975). "Determinants of community structure for coral reef fishes in an experimental habitat." Ecology **56**: 1343-1355.

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.

Stewart, M. C. (2001). Sediment management plan for Pelekane Bay watershed management project, Marine and Coastal Solutions International, Inc.

Tissot, B. and L. Hallacher (2000). Diver impacts on coral reefs at Kealakekua Bay, Hawai'i.

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

Wiegner, T., J. Beets, W. Dudley, et al. (2006). A review of coastal water monitoring data for developments in west Hawai`i. Hilo, Hawaii, University of Hawaii, Hilo.

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. (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.

DeVerse, K. and E. DiDonato (2004). Draft Water Quality Report, National Park Service**:** 69.

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.

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., 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.

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.

APPENDIX B. MARINE MACROINVERTEBRATES IN PELEKANE BAY IN 1976

Marine macroinvertebrates found in waters adjacent to Pu‘ukohola Heiau National Historic Site in April – June 1976 in the biotopes shown in Figure x. Observations were made from SCUBA surveys, snorkeling, and from samples collected from patch reefs, living and dead coral heads, rubble, and coralline and fleshy algae, and from sand and mud samples sieved through a 2 mm net. From Cheney et al. 1977.

A = Abundant; always seen, many individuals encountered
C = Common; localized populations, species in which more than two individuals were observed
R = Rare; one or two sporadic specimens observed
S = Seen, but no relative abundance measure applied

Species	Biotopes					
	Rubble/silt I	Sand/mud II	Pavement/ rubble III	Coral/ rubble IV	Patch reef V	Intertidal VI
Phylum Porifera (sponges)						
Cliona vastifica	S		S	S	S	
Terpios sp.			S			
Leucetta sp.			S			
various encrusting forms	S		S	S	S	S
Phylum Cnidaria (corals and hydroids)						
Pennaria tiarella	R		R	R		
Athelia edmondsoni	R		A	C	C	
Zoanthids			S	S	S	S
Montipora verrucosa		R	A	A	A	
M. patula			R	C	C	
M. verrilli					R	
Pavona varians				R	R	
P. explanulata					R	
Leptastrea bottae			C	R	R	
L. purpurea				R	R	
Cyphastrea ocellina	R		R	R	R	
Porites compressa	R	R	C	A	A	
P. lobata		R	C	A	A	
P. (Synaraea) sp.					R	
Pocillopora damicornis	A	R	A	C	C	R
P. meandrina		R	A	A	A	
Psammocora verrilli					R	

APPENDIX B (cont.)

Species	Biotopes					
	Rubble/silt I	Sand/mud II	Pavement/ rubble III	Coral/ rubble IV	Patch reef V	Intertidal VI
Phylum Platyhelminthes (flatworms)						
Polycladida (unidentified)						S
Phylum Sipunculoidea (peanut worms)						
Sipunculus sp.						S
Phylum Echiuroidea (peanut worms)						
(unidentified)	S			S		S
Phyla Ectoprocta and Entoprocta (moss animals)						
encrusting forms			S	S	S	
erect forms	S			S		
Phylum Annelida (segmented worms)						
Nereidae (large crawling worms)	S	S	S			
Sabellariidae (sand grain tube worms)	S		S	S	S	
Terebellidae (spaghetti worms)			S	S		
Sabellidae (fan worms)	S	S	S	S	S	
Serpulidae (calcareous tube worms)	S	S	S	S	S	S
Syllidae (small crawling worms)	S		S	S		
Phylum Arthropoda						
Insecta						
Halobates sp.	S		S			
Crustacea						
Amphipoda (unidentified)	S		S	S	S	S
Isopoda						
Apseudidae	S					

APPENDIX B (cont.)

Species	Biotopes					
	Rubble/silt I	Sand/mud II	Pavement/ rubble III	Coral/ rubble IV	Patch reef V	Intertidal VI
Arthropoda/Crustacea (cont.)						
Decapoda						
Macrura-Natantia (shrimp, ‘opae-kai)						
*Palaemon debilis** (glass shrimp, ‘opae-huna)						
Alpheus spp. (snapping shrimp)	S		S	S		
Callianassa sp. (mud shrimp)	S	S				
Anomura (hermit crabs, papa’i-iwi-pupu)						
Calcinus laevimanus	S					
C. elegans	S					
Clibanarus zebra			S			S
Brachyura (crabs)						
Hapalocarcinus marsupialus	S	S	S	S	S	S
Calappa hepatica (box crab)	S					
Portunus sanguinolentus	S					
Thalamita edwardsi	S					
Trapezia intermedia	S					
Phymodius ungulatus	S					
Zoozymodes biunguis	S					
Xanthodius biunguis	S					
Xantho crassimanus				S		S
Pseudozius caystrus						S
Chlorodopsis niger				S	S	
Carpilodes sp.					S	
Xanthid (misc. sp.)	S		S	S	S	S
Grapsus grapsus (Rock crab, ‘a’ama)						S
Metapograpsus messor	S					S
Perinea tumida	S					
Ocypode ceratophthalmus (ghost crab)						S

*found in brackish ponds (biotope VII) only.

APPENDIX B (cont.)

Species	Biotopes					
	Rubble/silt I	Sand/mud II	Pavement/ rubble III	Coral/ rubble IV	Patch reef V	Intertidal VI
Arthropoda/Crustacea						
Stomatopoda (mantis shrimp)						
Squilla. sp.	S					
Phylum Echinodermata						
Asteroidea (starfish)						
Asterope carinifera					S	
Ophiuroidea (brittle stars)						
Ophicoma erinaceus			S	S		S
O. brevipes			S			
Echinoidea (sea urchins)						
Echinothrix calamaris (wana)			R	C	C	
E. diadema (wana)	R		A	A	C	
Tripneustes gratilla (hawa'e)	R	R	C	C	C	
Astropyga radiata	S					
Echinometra mathaei ('ina-uli)	C		A	A	A	C
E. oblonga ('ina-uli)			C	R	R	A
Heterocentrotus mammilatus ('ina-'ula, slate pencil urchin)			R	C	R	
Holothuroidea (sea cucumbers, loli)						
Actinopyga mauritiana or *obesa*			S			S
Holothuria atra	S	S	S	S	S	
H. arenicola	S					S
H. impatiens						S
Phylum Chordata						
Tunicata (sea squirts) (unidentified forms)			S	S	S	S

APPENDIX B (cont.)

Species	Biotopes	
	Littoral I,III, VI	Offshore II, IV, V
Phylum Mollusca		
Amphineura (chitons)		
Ischnochiton petaloides	R	R
Gastropoda (snails)		
Littorina scabra (periwinkle)	A	
L. pintado (speckled periwinkle)	C	
Nerita polita (kupe'e, polished nerite)	R	
N. picea (pipipi, neglected nerite)	A	
Cellana sandwichensis ('opihi, limpet)	C	
Purpura harpa (dye harp)	C	
Siphonaria normalis (normal siphon)	C	
Morula uva	C	
Conus abbreviatus (abbreviated cone)	R	
C. ebraeus (Hebrew cone)	C	
C. flavidus (golden-yellow cone)		C
C. pulicarius (flea cone)		C
C. quercinus (oak cone)		R
C. sponsalis (Ceylon cone)	C	
Strombus maculatus (spotted stromb, pupu-mamaiki)	crabbed	
Trochus intextus (top shell, pupu-o-Ha'upu)	C	
Cypraea maculifera (reticulated cowry, leho-kolea)	R	
Maculotriton serriale	crabbed	
Nassarius reeveanus	crabbed	
Peristernia chlorostoma	crabbed	
Peristernia sp.	crabbed	
Terebra crenulata (crenulated auger)	R	
Hipponix pilosus (hoof shell)	A	C
H. foliatus (hoof shell)	S	
Notarchus lineolatus (sea hare)	S	
Nudibranch spp. (sea slugs)	S	S
Vermetid spp. (calcareous tube snails)	A	A
Bivalvia (clams and mussels)		
Brachidontes cerebristriatus (mussel)	A	A
Isognomon incisum (mussel)	C	
I. costellatum (mussel)	S	
Quidnipagus palatum (tellin)	C	
Periglypta reticulata (cockle)	C	

APPENDIX C. FISH SPECIES FOUND OFF OF PELEKANE BAY IN 1969 - 1970

Fish observed in waters offshore of Pu‘ukohola Heiau National Historic Site in September 1969 – May 1970. Fish counts were performed along transects shown in Figure x; species collected after detonations refer to fish collected at the sea surface after underwater detonations used to excavate the small-boat harbor basin. From Kanayama and Kawamoto 1970.

	Fish Counts				After Detonations	
FAMILY, *Species*	Sep 69	Nov 69	Apr 70	Jun 70	Nov 69	Apr-May 70
MYLIOBATIDAE (eagle ray)						
1. *Aetobatus narinari*	X	-	-	-	-	-
MURAENlDAE (moray eels)						
1. *Echidna nebulosa*	-	-	-	-	X	-
2. *Gymnothorax meleagris*	-	X	-	-	-	-
3. *G. eurostus*	-	-	-	-	-	X
4. *G. undulatus*	-	-	-	-	-	X
CONGRIDAE (white eels)						
1. *Conger marginatus*	-	-	-	-	X	-
FISTULARIIDAE (cornet fishes)						
1. *Fistularia petimba*	X	-	-	-	-	-
AULOSTOMIDAE (trumpet fishes)						
1. *Aulostomus chinensis*	X	X	-	-	-	-
HOLOCENTRIDAE (squirrelfishes)						
1. *Holocentrus spinifer*	-	-	X	-	-	X
2. *H. lacteoguttatus*	-	-	-	-	-	X
3. *H. diadema*	-	-	-	-	X	X
4. *Holotrachys lima*	-	-	-	-	-	X
5. *Myripristis multiradiatus*	-	-	-	X	X	X
6. *M. berndti*	-	-	X	-	-	X
MUGILIDAE (gray mullets)						
1. *Mugil cephalus*	-	-	-	-	-	X
POLYNEMIDAE (threadflns)						
1. *Polydactylus sexfilis*	X*	-	-	-	X	-
SERRANIDAE (groupers)						
1. *Ypsigramma* sp.	-	-	-	-	-	X
PSEUDOCHROMIDAE						
1. *Pseudogramma polyacantha*	-	-	-	-	-	X
KUHLIIDAE (aholeholes)						
1. *Kuhlia sandvicensis*	-	-	-	-	X	X
PRIACANTHIDAE (aweoweos)						
1. *Priacanthus cruentatus*	-	-	-	-	-	X
APOGONIDAE (cardinal fishes)						
1. *Apogon brachygrammus*	-	-	-	-	X	-
2. *A. snyderi*	-	-	-	-	X	X
3. *A. menesemus*	-	-	-	-	-	X

* caught in gill net

APPENDIX C (cont.)

	Fish Counts				After Detonations	
FAMILY, *Species*	Sep 69	Nov 69	Apr 70	Jun 70	Nov 69	Apr-May 70
CARANGIDAE (jack crevally)						
1. *Seriola dumerilii*	-	-	-	-	X	-
2. *Decapterus pinnulatus*	X	-	-	-	-	-
3. *Carangoides ajax*	-	-	-	-	X	-
4. *Caranx lugubris*	-	-	-	-	-	X
5. *C. sexfasciatus*	-	-	-	-	X	-
6. *Trachurops crumenophthalmus*	X*	-	-	-	-	-
LUTJANIDAE (snappers)						
1. *Lutjanus vaigiensis*	-	-	-	-	X	-
MULLIDAE (goat fishes)						
1. *Upeneus arge*	-	-	-	-	X	-
2. *Mulloidichthys samoensis*	X	X	X	X	X	X
3. *M. auriflamma*	X	X	-	-	-	-
4. *Parupeneus chryserydros*	X	X	-	X	-	-
5. *P. porphyreus*	X	X	-	X	-	X
6. *P. multifasciatus*	X	X	X	X	-	-
7. *P. pleurostigma*	-	-	-	X	-	-
CHAETODONTIDAE (butterfly fishes)						
1. *Centropyge potteri*	-	-	-	-	-	X
2. *Forcipiger longirostris*	X	X	-	X	-	-
3. *Chaetodon fremblii*	X	X	-	-	-	-
4. *C. auriga*	X	X	-	-	X	X
5. *C. unimaculatus*	X	X	-	X	X	X
6. *C. lunula*	X	X	X	X	X	X
7. *C. trifasciatus*	X	X	X	X	X	X
8. *C. ornatissimus*	X	X	X	X	X	X
9. *C. quadrimaculatus*	-	X	-	-	-	-
10. *C. multicinctus*	X	X	-	X	-	X
ll. *C. miliaris*	X	-	-	-	X	X
CIRRHITIDAE (hawkfishes)						
1. *Paracirrhites arcatus*	X	-	-	-	-	-
2. *P. forsteri*	X	-	-	X	-	-
3. *P. cinctus*	X	-	X	-	-	-
POMACENTRIDAE (damselfishes)						
1. *Dascyllus albisella*	X	-	-	X	-	X
2. *Abudefduf abdominalis*	X	X	X	X	-	X
3. *Plectroglyphidodon johnstonianus*	X	X	X	-	-	X
4. *Pomacentrus jenkensi*	X	X	X	X	-	X
5. *Chromis ovalis*	X	X	X	X	-	X
6. *C. leucurus*	X	X	X	X	-	X

* caught in gill net

APPENDIX C (cont.)

	Fish Counts				After Detonations	
FAMILY, *Species*	Sep 69	Nov 69	Apr 70	Jun 70	Nov 69	Apr-May 70
LABRIDAE (wrasses)						
1. *Bodianus bilunulatus*	-	-	-	-	-	X
2. *Labroides phthirophagus*	X	X	X	X	-	-
3. *Cheilinus rhodochrous*	X	X	X	X	X	X
4. *Thalassoma duperreyi*	X	X	X	X	-	-
5. *T. ballieui*	X	X	X	X	-	-
6. *Gomphosus varius*	X	X	X	X	-	-
7. *Coris flavovittata*	X	-	-	-	-	-
8. *C. gaimardi*	X	-	-	X	-	-
9. *Stehojulis axillaris*	X	X	-	-	-	-
10. *S. albovittata*	X	X	-	-	-	-
11. *Novaculichthys taeniourus*	X	-	-	-	-	-
12. *Anampses cuvieri*	X	-	-	-	-	-
SCARIDAE (parrotfishes)						
1. *Calotomus sandvicensis*	-	X	X	X	-	-
2. *Scarus dubius*	X	X	X	X	-	X
3. *S. perspicillatus*	X	X	X	-	-	X
4. *S. sordidus*	X	-	-	X	-	X
ZANCLIDAE (moorish idol)						
1. *Zanclus canescens*	X	X	X	X	-	-
ACANTHURIDAE (surgeonfishes)						
1. *Acanthurus sandvicensis*	X	X	X	X	X	X
2. *A. achilles*	X	X	-	X	-	-
3. *A. leucopareius*	X	X	-	X	-	X
4. *A. nigrofuscus*	X	X	X	X	X	X
5. *A. nigroris*	X	X	X	X	-	-
6. *A. olivaceus*	-	-	-	-	-	X
7. *A. dussumieri*	X	-	-	-	-	X
8. *A. xanthopterus*	X	X	-	-	X	X
9. *A. mata*	-	X	X	X	X	X
10. *Ctenochaetus strigosus*	X	X	X	X	-	-
11. *Zebrasoma flavescens*	X	X	X	-	-	-
12. *Z. veliferum*	X	X	X	X	-	-
13. *Naso lituratus*	X	X	X	X	-	X
14. *N. hexacanthus*	X	-	-	-	-	-
15. *N. unicornis*	-	-	-	-	X	X
ELEOTRIDAE						
1. *Asterropteryx semipunctatus*	-	-	-	-	X	-
BLENNIIDAE (blennies)						
1. *Exallias brevis*	X	X	X	X	-	X
2. *Cirripectus obscurus*	X	X	X	X	-	-
BROTULIDAE						
1. *Brotula multibarbata*	-	-	-	-	-	X
SCORPAENIDAE (scorpion fishes)						
1. *Dendrochirus brachypterus*	-	-	-	-	-	X
2. *Scorpaenodes guamensis*	-	-	-	-	-	X

APPENDIX C (cont.)

	Fish Counts				After Detonations	
FAMILY, *Species*	Sep 69	Nov 69	Apr 70	Jun 70	Nov 69	Apr-May 70
BALISTIDAE (triggerfishes)						
1. *Xanthichthys ringens*	-	X	-	-	-	-
2. *Rhinecanthus rectangulus*	X	X	X	X	-	X
3. *Melichthys buniva*	X	X	X	X	-	X
4. *M. vidua*	X	-	-	-	-	-
5. *Balistes bursa*	-	-	-	-	-	X
MONACANTHIDAE (filefishes)						
1. *Pervagor spilosoma*	-	-	-	X	-	X
2. *P. melanocephalus*	-	-	-	-	-	X
3. *Amanses carolae*	X	X	-	-	-	X
4. *A. sandwichiensis*	-	-	-	-	-	X
OSTRACIONTIDAE (boxfishes)						
1. *Ostracion lentiginosus*	X	X	-	-	X	X
TETRAODONTIDAE (puffers)						
1. *Arothron meleagris*	X	-	-	-	X	X
2. *A. hispidus*	-	-	-	-	X	X
CANTHIGASTERIDAE (sharpbacked puffers)						
1. *Canthigaster jactator*	X	X	X	-	-	X
DIODONTIDAE (spiny puffers)						
1. *Diodon hystrix*	-	X	-	X	X	X
ANTENNARIIDAE (frogfishes)						
1. *Abantennarius analis*	-	-	-	-	-	X
2. *Antennarius drombus*	-	-	-	-	-	X
TOTAL NUMBER OF SPECIES	65	52	35	43	31	64

APPENDIX D. FISH SPECIES OBSERVED IN AND ADJACENT TO PUHE IN 1976

Fish species observed in the waters in and adjacent to Pu‘ukohola Heiau National Historic Site in April – June 1976. Biotopes surveyed are shown in Figure 12. Observations of offshore species were made during six hours of SCUBA surveys. Species in intertidal and anchialine pond habitats were collected for identification using hand nets and “mini spears”. Species names are those used by Cheney et al. (1977); where current names differ they are shown in parentheses. From Cheney et al. 1977.

R = Rare; one or two sporadic individuals seen during surveys
C = Common; more than two individuals were observed
A = Abundant; many individuals were encountered
+ = Adults
- = Juveniles
±= Adults and juveniles

	Biotopes				
	Littoral		Offshore		Pond
Species	I, III	VI	II	IV, V	VII
Carcharhinidae (requiem sharks, mano)					
Carcharhinus menisorrah (grey reef shark)	C+		C+		
C. melanopterus (blacktip shark)	C+		C+		
Triakidae (leopard sharks, mano)					
Triaenodon obesus (whitetip shark)	C+		C+	C+	
Myliobatidae (eagle rays)					
Aetobatus narinari	R+				
Muraenidae (moray eels, puhi)					
Gymnothorax eurostus		R+			
Echidna nebulosa		R+			
Gobiidae (gobies, ‘o’opu)					
Bathygobius fuscus		C±			
Blenniidae (blennies)					
Istiblennius zebra (pao’o)		A±			
Exallias brevis (pao’o kauila)				C+	
Eleotridae (‘o’opu)					
Asterropteryx semipunctatus	C+	C+			
Kuhliidae (aholehole)					
Kuhlia sandvicensis		A±			
Mugilidae (mullets, ‘ama’ama)					
Mugil cephalus	A±	A-	A+		
Holocentridae (squirrelfishes)					
Adioryx lacteoguttatus (‘ala’ihi)		R-			
Cichlidae					
Tilapia mossambica					A±
T. macrochir					A±

APPENDIX D (cont.)

	Biotopes				
	Littoral		Offshore		Pond
Species	I, III	VI	II	IV, V	VII
Mullidae (goatfishes)					
Mulloidichthys auriflamma (*M. flavolineatus*) (weke-‘ula)			A+	R+	
Parupeneus porphyreus (kumu)			R+		
P. pleurostigma (malu)			C+		
P. multifasciatus (moano)			A±		
Lutjanidae (snappers)					
Lutianus vaigiensis (*Lutjanus fulvus*)			C+		
Labridae (wrasses, hinalea)					
Thalassoma lutescens				R+	
T. duperreyi (hinalea lau-wili)				A±	
Gomphosus varius (‘aki-lolo)				A±	
Coris gaimardi (hinalea-lolo)				C+	
Labroides phthirophagus (cleaner wrasse)				C±	
Halichoeres sp.				R-	
H. ornatissimus (la’o)				R±	
Stethojulis balteatus (‘omaka)				R+	
Cheilinus rhodochrous (*Oxycheilinus unifasciatus*) (po’ou)				C+	
Scaridae (parrotfishes, uhu)					
Scarus dubius				A±	
S. sordidus				A±	
Calotomus sandvicensis (*C. carolinus*)				C±	
Pomacentridae (damselfishes)					
Abudefduf abdominalis (maomao)		A-		A+	
Dascyllus trimaculatus	R±				
D. albisella				C±	
Pomacentrus jenkinsi (*Stegastes fasciolatus*)				A±	
Chromis ovalis				A±	
C. vanderbilti				C±	
Plectroglyphidodon johnstonianus				C±	
Chromis hanui				C±	
Zanclidae (moorish idol, kihikihi)					
Zanclus canescens (*Z. cornutus*) (kihikihi)				R+	

APPENDIX D (cont.)

	Biotopes				
	Littoral		Offshore		Pond
Species	I, III	VI	II	IV, V	VII
Acanthuridae (surgeonfishes)					
Acanthurus triostegus (manini)				A±	
A. mata (*A. blochii*) (pualu)				A±	
A. nigrofuscus				A±	
A. nigroris (maiko)				A±	
A. olivaceus (na’ena’e)				C±	
Ctenochaetus strigosus (kole)				A±	
Zebrasoma veliferum				R+	
Chaetodontidae (butterfly fishes)					
Chaetodon trifasciatus				A±	
C. unimaculatus (one-spot butterfly fish)				A+	
C. miliaris (lemon butterfly fish)				R+	
C. ornatissimus (ornated butterfly fish)				C+	
C. auriga				C+	
Monacanthidae (filefishes)					
Pervagor spilosoma (‘o’ili-‘uwi’uwi)				R+	
Canthigasteridae (sharpbacked puffers)					
Canthigaster jactator				R+	
Tetraodontidae (puffers, balloonfishes)					
Arothron meleagris				R+	
A. hispidus (‘o’opu-hue)				R+	
Diodontidae (porcupine fishes, spiny puffers)					
Diodon hystrix (‘o’opu-kawa)				R+	
Ostraciontidae (boxfishes)					
Ostracion lentiginosus (*O. meleagris*) (moa)				R+	

APPENDIX E. FISH SPECIES AND ABUNDANCE ON REEF TRANSECTS IN 1976

Fish species observed in three replicate quantitative surveys along two transects in biotope V off of Puʻukohola Heiau National Historic Site (Figure 12) in April 1976. Species and abundance data from Table 4 in Cheney et al. 1977 ; transect means and overall means (#/transect) are recalculated from original data and differ slightly from values reported in Cheney et al. 1977. Species names are those used by Cheney et al. (1977); where current names differ they are shown in parentheses. A = 4/2/1976 morning survey, B = 4/10/1976 morning survey, C = 4/10/1976 afternoon survey.

	Inner Transect (Line 1)				Outer Transect (Line 2)				Overall Mean
Species	A	B	C	Mean	A	B	C	Mean	
Mulloidichthys samoensis (*M. flavolineatus*)	0	0	0	0.00	97	84	4	61.67	30.83
Chromis ovalis	14	21	37	24.00	20	42	42	34.67	29.33
Scarus sordidus	2	11	5	6.00	44	20	6	23.33	14.67
Thalassoma duperreyi	15	13	14	14.00	20	13	11	14.67	14.33
Abudefduf abdominalis	22	9	16	15.67	2	10	11	7.67	11.67
Pomacentrus jenkinsi	9	14	8	10.33	12	5	5	7.33	8.83
Ctenochaetus strigosus	4	1	5	3.33	9	9	11	9.67	6.50
Acanthurus nigrofuscus	0	0	0	0.00	9	3	9	7.00	3.50
Gomphosus varius	2	2	2	2.00	3	3	7	4.33	3.17
Chaetodon trifasciatus	3	4	2	3.00	1	1	1	1.00	2.00
Scarus dubius	0	0	2	0.67	2	3	1	2.00	1.33
Chaetodon unimaculatus	0	0	0	0.00	4	1	0	1.67	0.83
Parupeneus multifasciatus	1	2	1	1.33	1	0	0	0.33	0.83
Thalassoma ballieui	1	0	0	0.33	3	1	0	1.33	0.83
Arothron meleagris	0	0	0	0.00	0	2	2	1.33	0.67
Chaetodon miliaris	0	0	0	0.00	0	3	0	1.00	0.50
Lutianus vaigiensis (*Lutjanus fulvus*)	0	0	0	0.00	1	2	0	1.00	0.50
Acanthurus mata	0	0	0	0.00	1	1	0	0.67	0.33
Acanthurus nigroris	0	0	0	0.00	0	0	2	0.67	0.33
Calotomus sandvicensis (*C. carolinus*)	0	0	0	0.00	2	0	0	0.67	0.33
Stethojulis balteatus	0	0	0	0.00	1	1	0	0.67	0.33
Acanthurus triostegus	0	0	1	0.33	0	0	0	0.00	0.17
Canthigaster jactator	0	0	0	0.00	1	0	0	0.33	0.17
Chaetodon multicinctus	0	0	0	0.00	1	0	0	0.33	0.17
Chaetodon ornatissimus	1	0	0	0.33	0	0	0	0.00	0.17
Chaetodon quadrimaculatus	0	0	0	0.00	1	0	0	0.33	0.17
Labrid sp.	0	0	0	0.00	0	0	1	0.33	0.17

APPENDIX E (cont.)

Species	Inner Transect (Line 1)				Outer Transect (Line 2)				Overall Mean
	A	B	C	Mean	A	B	C	Mean	
Labroides phthirophagus	0	0	0	0.00	0	0	1	0.33	0.17
Naso lituratus	0	0	1	0.33	0	0	0	0.00	0.17
Ostracion lentiginosus (*O. meleagris*)	0	0	1	0.33	0	0	0	0.00	0.17
Paracirrhites arcatus	0	1	0	0.33	0	0	0	0.00	0.17
Pervagor spilosoma	0	0	0	0.00	1	0	0	0.33	0.17
Plectroglyphidodon johnstonianus	1	0	0	0.33	0	0	0	0.00	0.17
Scarus sp.	0	0	0	0.00	0	1	0	0.33	0.17
Zanclus canescens (*Z. cornutus*)	0	0	0	0.00	1	0	0	0.33	0.17
Zebrasoma veliferum	0	0	1	0.33	0	0	0	0.00	0.17

APPENDIX F. MARINE VERTEBRATES OBSERVED OFF OF PUHE, 1976 - 2005

Marine vertebrates in subtidal habitats off of PUHE, 1976 - 2005. Data are from Cheney et al. (1977), Tissot et al. (1998), and Beets et al. (in review). Areas surveyed differ between studies - in particular, Biotope I (Figure 12) was surveyed by Cheney et al. (1977) and Tissot (1998), but not by Beets et al. (2006), and Biotope I species in Cheney et al. (1977) are grouped with Biotope III species and cannot be separated to assure consistency across studies. Qualitative data thus include all results from Biotopes I – V, although no fish species were observed in Biotope I by Tissot et al. (1998). Qualitative data from Cheney et al. (1977) and Tissot (1998) include relative abundance data which are not shown here. Transect surveys by Cheney et al. (1977) and Tissot et al. (1998) all were conducted in Biotope V (but at different sites – see Figures 12 and 15). Transect surveys by Beets et al. (in review) were conducted at 9 sites including several well outside of the regions surveyed by Cheney et al. (1977) and Tissot et al. (1998) (Figure 11). Data from these surveys are separated into sites in Biotope V (16, 16A, 36 = Xsect_{V}) and others (Xsect_{other}). Subscripts in these two categories identify sites where species were observed.

	1976		**1996**		**2005**		
Family/Species	Qual	Xsect	Qual	Xsect	Qual	Xsect_{V}	Xsect_{other}
Marine Fishes							
Family Carcharhinidae							
Carcharhinus melanopterus	X		X	X	X		
blacktip reef shark							
C. menisorrah	X						
grey reef shark							
Triaenodon obesus	X						
whitetip reef shark							
Family Myliobatidae							
Aetobatus narinari	X						
spotted eagle ray							
Family Muraenidae							
Echidna nebulosa					X		
snowflake moray							
Gymnothorax flavimarginatus					X		
yellowmargin moray							
Family Congridae							
Conger cinereus					X		
mustache conger							
Family Synodontidae							
*Synodus sp.***			X	X			
unidentified							
Family Scorpaenidae							
Sebastapistes coniorta							X_{18}
speckled scorpionfish							
Family Caracanthidae							
*Caracanthus typicus**					X		
Hawaiian orbicular velvetfish							
Family Serranidae							
Cephalopholis argus					X		
peacock grouper							

Appendix F (cont.). Marine vertebrates observed off of PUHE, 1976 - 2005.

	1976		1996		2005		
Family/Species	Qual	Xsect	Qual	Xsect	Qual	Xsect$_{V}$	Xsect$_{other}$
Family Kuhliidae							
*Kuhlia sandvicensis**			X				
Hawaiian flagtail							
Family Cirrhitidae							
Paracirrhites arcatus		X	X(1)	X			
arc-eye hawkfish							
Family Apogonidae							
*Apogon sp.***			X	X			
unidentified							
Family Lutjanidae							
Lutjanus fulvus	X(2)	X(2)	X(3)	X(3)		X_{16}	$X_{2A,40}$
blacktail snapper							
Family Mugilidae							
Mugil cephalus	X		X		X		
striped mullet							
Family Mullidae							
Mulloidichthys flavolineatus	X(4)	X(5)	X	X		X_{16}	
yellowstripe goatfish							
M. vanicolensis			X	X			
yellowfin goatfish							
Parupeneus insularis (3)			X(1)(6)	X(6)	X		
doublebar goatfish							
P. cyclostomus			X	X			
blue goatfish							
P. multifasciatus	X	X	X	X		X_{16}	X_{18}
manybar goatfish							
P. pleurostigma	X						
sidespot goatfish							
*P. porphyreus**	X						
whitesaddle goatfish							
Family Chaetodontidae							
Chaetodon auriga	X		X	X			X_{40}
threadfin butterflyfish							
C. lunula			X	X	X		
raccoon butterflyfish							
C. lunulatus					X		
oval butterflyfish							
*C. miliaris**	X	X	X(1)	X			
milletseed butterflyfish							
*C. multicinctus**		X	X(1)	X			
multiband butterflyfish							
C. ornatissimus	X	X	X	X		X_{16A}	
ornate butterflyfish							
C. quadrimaculatus		X	X(1)	X			X_{18}
fourspot butterflyfish							
C. trifasciatus	X	X	X(1)	X			
melon butterflyfish							

Appendix F (cont.). Marine vertebrates observed off of PUHE, 1976 - 2005.

Family/Species	**1976**		**1996**		**2005**		
	Qual	Xsect	Qual	Xsect	Qual	Xsect$_{V}$	Xsect$_{other}$
Family Chaetodontidae (cont.)							
C. unimaculatus	X	X	X	X	X		
teardrop butterflyfish							
Family Pomacentridae							
*Abudefduf abdominalis**	X	X	X(1)	X		X_{36}	
Hawaiian sergeant							
A. sordidus					X		
blackspot sergeant							
A. vaigiensis					X		
Indo-Pacific sergeant							
*C. hanui**	X		X	X			
chocolate-dip chromis							
*C. ovalis**	X	X	X(1)	X	X		
oval chromis							
C. vanderbilti	X				X		
blackfin chromis							
*Dascyllus albisella**	X		X(1)	X	X		
Hawaiian dascyllus							
D. trimaculatus	X						
domino damselfish							
Plectroglyphidodon imparipennis			X	X	X		
brighteye damselfish							
P. johnstonianus	X	X	X	X			
blue-eye damselfish							
Stegastes fasciolatus	X(7)	X(7)	X	X		X_{16A}	X_{18}
Pacific gregory							
Family Labridae							
*Coris flavovittata**			X(1)	X			
yellowstriped coris							
C. gaimard	X		X	X			
yellowtail coris							
*C. venusta**					X		
elegant coris							
Coris spp.**				X			
wrasse							
Gomphosus varius	X	X	X	X		$X_{16A,36}$	X_{18}
bird wrasse							
Halichoeres ornatissimus	X		X	X			
ornate wrasse							
H. sp.**	X						
unidentified							
*Labroides phthirophagus**	X	X	X(1)	X		X_{16A}	
Hawaiian cleaner wrasse							
Oxycheilinus unifasciatus	X(8)				X		
ringtail wrasse							

Appendix F (cont.). Marine vertebrates observed off of PUHE, 1976 - 2005.

	1976		**1996**		**2005**		
Family/Species	Qual	Xsect	Qual	Xsect	Qual	Xsect_{V}	$\text{Xsect}_{\text{other}}$
Family Labridae (cont.)							
*Stethojulis balteata**	X	X	X(1)	X		X_{16A}	X_{18}
belted wrasse							
*Thalassoma ballieui**		X	X	X			X_{18}
blacktail wrasse							
*T. duperrey**	X	X	X	X		$X_{16,36}$	$X_{1A,18}$
saddle wrasse							
T. lutescens	X						
sunset wrasse							
Labrid sp.**		X	X(1)	X			
wrasse							
Family Scaridae							
Calotomus carolinus	X(9)	X(9)	X(1)(9)	X(9)			
stareye parrotfish							
*Chlorurus perspicillatus**					X		
spectacled parrotfish							
C. sordidus	X(10)	X(10)	X(1)	X		$X_{16,16A,36}$	X_{18}
bullethead parrotfish							
*Scarus dubius**	X	X	X(1)	X			
regal parrotfish							
S. psittacus						X_{16A}	X_{18}
palenose parrotfish							
S. rubroviolaceus							X_{18}
redlip parrotfish							
*S. sp.***		X				$X_{16A,36}$	
unidentified parrotfish							
S. spp. (juveniles)**			X	X			
unidentified parrotfish							
Family Blenniidae							
Exallias brevis	X						
shortbodied blenny							
Family Gobiidae							
Asteropteryx semipunctatus	X						$X_{1A,40}$
halfspotted goby							
Coryphopterus sp.							X_{1A}
Hawaiian sand goby							
*Psilogobius mainlandi**							$X_{1A,35,41}$
Hawaiian shrimp goby							
Family Zanclidae							
Zanclus cornutus	X(11)	X(11)	X(1)(12)	X(11)			
Moorish idol							
Family Acanthuridae							
Acanthurus achilles					X		
Achilles tang							
A. blochii	X(13)	X(13)	X	X		$X_{16,36}$	X_{40}
ringtail surgeonfish							

Appendix F (cont.). Marine vertebrates observed off of PUHE, 1976 - 2005.

	1976		**1996**		**2005**		
Family/Species	Qual	Xsect	Qual	Xsect	Qual	Xsect_V	$\text{Xsect}_{\text{other}}$
Family Acanthuridae (cont.)							
Acanthurus dussumieri					X		
eyestripe surgeonfish							
A. leucopareius			X	X			
whitebar surgeonfish							
A. nigrofuscus	X	X	X	X		$X_{16,16A,36}$	X_{18}
brown surgeonfish							
A. nigroris	X	X	X	X	X		
bluelined surgeonfish							
A. olivaceus	X				X		
orangeband surgeonfish							
A. triostegus	X	X	X	X		X_{36}	$X_{18,40}$
convict surgeonfish							
A. xanthopterus					X		
yellowfin surgeonfish							
C. strigosus	X	X	X	X		X_{16A}	X_{18}
goldring surgeonfish							
Naso lituratus		X	X(1)	X	X		
orangespine unicornfish							
Zebrasoma veliferum	X	X	X(1)	X			
sailfin tang							
Family Balistidae							
Melichthys niger							X_{18}
black durgon							
R. rectangulus							X_{18}
reef triggerfish							
*Pervagor spilosoma**	X	X	X(1)	X			
yellowtail filefish							
Family Ostraciidae							
Ostracion meleagris	X(14)	X(14)	X	X			
spotted boxfish							
O. spp.**			X(1)	X			
boxfish							
Family Tetraodontidae							
Arothron hispidus	X						
stripebelly puffer							
A. meleagris	X	X	X(1)	X	X		
spotted puffer							
Canthigaster amboinensis					X		
ambon toby							
*C. jactator**	X	X	X(1)	X		X_{16}	
Hawaiian whitespotted toby							
Family Diodontidae							
Diodon holocanthus					X		
spiny balloonfish							
D. hystrix	X						
porcupinefish							

Appendix F (cont.). Marine vertebrates observed off of PUHE, 1976 - 2005.

	1976		**1996**		**2005**		
Family/Species	Qual	Xsect	Qual	Xsect	Qual	Xsect$_V$	Xsect$_{other}$
Marine Turtles							
Chelonia mydas			X				
green sea turtle							

* -endemic species
** could not be identified to species level
(1) Listed in Tissot et al. (1998) qualitative species list but no abundance code given
(2) Listed as *L. vaigiesis*
(3) Includes species noted separately as *L. vaigiesis*
(4) Listed as *M. auriflamma*
(5) Listed as *M. samoensis*
(6) Listed as *P. bifasciatus*
(7) Listed as *Pomacentrus jenkinsi*
(8) Listed as *Cheilinus rhodochrous*
(9) Listed as *C. sandvicensis*
(10) Listed as *Scarus sordidus*
(11) Listed as *Z. canescens*
(12) Includes species listed separately as *Z. canescens*
(13) Listed as *A. mata*
(14) Listed as *O. lentiginosus*

APPENDIX G. STATE OF HAWAII 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 PUHE 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 (Hawaiʻi).

(F) The following natural estuaries: Lumahaʻi and Kilauea estuaries (Kauaʻi).

(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 Hawaiʻi'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	200.00	350.00	500.00
		Dry	150.00	250.00	350.00
NH4	µg NH4-N/l	Wet	6.00	13.00	20.00
		Dry	3.50	8.50	15.00
NO3+NO2	µgNO3-N/l	Wet	8.00	20.00	35.00
		Dry	5.00	14.00	25.00
TDP	µg P/l	Wet	25.00	50.00	75.00
		Dry	20.00	40.00	60.00
Chl-a	µg/l	Wet	1.50	4.50	8.50
		Dry	0.50	1.50	3.00
Turb	ntu	Wet	1.5	3.00	5.00
		Dry	0.40	1.00	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 Hawaiian 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) Hawaiʻi: Honaunau, Kiholo

(B) Class II. Hawaiʻi: 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: Hawai‘i: Puako

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

(iv) Wave exposed reef communities: Hawai‘i (n/a)

(v) Protected reef communities: Hawai‘i: 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. [Hawai‘i: 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 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.

As the nation’s principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-46, November 2006