Chapter 3. Physical Environment

3.1 Refuge Introduction

The O‘ahu National Wildlife Refuge Complex (Complex) is located on the Island of O‘ahu, within the State of Hawai‘i. The Complex consists of James Campbell NWR, Pearl Harbor NWR, and O‘ahu Forest NWR. Management of the Complex is conducted from the Service office located in Hale‘iwa on the north shore of O‘ahu . This CCP focuses on the James Campbell NWR.

James Campbell NWR is located on the northeastern coast of O‘ahu near the community of Kahuku. As of September 2011, the Service owns 934 acres of habitat, including permanent, seasonal, and ephemeral wetlands, shrublands, coastal strand, sand dunes, and aquaculture ponds under lease from the Service. An additional 151 acres are in the process of acquisition within the approved boundary.

3.2 Climate

Located 2,400 miles southwest of the nearest continental landmass, the Hawaiian Islands are the most isolated archipelago in the world. The climate of Hawai‘i is generally constant throughout the year, with only minor periods of diurnal and seasonal variability. During the summer season (May-September), temperatures are slightly warmer, conditions are drier, and trade winds originate from the northeast. The winter season (October-April) is characterized by cooler temperatures, higher precipitation, and gustier winds. The trade winds also produce differences within the two physiographic provinces. On the windward or northeastern side of O‘ahu, climatic conditions are relatively wet and strongly influenced by patterns of orographic rainfall. The leeward areas in the southern and western portion of the island experience decreased winds, less rain, and are subject to southerly Kona storms (Juvik and Juvik 1998).

O‘ahu climate is influenced by three interacting climatic factors: (1) the Hadley cell, (2) the oceanic position of the major Hawaiian Islands, and (3) topography. The Hadley cell is a system of atmospheric circulation that is propelled by warm air rising near the equator and cool sinking air in the subtropics. In the Northern Hemisphere, air flowing within this system is reflected by the Earth’s rotation to create northeasterly winds referred to as trade winds. Wind patterns, rainfall distribution, and other climatic conditions are also affected by the geographic location of Hawai‘i (Juvik and Juvik 1998, Lau and Mink 2006).

Trade winds in Hawai‘i originate from a high-pressure system located northeast of the archipelago called the North Pacific anticyclone. During the summer season, this system is stable and trade winds occur 80-95 percent of the time (Oki 2005). This high-pressure cell further regulates Hawai‘i’s climate because it shifts seasonally, causing trade wind and precipitation differences. During the winter and spring season, the North Pacific anticyclone moves further south and weakens, causing less persistent trade winds (50-80 percent of the time) and a greater chance of storms (Lau and Mink 2006).

Furthermore, the varied topography of the island affects the climate. The alignment, shape, and height of the mountains moderate wind patterns and cause moist air to rise near the mountain ranges. Excess clouds accumulate near mountain peaks and enhance precipitation amounts, referred to as orographic rainfall (Juvik and Juvik 1998, Lau and Mink 2006). The coastal, leeward sides of the mountains receive less precipitation because the air loses moisture as it ascends the windward side (Oki 2005).

Prevailing ocean currents influence weather patterns by moderating the surrounding surface air temperatures (as a result of differential heat adsorption and advection of heat). Ocean currents around the Hawaiian Islands are moderated by the North Pacific anticyclone, a clockwise gyre that extends from the tropics to the North Pacific. The east to west flowing North Equatorial Current splits at the Island of Hawai‘i, creating a northern branch current that is 65 miles wide. Ocean surface water temperatures surrounding O‘ahu range from a mean of 75°F from February-April, to about 81°F between August-October (Juvik and Juvik 1998, Lau and Mink 2006).

Located near the community of Kahuku, the Refuge has a climate characteristic of lowland areas on the windward side of O‘ahu. Annual temperatures on the Refuge range from 68.9-80.8°F. Annual precipitation in James Campbell NWR is between 26-28 inches. Evaporation rates in the area are dependent on cloud cover and rainfall (Hunt and De Carlo 2000, DBEDT 2007).

Due to its location on the northern tip of O‘ahu, Kahuku is considered a high wind energy site. Wind speed ranges from 14.5-16.8 mph, with increasing speed on the northern portion of the Refuge. The prevailing northeasterly trade winds are present nearly 90 percent of the year in Kahuku and the southerly Kona winds are present approximately 10 percent of the year. On the northern coast of O‘ahu, the average humidity is roughly 74.6 percent, with slight seasonal variation (Group 70 Limited 1989, HECO 2004, Lau and Mink 2006).

Kahuku Wind turbines generate power adjacent to Refuge George Fisher/USFWS

3.2.1 Global Climate Changes and Projections

Global climate change is supported by a continuously growing body of unequivocal scientific evidence. The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body organized by the World Meteorological Organization and the United Nations Environment Programme in order to assess the causes, impacts, and response strategies to changes in climatic conditions. According to the Fourth Assessment Report by the IPCC, global temperatures on the Earth's surface have increased by 1.33°F over the last 100 years. This warming trend has accelerated within the last 50 years, increasing by 0.23°F each decade. Global ocean temperatures to a depth of almost 2,300 feet have also increased, rising by 0.18°F between 1961-2003 (Solomon et al. 2007).

Global forecasting models offer a variety of predictions based on different emission scenarios. The U.S. government agency Overseas Private Investment Corporation (OPIC) suggests that a further increase in greenhouse gas (GHG) emissions could double atmospheric concentrations of CO_2 by 2060 and subsequently increase temperatures by as much as 2-6.5°F over the next century. Recent model experiments by the IPCC show that if GHGs and other emissions remain at 2000 levels, a further global average temperature warming of about 0.18°F per decade is expected. Sea level rise (SLR) is expected to accelerate by two to five times the current rates due to both ocean thermal expansion and the melting of glaciers and polar ice caps. Recent modeling projects sea level to rise 0.59-1.93 feet by the end of the 21st century. These changes may lead to more severe weather, shifts in ocean circulation (currents, upwelling), as well as adverse impacts to economies and human health. The extent and ultimate impact these changes will have on Earth's environment remains under considerable debate (OPIC 2000, Buddemeier et al. 2004, Solomon et al. 2007, IPCC 2007).

3.2.2 Climate Change in Hawai‘i

Small island groups are particularly vulnerable to climate change. The following characteristics contribute to this vulnerability: (1) small emergent land area compared to the large expanses of surrounding ocean; (2) limited natural resources; high susceptibility to natural disasters; and (3) inadequate funds to mitigate impacts (IPCC 2001). Thus, Hawai‘i is considered to have a limited capacity to adapt to future climate changes. The Pacific Islands Regional Integrated Science and Assessment is working to develop programs dealing with climate risk management in the Pacific region. The Service is supporting the development of regional Landscape Conservation Cooperatives that will integrate local climate models with models of climate-change responses by species, habitats, and ecosystems. The regional version of these Landscape Conservation Cooperatives is the Pacific Islands Climate Change Cooperative (PICCC), headquartered in Honolulu, Hawai‘i, but working across the Pacific. The PICCC was established in 2010 to assist those who manage native species, island ecosystems, and key cultural resources in adapting their management to climate change for the continuing benefit of the people of the Pacific Islands. The PICCC steering committee consists of more than 25 Federal, State, private, indigenous, nongovernmental conservation organizations, and academic institutions, forming a cooperative partnership that determines the overall organizational vision, mission, and goals (IPCC 2007).

Similar to the rest of the world, temperatures in Hawai‘i are rising. The EPA has estimated that the average surface temperature in Honolulu, Hawai‘i has increased by 4.4°F over the last century. In particular, nighttime temperatures are notably warmer, increasing by about 0.5°F per decade over the past 30 years. Recent studies have shown that this rising average night temperature is greater at high

elevation sites than lower areas. Sea surface temperature near the islands has been increasing recently, showing a 0.72°F rise between 1957-1987. Sea level around the Hawaiian Islands is rising by 6-14 inches per century. Over the last 90 years, precipitation has also decreased approximately 20 percent (EPA 1998, Arakawa 2008, Giambelluca 2008).

As a result of these shifts, Hawai‘i is developing means to reduce its GHG emissions. In 1990, it is estimated that 15,985,225 tons of CO_2 were emitted in Hawai‘i. Other major GHG released that year include 75,736 tons of methane (CH_4) and 690 tons of nitrous oxide (N_2O). These estimates do not include fuels that were exported, used on international aircraft or ship operations, or used by the military in the State. International, military, and overseas CO_2 emissions were estimated to be 7,363,261 tons in 1990 (DBEDT and DOH 1999). In 2007, the State of Hawai‘i enacted Act 234, which sets the goal to reduce GHG emissions to 1990 levels by 2020.

Global and regional predictive climate simulations may not capture unique and important features of the Hawaiian climate. Existing large-scale models show large variability and uncertainty for the Hawaiian Islands; thus, applying these models to predict local conditions must be done with caution until more fine-scaled models are developed. Models from the IPCC and United Kingdom Hadley Centre’s climate model suggested that by 2100 annual temperatures in Hawai‘i could increase by 3°F, with a slightly higher increase in fall. Other estimates predict a 5-9°F rise by the end of the 21st century. Future changes in precipitation are uncertain, dependent largely on shifts in El Niño/La Niña events. Some predictions forecast an additional rise of 17-25 inches by 2100, while others suggested decreased precipitation (TenBruggencate 2007, Timm 2008).

Projected impacts that may have a significant effect on the coastal national wildlife refuges on O‘ahu are discussed below.

3.2.3 Sea Level Rise

According to the IPCC, the oceans are now absorbing more than 80 percent of the heat added to the Earth’s climate system. Since 1961, this absorption has caused average global ocean temperatures to increase and seawater to expand. Thermal expansion of the sea is the primary cause of global sea level changes. Melting ice-sheets, ice caps, and alpine glaciers also influence ocean levels. Worldwide, sea level changes have historically occurred on a small scale; however, scientific evidence suggests that the current, accelerated rate of global change began between the mid-1800s and 1900s. Similarly, sea levels in the Pacific have regularly changed over the centuries due to variations in solar radiation. Since 1800, sea levels in the Pacific region have been rising. During the last century, these levels have risen about 6 inches and this is likely to rapidly increase in the next century (Noye and Grzechnik 2001, GAO 2007).

Due to localized geographic and oceanographic variations, it is not possible to discuss SLR on a global scale. Near Pacific Island ecosystems, SLR is influenced by the rate and extent of global sea level rise, as well as changes in episodic events, such as the El Niño Southern Oscillation and storm-related conditions. Topography and exposure to normal and storm swell produce localized differences. Furthermore, it is important to note that shoreline sea levels are historically and currently influenced by isostatic tectonic changes as the islands move with the Pacific Plate, which are not due to global changes in sea level. Thus, sea level change in the Pacific is highly variable due to geologic uplift (Michener et al. 1997, Carter et al 2001).

Hawai‘i’s sea level appears to be rising at a slower rate than the global seas. Based on tide gauge records at the Honolulu Harbor, the sea level surrounding O‘ahu has risen at a rate of 0.0551 inches per year. Geological uplift contributes about 0.0016 inches per year. The University of Hawai‘i Sea Level Center has estimated that from 1905-2006 mean sea level rose about 0.0417 inches per year. Although most of this rise is due to isostatic sinking of the tectonic plate, global-warming induced SLR has the potential to intensify this rise. As of the date of this CCP, the most recent scientific models predict a SLR of approximately 1 foot by the year 2050 along the Hawaiian coastlines. In addition, although average annual rainfall totals for Hawai‘i are expected to decline due to climate change, individual severe storm events with increased local rainfall totals are expected to increase (Nakiboglu et al. 1983, Caccamise et al. 2005, Fletcher pers. comm.).

In an effort to address the potential effects of SLR on national wildlife refuges, the Service contracted the application of the Sea Level Affects Marshes Model (SLAMM) 6 for several Pacific Region refuges. This analysis is designed to assist in development of long-term management plans. The SLAMM model predictions for James Campbell NWR suggest that inland inundation within this Refuge will occur given SLR scenarios of approximately 1.6 feet (eustatic) and beyond. There are two major channels through which saline inundation will occur; Bakahan ditch at the northeast of the site and Ki‘i Outlet channel in the region of the Refuge’s pumphouse.

Model results suggest that much of the coastal dune area could become inundated in higher SLR scenarios. These inundated areas include the Kahuku Airstrip and areas south and east of the strip. Unlike the rest of the coast, inundated zones near the airstrip are not protected by high dunes. There does remain some uncertainty as to land disposition after flooding. The SLAMM assumes that land close to the ocean will convert to beach and inland regions will convert to transitional salt marshes, salt marshes, and mudflats. All of these predictions are estimated 50-100 years in the future, well beyond the scope of this CCP.

There is always uncertainty about how regularly flooded wetlands will respond to the signal of increased SLR. The most important effects of SLR at the James Campbell NWR are the gradual inundation and flooding of historic wetlands and dryland areas, as well as increases in the salinity of wetlands. Salinity alterations have the potential to shift aquatic plants and animal communities that do not tolerate high salinity. Higher sea levels may inundate these low-lying land areas, potentially helping Refuge personnel to reclaim/restore former wetland areas for endangered waterbirds.

A new study funded by the PICCC is currently underway which will produce the most up-to-date high-resolution maps depicting projected SLR impacts on James Campbell NWR. This study should be completed in 2012.

3.2.4 Climate Change Effects on Water Resources

The impact of climate change on water resources is dependent on shifts in precipitation amounts, evaporation rates, storms, and events such as the El Niño Southern Oscillation (ENSO). This is an ocean-atmosphere phenomenon in which the normal oceanic and atmospheric circulation patterns of the Pacific Ocean temporarily collapse. During normal years, strong trade winds move counterclockwise in the southern hemisphere and clockwise in the northern hemisphere, causing surface water to move westward. These winds also produce upwelling that brings high nutrient waters to the surface. During ENSO, trade winds in the western Pacific stop and the warm mass of water in the west moves eastward, causing shifts in the location of evaporation. As a result, heavy

rains occur in normally dry areas such as the central Pacific islands. In addition to more precipitation, these winds bring upwelling of warm water, which is devoid of nutrients. This causes productive communities to collapse and subsequent death of fish and birds.

While ENSO events have increased in intensity and frequency over the past decades, some longer-term records have not found a direct link to global warming and do not predict significant changes in ENSO; however, a majority of climate forecasts do suggest an evolution toward more "El Niño-like" patterns. Most climate projections reveal that this trend is likely to increase rapidly in the next 50 years. However, other models predict more "La Niña-like" conditions in the Hawaiian Islands (Walther et al. 2002, Buddemeier et al. 2004, Timm 2008).

A trend toward ENSO patterns will impact sea levels, sea temperatures, rainfall amounts, evaporation rates, and the occurrence of hurricanes; however, the exact impact of climate change on water resources is difficult to predict due to spatial variability. On a global scale, mean precipitation is anticipated to increase. Current climate models project that tropical Pacific and high latitude areas will experience increasing precipitation amounts, while precipitation is likely to decrease in most subtropical regions. A current trend toward this increase is supported by lowered salinity levels in both the mid- and high-latitude oceanic waters. If the opposite effect takes place, decreasing precipitation or increasing evaporation will further stress meager surface and groundwater resources. Lack of rain could lower the amount of freshwater lens recharge and decrease available water supplies. Reduced rainfall or increased evaporation will cause a corresponding increase in the demand for residential, commercial, or agricultural water (Giambelluca et al. 1996, Solomon et al. 2007, Parry et al. 2007).

Most climate projections suggest that more intense wind speeds and precipitation amounts will accompany more frequent tropical typhoons/cyclones and increased tropical sea surface temperatures in the next 50 years. The Third Assessment of the IPCC (2001) has concluded with "intermediate confidence" that the intensity of tropical cyclones is likely to increase by 10-20 percent in the Pacific region when atmospheric levels of CO_2 reach double preindustrial levels (McCarthy et al. 2001). One model projects a doubling of the frequency of 4 inches per day rainfall events and a 15-18 percent increase in rainfall intensity over large areas of the Pacific. Solomon et al. (2007) states that it is "more likely than not" that the rise in intense tropical cyclones is due to anthropogenic activity (Walther et al. 2002, Solomon et al. 2007).

An increase in heavy storms and surf will result in increased flood risks, sedimentation, and impeded drainage in Hawai‘i. In particular, the low-elevation Refuge units will be vulnerable to changes in storm frequency, intensity, and directionality. These events have the potential to denude vegetation or affect the biogeochemistry of the wetlands (DBEDT and DOH 1999).

3.2.5 Ecological Responses to Climate Change

Evidence suggests that recent climatic changes have affected a broad range of individual species and populations in both the marine and terrestrial environment. Organisms have responded by changes in phenology (timing of seasonal activities) and physiology; range and distribution; community composition and interaction; and ecosystem structure and dynamics. The reproductive physiology and population dynamics of amphibians and reptiles are highly influenced by environmental conditions such as temperature and humidity. For example, sea turtle sex is determined by the temperature of the nest environment; thus, higher temperatures could result in a higher female to

male ratio. In addition, increases in atmospheric temperatures during seabird nesting seasons will also have an effect on seabirds and water birds (Duffy 1993, Walther et al. 2002, Baker et al. 2006).

Changes in ocean temperature, circulation, and storm surge due to climate change will impact seabird breeding and foraging. The ENSO has been shown to cause seabirds to abandon habitats, nest sites, and foraging areas for colder/warmer waters. Studies have found that nesting success is reduced for some species during this climatic event. Oceanographic changes associated with ENSO may also increase or decrease food supply for seabirds and subsequently impact populations that forage offshore. Shifts in marine temperature, salinity, turbidity, currents, depth, and nutrients will have an impact on seabird and water bird prey composition and availability. Although these potential changes may impact seabirds throughout the Hawaiian Islands, contrary evidence suggests that seabirds may have coped with and evolved around climatic changes in the past (Duffy 1993).

Warming has also caused species to shift toward the poles or higher altitudes and changes in climatic conditions can alter community composition. For example, increases in nitrogen availability can favor those plant species that respond to nitrogen rises. Similarly, increases in CO_2 levels can impact plant photosynthetic rates, decrease nutrient levels, and lower herbivore weights. Although there is uncertainty regarding these trajectories, it is probable that there will be ecological consequences (Vitousek 1994, Walther et al. 2002, Ehleringer et al. 2002).

Climate change has the potential to influence two important ecological issues in the State of Hawai‘i: endangered species and pest species. The majority of U.S. endangered species are found in the State of Hawai‘i. Species declines have resulted from habitat loss, introduced diseases, and impacts from pest species. Changes in climate will add an additional threat to the survival of these species as warmer night temperatures can increase the rate of respiration for native vegetation, resulting in greater competition from pest plants. Furthermore, climate change may enhance existing pest species issues because alterations in the environment may increase the dispersal ability of flora or fauna. Species response to climate change will depend on the life-history, distribution, dispersal ability, and reproduction requirements of the species (DBEDT and DOH 1998, Middleton 2006, Giambelluca 2008).

3.3 Geology and Soils

The Hawaiian Islands were formed by a series of volcanic eruptions that occurred at hotspots beneath the Earth’s crust. As the tectonic plate slowly drifted, magma welled up from fixed spots creating a linear chain of islands. O‘ahu is the third-largest island in the chain with a total land area of 597.1 square miles. The island is mostly composed of the heavily eroded remnants of two large Pliocene shield volcanoes that broke the surface of the Pacific Ocean at different times and continued building to eventually form a single island. The western Wai‘anae volcano is approximately 2.7-3.4 million years old. It consists of shield lavas overlain by a thick sequence of post-shield alkalic basalt. The Ko‘olau Volcano on the east formed about 2.2-2.5 million years ago and is comprised of shield lavas (Ko‘olau Basalt) as well as rejuvenated stages, termed the Honolulu Volcanics. The sea level around O‘ahu has repeatedly fluctuated during various glacial epochs. During a period of higher sea level, a coral reef platform developed around the perimeter of the island. This platform currently makes up the island’s shoreline (Juvik and Juvik 1998).

Soils on Oʻahu were classified by the U.S. Department of Agriculture (USDA) Soil Conservation Service. Soils and sediments on low-lying areas of Oʻahu have been influenced primarily by periods of changing sea levels and human modifications (Juvik and Juvik 1998).

The Kahuku area of Oʻahu has a complex geological history. Eroded shield volcanoes, such as the Koʻolau Volcano, typically have dike complexes of basaltic material associated with active rift zones. These massive sheets of rock extend vertically into the lava flows, inhibiting normal groundwater flow. The Kahuku coastal plain is underlain by marine sediments and basaltic alluvium that has eroded from the Koʻolau Mountains. Two alluvial fans, or fan shaped deposits, unfold on the coastal plain near the Refuge as a result of stream deposition (Hunt 1996, Hunt and De Carlo 2000).

The ponds at the Punamanō and Kiʻi Units are underlain with black, organic-rich mud that is several feet thick (Hunt and De Carlo 2000). According to the Soil Conservation Service, the following soil classifications are found within the Refuge:

Jaucas sand, 0-15 percent slopes (JaC): This sandy soil is single grain, pale brown to very pale brown, with a depth of more than 30 inches. Due to the accumulation of organic matter and alluvium, the surface layer may be dark brown. Narrow strips of beaches, as well as Pūlehu, Mokulēʻia, and Keaʻau soils may also be present. The soil is neutral to moderately alkaline and in general the slope does not exceed 7 percent. Jaucas sand has rapid permeability and runoff is very slow to slow. Because the soil is loose, wind erosion is a severe hazard in areas without vegetation. Water erosion is considered a slight hazard (Foote et al. 1972).

Keaʻau clay, saline, 0-2 percent slopes (KmbA): Found on the coastal plains of Oʻahu, this soil occurs in depressions near the ocean or in limestone pockets. The surface layer is very dark grayish-brown clay with a platy or vesicular structure. The subsoil is very dark grayish-brown and dark-brown, mottled clay. This soil is unique in the Keaʻau series because it is strongly affected by salts. Areas underlain by Keaʻau clay are often drained or filled for various uses (Foote et al. 1972).

Fill land (Fd): This classification includes areas filled with bagasse and slurry from sugar mills, as well as material from dredging and soil excavations (Foote et al. 1972).

Waialua silty clay (WkA): Characteristics of this soil type are: moderate permeability; slow runoff; slight erosion hazard; roots penetrate to a depth of 5 feet or more in places; surface soils are 12 inches thick, subsoil about 26 inches thick; shrink-swell potential is moderate (Foot et al. 1972).

Kaloko clay, noncalcareous variant (Kfb): The noncalcareous variant of the Kaloko series occurs in slight depressions on the coastal plains of Oʻahu. More acidic and grayer than the other soils in the Kaloko series, this soil is underlain by noncalcareous material. The surface layer is very dark gray clay, while the subsoil is gray or grayish-brown prismatic clay. The substratum is massive clay and silty clay. Small areas of very deep, well-drained alluvial soils were also identified in drainage ways. The permeability of this soil is ranked as slow, runoff is very slow, and the erosion hazard is none to slight (Foote et al. 1972).

Coral outcrop (CR): Coral outcrop, which is comprised of coral or cemented calcareous sand, can be found on Oʻahu between 0-100 feet in elevation. It is geographically associated with Jaucas, Keaʻau, and Mokulēʻia soils. Within the cracks, crevices, and depressions of the coral outcrop, a thin layer of

friable, red soil material can be found. Sparse vegetation typically grows in coral outcrop (Foote et al. 1972).

Beaches (BS): This land type consists of light-colored sands derived from coral and seashells (Foote et al. 1972).

3.4 Hydrology

The hydrologic processes that occur in the Hawaiian Islands are unique compared to continental landmasses or temperate zones. Drainage basins are typically small and streams are characterized by steep longitudinal profiles and numerous waterfalls. The Island of Oʻahu has 57 perennial streams. Stream flow depends on the climatic and geological features of the area. For example, some streams on Oʻahu have lengthy dry reaches under natural conditions due to permeable underlying rock. Oʻahu also has a vast amount of groundwater, which supplies most of the domestic water supply (Lau and Mink 2006).

The combination of intense storms, steep terrain, and urban land uses causes flooding in certain areas of Oʻahu. The Flood Insurance Rate Maps prepared by the Federal Emergency Management Agency's National Flood Insurance Program depict flood hazard areas throughout the State. The maps classify land within the Refuge boundary into four zones depending on the expectation of flood inundation (Figure 3-4).

The Kahuku basin, which drains approximately 7.6 square miles, ranges in elevation from 0-1,800 feet on the northern slopes of the Koʻolau Mountains. This basin also includes a 3.2-square mile low-lying coastal floodplain. Streams in the Kahuku area are typically short and steep, causing periods of high peak floods. ʻŌhiʻa, Kalaeokahipa, and Hoʻolapa are intermittent streams in the Kahuku area (Smith, Young & Assoc. 1990, Hunt and De Carlo 2000).

Groundwater in the Kahuku area primarily occurs as a basal freshwater lens in the dike-free Koʻolau Basalt and overlying unconsolidated and consolidated sedimentary deposits. This aquifer extends from Punaluʻu Valley to Kahuku Point. Groundwater levels in the region vary between 7-20 feet above mean sea level, with lower levels near the shore. Regionally, groundwater moves from the volcanic-rock aquifers into the overlying sedimentary deposits and eventually discharges to the ocean. Flow to the ocean is estimated from 2-4 million gallons per day (mgd) per mile of shoreline, depending on rock permeability. Mean annual groundwater recharge due to rainfall infiltration is approximately 3.8 mgd. Additional recharge occurs as a result of inflow from the adjacent dike complex. Historically, aquifers were heavily developed for agriculture in this region; however, when sugarcane cultivation ceased in 1971, estimated water use declined significantly (Mink 1982, Smith, Young & Assoc. 1990, Miller et al. 1999).

Naturally occurring wetlands are situated along the coastal Kahuku plain. The Kiʻi Unit of the Refuge is a remnant of a formerly larger marsh that has been drastically modified by agriculture. In 1976, the Service began to supply the assemblage of ponds with water from adjacent ditches and artesian wells. There are a total of seven ponds (identified as Ponds A-G) within the Kiʻi Unit, which are separated from each other by earthen berms or levees (Figure 3.5). Pond water levels generally average between 3-4.5 feet. The most seaward ponds (Ponds A and E) typically maintain lower water

levels, between 1.5-3 feet. Water levels in the adjacent ditch system are lower than the pond levels, averaging 2 feet. The pH levels range between 6.95-8.15 (Hunt and De Carlo 2000). According to Hunt and De Carlo, the drainage area for the Ki‘i Unit is approximately 3.87 square miles. These subwatershed areas, in decreasing size, include ‘Ōhi’a Ai Gulch, Kalaeokahipa Gulch, Hospital ditch, and runoff from a residential subdivision.

Ground water inflows do not substantially contribute to the ponds; rather, the primary water source for the ponds is a single 12-inch artesian well that is connected to a 12-inch distribution system. Since 2001, the average water temperature and salinity of the water in the well has been 72.5°F and 0.41 ppt, respectively. Pipelines feed water into ponds G, F, C, and B. Subsequently, water is fed to ponds D and A through control structures in ponds F and B, respectively. Pond E is not supplied by water from the well, but is fed by control structures connected to the ditches. Direct rainfall supplements water provided by the well. During periods of heavy precipitation, control values are manually adjusted to regulate the amount of water distributed into each pond. The well is turned off during excessively high rain periods to prevent flooding. The Refuge is currently allotted 1 mgd. Prior to July 2004, the Refuge utilized 3 artesian wells of 3-inch diameter, which piped water into the 7 impoundments. Use has ceased, but the wells remain onsite.

An abandoned ditch system drains the seaward Kahuku coastal plain. Within the Ki‘i Unit, several ditches can be found including the Hospital ditch, the Punamanō ditch, the Ki‘i ditch, and the Raboy ditch. An outlet ditch then discharges this water to the ocean. Five of the seven ponds dump into the ditch system. Water from the adjacent ditch systems is not used as a supplemental water source for the ponds due to concern of contamination on upland properties.

In contrast to the Ki‘i Unit, the Punamanō Unit of the Refuge is naturally fed by rainfall, runoff, springs and groundwater seepage. Water flows from the marsh into Punamanō ditch and continues easterly. Currently, the unit consists of a north and south pond that are intermittently connected. The north pond has a water level of 2.5 feet above sea level. The temperature in the north pond is measured at 74.7°F, which is colder than ponds located further south. This suggests water may be coming from a separate, local source derived from the Ko‘olau Mountains or it may be caused by evaporative cooling. The drainage area of the Punamanō Unit is 0.42 square miles (Hunt and De Carlo 2000).

Figure 3.1. Historic Land Divisions

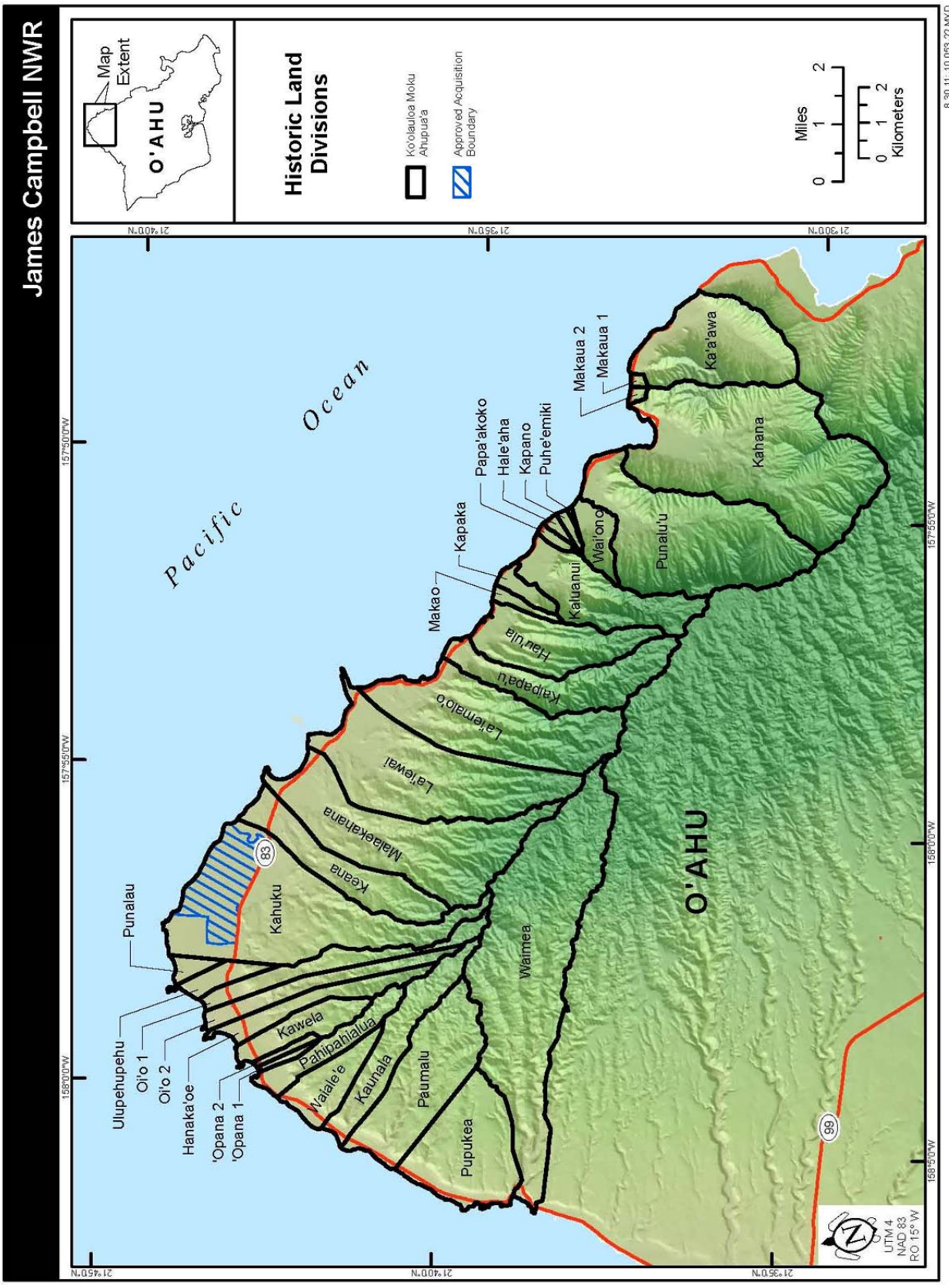

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Figure 3.2. Refuge Land Status & Boundary

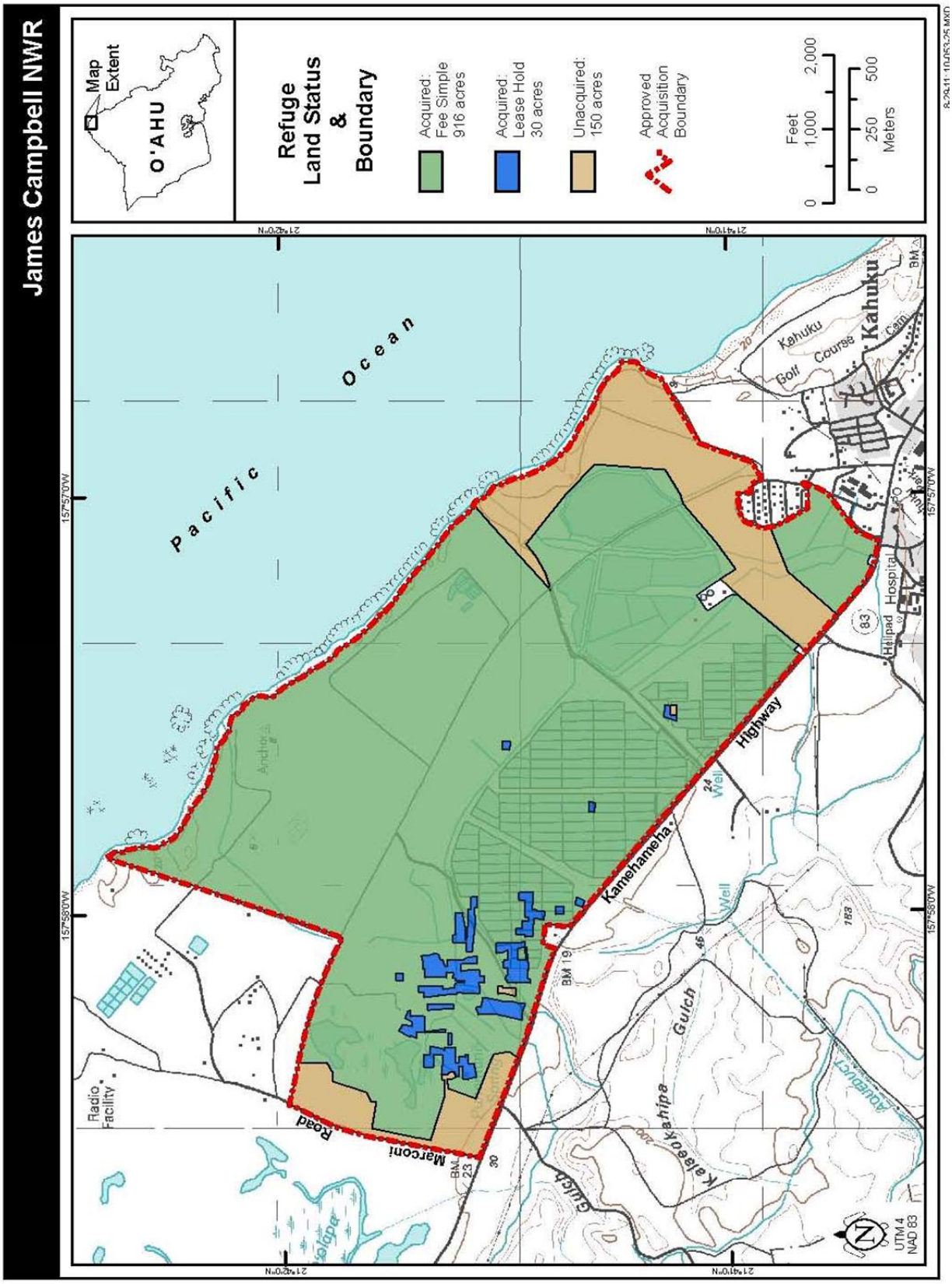

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Figure 3.3. Soil Series

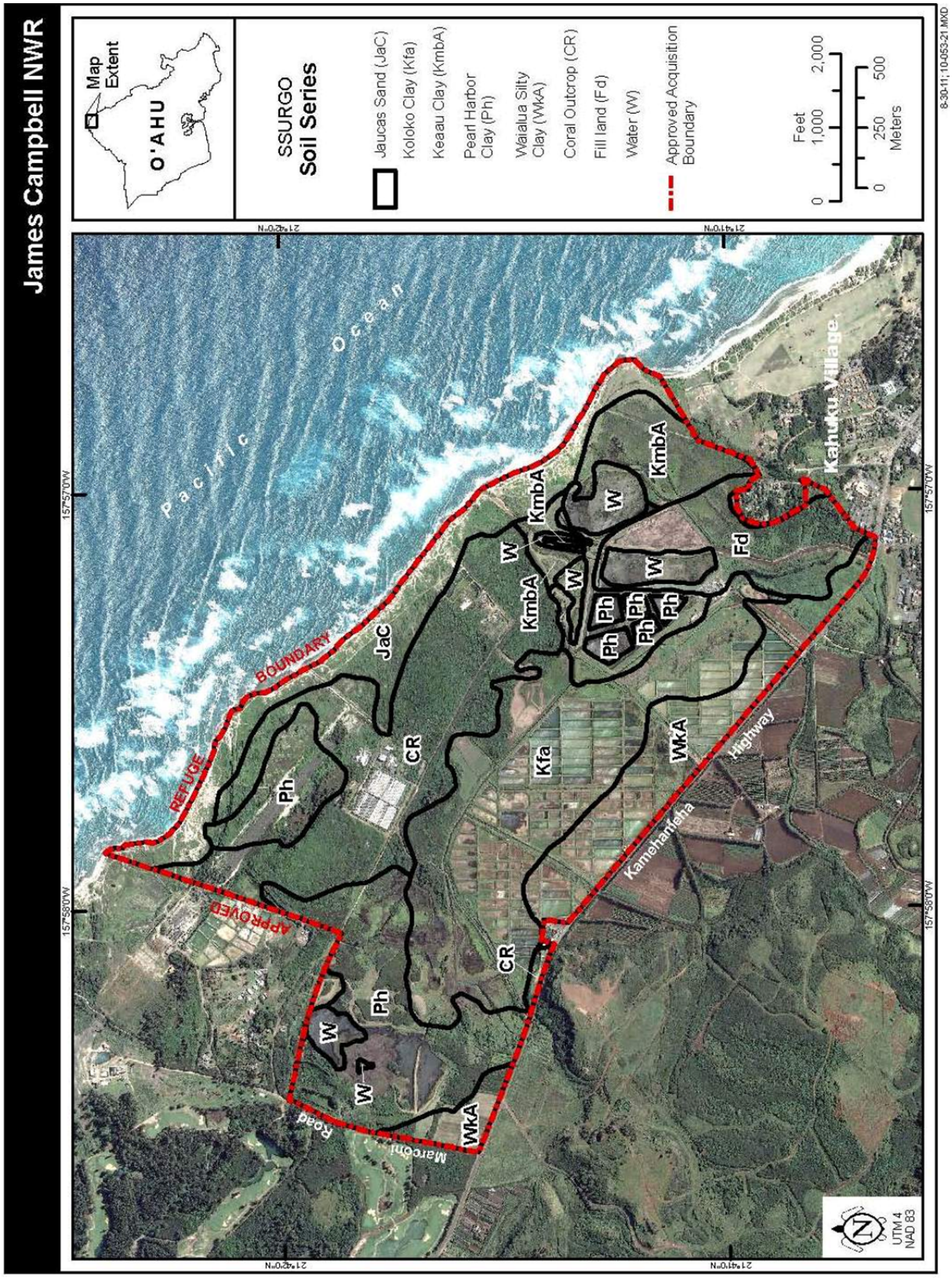

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Figure 3.4. Flood Hazard Zones

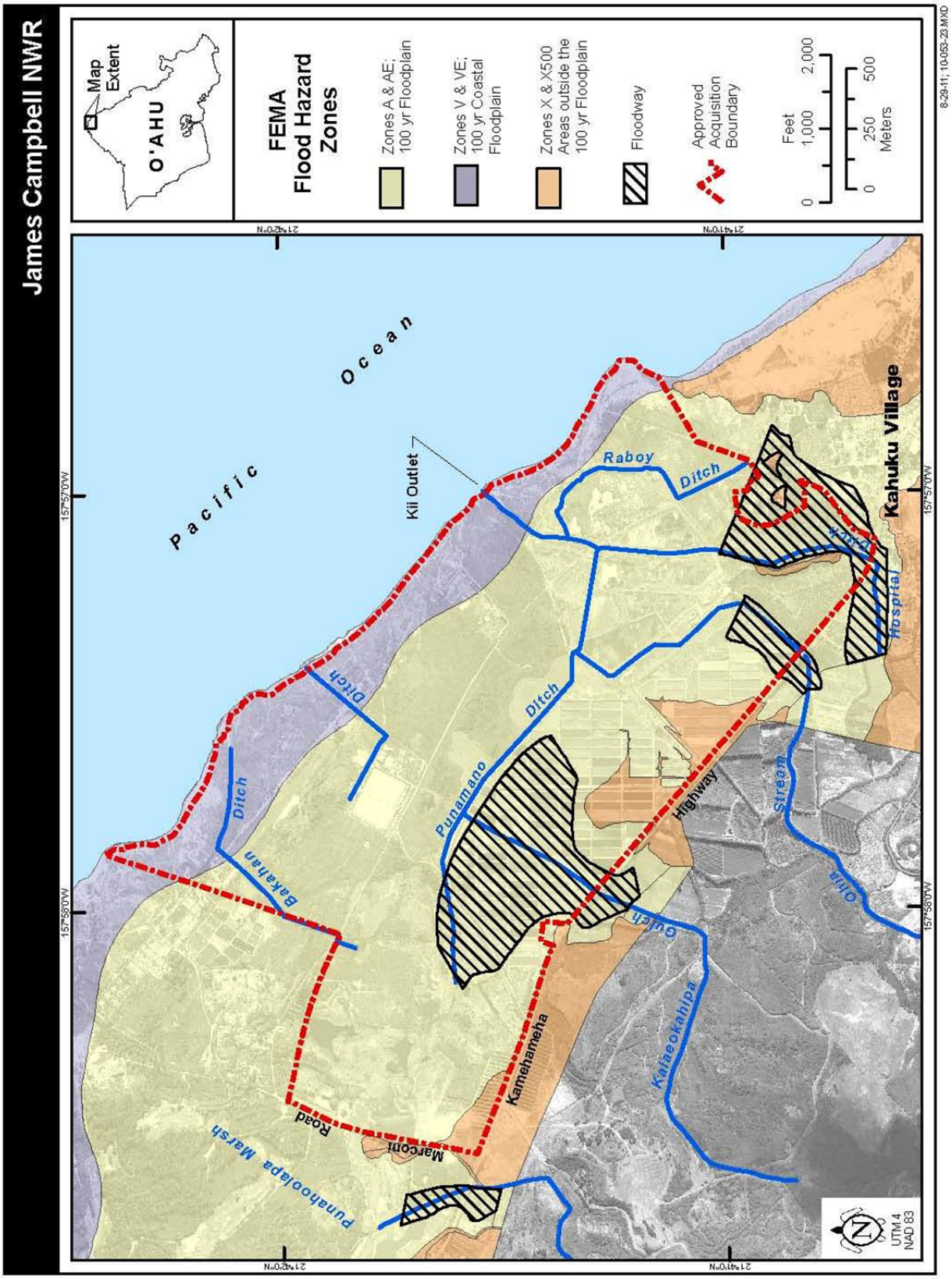

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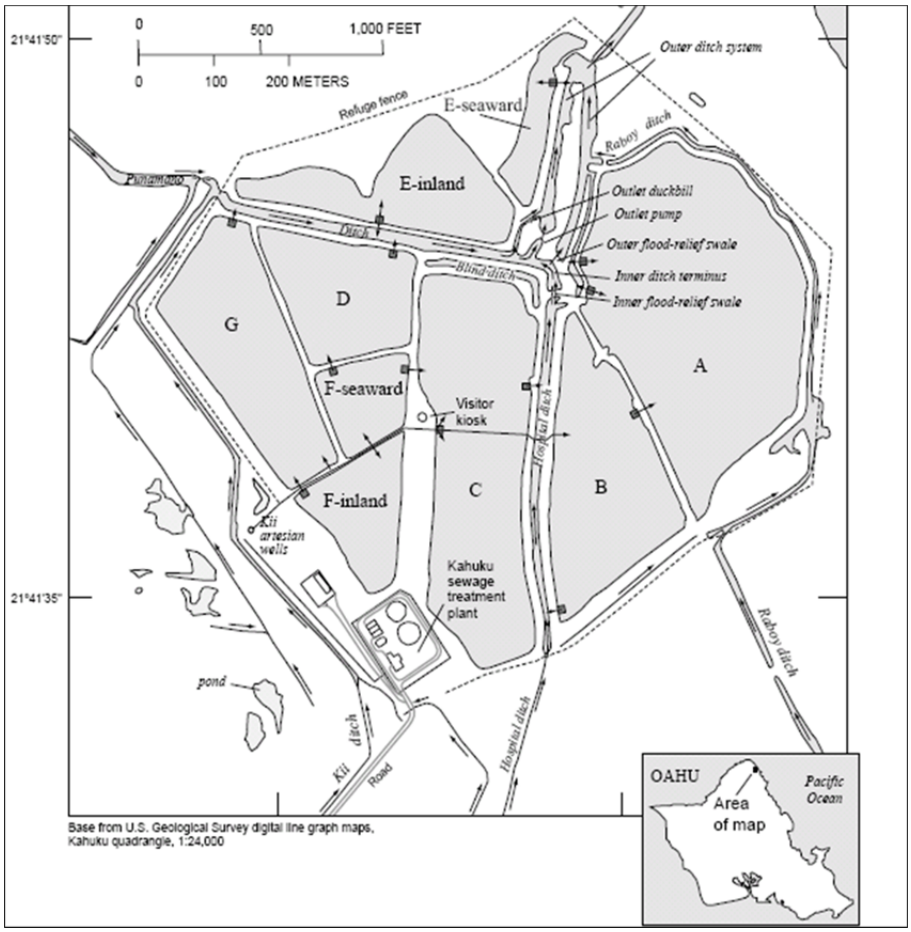
Figure 3.5. Hydrologic features of the Ki‘i Unit, James Campbell NWR.



Source: Hunt and De Carlo (2000).

3.5 Topography/Bathymetry

The interior portions of O‘ahu gradually slope inward to a broad central valley. In contrast, the outer seaward slopes are tall and steep as a result of erosion from wind, rain, and sea. Bathymetric mapping reveals that giant landslides and the associated slope failures are a significant component to the erosional history of the island. The coastal region of Kahuku is comprised of low coastal terraces less than 10 feet above sea level. The topography of the Refuge is nearly flat except for higher elevation dunes that lie seaward of the coastal terraces, inhibiting surface water flow to the ocean and causing ponding in the interior portions (Moore 1964, Polhemus 2007).

Lithified outcrops of eolianite along Kahuku Point and Makahoa Point create a sharp and jagged surface that makes access to the windward shoreline difficult. Extensive ridges of beach rock on the foreshore are found along the entire area. Along the windward coast, limestone outcrops and offshore islets can be found. Offshore fringing reefs are more extensive east of Kahuku Point due to the decreased wave energy compared to the northern coastline (Fletcher et al 2002).

3.6 Environmental Contaminants

The Agency for Toxic Substances and Disease Registry defines a contaminant as "a substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects." Contaminants commonly include pesticides and pesticide residues, industrial chemicals, fertilizers, metals, and other toxic substances. By altering biological or physical processes, contaminants may produce adverse effects to an ecosystem.

Contaminants are an important consideration of refuge management because wetlands depend on a constant supply of water for their maintenance. The quality of the habitat for the birds to be protected depends to a great extent on the quality of the water. Concern with the quality of surface and ground water has been the focus of extensive monitoring and study on O‘ahu for many years.

A Level II Contaminant Survey of sediments and tissues conducted in 1991 by the Service and a groundwater sampling conducted by the City of Honolulu in 1996 reported no contaminants at the Punamanō and Ki‘i units. However, a Ki‘i surface water sample by the University of Hawai‘i revealed high Polychlorinated biphenyls (PCBs) concentrations. A followup Level 1 Preacquisition Contaminant Survey was subsequently performed in 1998 to characterize the PCB contamination. These PCB detections were reported in 6 soil samples in a 20 by 50 feet area. This detection was due to a small, inadvertent spill of transformer oil that occurred in the late 1970s near the outlet channel. The PCB concentrations exceeded the ecological screening value of 0.023 parts per million (ppm), suggesting further evaluation and potential remediation. At that time, the Service determined that it was safer to leave the PCBs in place than attempt to remove the contaminated soil. Follow-up monitoring is recommended to ensure the decision to leave the contamination in place has no negative impacts to endangered species in the Refuge (Harding ESE 2001).

Hunt and De Carlo (2000) conducted inorganic and organic chemical analysis by collecting water and sediment samples on the Refuge during a dry season (1994) and a wet season (1997). In 1994, water samples were collected from five sites and sediment samples from three sites in the Ki‘i Unit ponds. The 1997 survey consisted of water samples from the same five sites, as well as four additional water sample sites located on ditches and storm drains.

No significant water contamination by heavy metals or other potentially toxic trace elements was found during these studies. Elevated arsenic concentrations were detected between the dry season and wet season surveys, possibly due to fertilizer or pesticide runoff from upstream agricultural areas. In addition, a sample collected from Ki‘i Pond C during the 1994 survey had a copper concentration of 8.2 micrograms per liter (µg/L), which exceeds the aquatic life chronic criteria (6.5 µg/L) within the EPA ambient water-quality criteria. However, copper is naturally abundant in volcanic soils and consequently also occurs in higher concentrations in many sediments and waters. All other concentrations were comparable to heavy metal amounts found in nonimpact or low-impact areas throughout O‘ahu. Trace concentrations of several pesticides (including atrazine, simazine, chorpyrifos, diazinon, and trifluralin) were also detected in the water samples (Hunt and De Carlo 2000).

In the sediment samples, the organochlorine pesticide dichloro-diphenyl-trichloroethane (DDT) and its breakdown products dichloro-diphenyldichloro-ethylene (DDE) and dichloro-diphenyl-dichloroethane (DDD) were detected at or above the minimum reporting limit in surface samples of

bottom sediment from Ponds C and D at the Ki‘i Unit, as well as in a sediment core taken at Punamanō north pond. Concentrations were not at a level that posed any ecological risk. Trace concentrations of ametryn were detected at Pond C at Ki‘i and at Punamanō. Trace concentrations of bromacil, carboxin, diphenamid, and simetryn were detected in at the Punamanō core, and a trace of propachlor was detected at Ki‘i Pond D. The volatile organic compound toluene was detected at pond C (Hunt and De Carlo 2000).

The inorganic chemical survey results from the Ki‘i and Punamanō Units were compared with available sediment-quality guidelines for freshwater sediments. In the Ki‘i Unit, copper and zinc concentrations in sediments from Ponds C and D exceeded the guidelines. Sediments from the north pond at the Punamanō Unit exceeded copper concentration limits. However, as these are naturally abundant in Hawaiian volcanic soils and are similar to concentrations found in other areas of O‘ahu, the Service determined that no adverse biological effects would be associated with the contaminated sediment (Hunt and De Carlo 2000).

3.7 Land Use

The Administration Act identifies six priority wildlife-dependent visitor uses on refuges: hunting, fishing, wildlife observation and photography, and EE and interpretation. According to the Refuge Recreation Act of 1962, all recreational activities must be compatible with the primary purpose of the Refuge. Other laws or policies that may affect land use include: the Endangered Species Act of 1973; the Clean Water Act (CWA) or Federal Water Pollution and Control Act; the Migratory Bird Treaty Act of 1918; Executive Order 11988 (Floodplain Management); Executive Order 11990 (Protection of Wetlands), the Hawai‘i Coastal Zone Management Act of 1977 (Hawai‘i Revised Statutes, Chapter 205A); and the Master Plan for the Hawaiian Wetland NWR Complex (1983).

Under the State Land Use Law (Act 187), Hawai‘i Revised Statute Chapter 205, all lands and waters in the State are classified into four districts: Agriculture, Rural, Conservation, and Urban. Conservation Districts are further divided into five subzones: Protective, Limited, Resource, General, and Special (Hawai‘i Administration Rules, Title 13, Chapter 5). Land use is also dictated by zoning ordinances from the City and County of Honolulu.

The O‘ahu General Plan is a comprehensive document with objectives and policies to address the physical, social, economic, and environmental concerns affecting the City and County of Honolulu. Island planning is further divided into eight regional areas that are guided by Development Plans or Sustainable Communities Plans (DPP 2006). The James Campbell NWR is located next to the community of Kahuku, within the Ko‘olau Loa Sustainable Community Plan area.

3.7.1 Historic Land Divisions

The concept of private property was unknown to Native Hawaiians prior to Western contact, but they did follow a complex system of land division. All land was controlled by the highest ali‘i (chief or king) who held it in trust for the whole population. The ali‘i designated who supervised these lands based on their rank and standing. Each island was divided into several moku (units). O‘ahu was divided into six moku. Each moku was divided into smaller units known as ahupua‘a. Shaped by

island geography, each ahupuaʻa was a wedge-shaped area of land running from the uplands to the sea, following the natural boundaries of the watershed. The Refuge is located within the Kahuku ahupuaʻa (Figure 3.1). Each ahupuaʻa contained the resources the human community needed, from fish and salt, to fertile land for farming taro or sweet potato, to koa and other trees growing in upslope areas. Each ahupuaʻa was ruled by an aliʻi and administered by a konohiki (headman or landlord) (Kamehameha 2011).

Stewardship of the land and its resources was formalized through the kapu system. The kapu, enforced by konohiki and kahuna (Hawaiian priest), placed restrictions on fishing certain species during specific seasons, on gathering and replacing certain plants, and on many aspects of social interaction as well. In this way, the community maintained a sustainable lifestyle (Kamehameha 2011).

The native landscape described in Land Commission testimonies (circa 1848) correlates with the verdant lush tropical landscape that was first witnessed by European explorers a half a century earlier. These conditions facilitated all phases of crop procurement for Native Hawaiians and provided rich marine resources, salt production capabilities, spring-fed marsh areas for taro, and suitable fish pond locations. Numerous testimonies attest to the rich hala groves within the general Kahuku plain. Coastal resources provided nearly all the necessary sustenance to establish coastal villages; while the adjacent steep hills, ridges, and lush upland regions of the Koʻolau Range provided additional forested resources (Dougherty and Moniz-Nakamura 2005).

3.7.2 Ranching

The Mahele of 1848 changed land tenure in the Hawaiian Islands by defining land ownership and providing a legal course for land exchanges and purchases. A number of influential and powerful individuals were poised to secure large tracts of land through their close association with King Kamehameha III. These foreign investors were able to secure large tracts of lands awarded to either the king, konohiki, and to the government and people of Hawaiʻi. Robert Moffitt, an Irish cattleman, secured large tracts of crown and konohiki lands along the northern point of Oʻahu and quickly transformed the landscape into pasturelands for ranching pursuits that included sheep flocks and cattle herds. The pasture lands extended along the coastal plain from the shoreline to the base of the Koʻolau Range (Dougherty and Moniz-Nakamura 2005).

In 1850-51, only 3 years after the Mahele, Englishman Charles Hopkins purchased over 8,000 acres of Hawaiian lands and founded Kahuku Ranch for cattle and sheep. Other Englishmen who acquired large tracts of Kahuku lands at this time included R.C. Wyllie and H.A. Widemann. By 1873, Kahuku Ranch was owned solely by H.A. Widemann. In 1874, Kahuku Ranch was renamed Kahuku and Mālaekahana Ranch, and was sold to Julius Richardson, and in 1876, Richardson sold the ranch to James Campbell (Wilcox 1975).

3.7.3 Sugar, Pineapples, and Trains

Kahuku Plantation Co. #1 c. 1946
Bishop Museum Collection

A consortium of interests formed during the following decades. Development of islandwide transportation routes, ranches, land colonization, and sugar plantations coalesced, creating the conditions that facilitated rapid change within Kahuku. Benjamin Dillingham spearheaded efforts to construct rail lines to Kahuku to transport raw sugar to the wharves in Honolulu. In 1890, James Campbell leased his Kahuku Ranch lands to Dillingham for 50 years, who then subleased these lands and the water rights to James Castle. The Kahuku Plantation Company, incorporated in 1890 through the partnership of James Castle and Alexander Young, planted 2,800 acres of cane and produced their first harvest in 1892. The crops were hauled to the Kahuku mill and from there were transported to the landing where the cane was shipped to Honolulu (Kuykendall 1967, Wilcox 1975).

The railway reached Kahuku in 1899 and remained in operation for 58 years. The Kahuku Plantation Co. and O‘ahu Railway & Land Co.began leasing land for pineapple cultivation during the mid-1900s. Ultimately, large areas of Kahuku were leased to the California Packing Corporation that later became the Del Monte Corp., who later subleased lands to the U.S. government for use as military training areas (Smith 1989).

Annexation of Hawai‘i to the United States and WorldWar II contributed to higher labor costs for plantation owners, and this combined with an expanding global sugar market reduced the plantation’s market competitiveness. The sugar mill was officially shut down in 1971 (Wilcox 1975).

Private First Class Angelo Reina guards a lonely beach position at Kahuku © Rosenberg, March 1945

3.7.4 Military Use

Land developments of the area during World War II-era military modification included three emergency landing airstrips at the northern tip of O‘ahu (Kahuku Point Airfield, Kahuku Golf Course, and Kahuku Village), radio tower installations, barracks, and concrete bunkers.

The 18th Air Base Group, 47th Pursuit Squadron, was stationed in Kahuku to protect the airfield and man shoreline fortifications. B-24s and B-17s were based at Kahuku for short periods of time during World War II. Most of the buildings and support structures associated with the Kahuku Air Field have been removed. A portion of the old runway, a few scattered concrete pillboxes, and antenna supports covered by low brush and debris can be found in the coastal shrubland (McKillop 2005).

The Kahuku Training Area is situated southwest of the Refuge on the slopes of the Koʻolau Mountain Range. It remains an active training area available for military units in Hawaiʻi to maintain their combat readiness.

3.7.5 Land Use Today

Modern-era activities generating further land modifications include diversified agricultural pursuits and extensive aquaculture farm facility construction. Hotel and golf course developments located on the coastal plain represent considerable land modifications of relatively large, contiguous areas. These activities combined with smaller developments have produced widescale land changes on the Kahuku Plain. The Refuge is bordered by Kamehameha Highway to the south and the Pacific Ocean to the north. Adjacent land uses to the south include First Wind windfarm, Kahuku Wastewater Treatment Plant, Kahuku Golf Course, the abandoned Kahuku sugar mill, Kahuku Hospital, Kahuku High School, and the northern section of the Mālaekahana State Recreation Area. Land uses to the northwest include kuleana lands, Links Golf Course, and the Turtle Bay Resort. Turtle Bay Resort is a 26-acre hotel and commercial development north of the Refuge. Potential future uses of lands adjacent to the Refuge include agriculture, aquaculture, golf courses, parks, conservation areas, or residential development.

During the sugar cane era, the Kiʻi area was used as settling ponds to wash sugar cane at the Kahuku Sugar Mill. When the mill closed in 1971, the ponds dried and were no longer used by waterbirds. The Service entered into a long-term lease agreement with the landowner, the Estate of James Campbell, to increase waterbird habitat. Restoration at the Kiʻi Unit began in 1977. In addition to agricultural uses, Punamanō Pond was once used as a fishpond by local residents.

On May 25, 2006, the James Campbell National Wildlife Refuge Expansion Act of 2005 (the Act), Public Law 109-225, expanded the existing Refuge boundary by approximately 750 acres, creating a total of 1,100 acres of protected wildlife habitat. The new area, which includes coastal lowland wetlands, dunes, and strand habitat makai (seaward) of Kamehameha Highway in the Kahuku coastal plain, linked the original Refuge units to the ocean shore. The Act was enacted by Congress and the President due to longstanding public concerns for protecting Oʻahu's natural resources and open space on the Kahuku coastal plain.

Romy's Kahuku Prawns & Shrimp
Laura Beauregard/USFWS

There are two commercial lessees on the Refuge, Romy's and Ming Dynasty, that raise freshwater shrimp and prawns in aquaculture ponds next to Kamehameha Highway. They are located on a parcel of land acquired by the Refuge in December 2009. Under an agreement with the James Campbell Company, these leases were transferred to the Service and will expire in 2023.

Two other small commercial aquaculture farms are also currently in operation on newly acquired Refuge lands. One cultivates sea asparagus on lands under the Ming Dynasty lease but is not covered by the lease and the second raises ogo (seaweed) on

Parcel 4 which was acquired by the Refuge in January 2011. Neither of these commercial operations (under a single ownership) were covered by the original purchase agreement which allowed existing long-term leases to remain on the property until 2023 and neither is considered appropriate uses under current Refuge System policy. Both ventures will need to cease operations on the Refuge. The Service is working cooperatively with the business owner to provide an opportunity for both operations to relocate off of the Refuge.

3.8 Refuge Facilities

Equipment storage and maintenance operations for all of the O‘ahu National Wildlife Refuge Complex are based out of the Ki‘i Unit of the James Campbell NWR. The baseyard is located near the current public entrance off Kamehameha Highway within a fence along the southwest perimeter of the Ki‘i Unit. The area encompassed by the facility is approximately 1 acre and consists of a maintenance equipment storage and office facility within a metal building (constructed in 2003). There is a three-sided roofed area for additional storage and four portable secured storage containers used to safeguard tools and other management-related equipment and materials. Two kiosks and interpretative signs demark a short nature walk.