Chapter 3
Physical Environment

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Chapter 3. Physical Environment

The Hawaiian Archipelago is the world's most isolated group of islands, lying approximately 2,400 miles southwest of San Francisco, CA. Apart from Niʻihau, the island of Kauaʻi is the oldest and northernmost island of the eight main Hawaiian Islands in the Hawaiian Archipelago. Located 103 miles northwest of Honolulu, Kauaʻi is near the middle of the Pacific Ocean and south of the Tropic of Cancer. Commonly referred to as "The Garden Isle," Kauaʻi Island is characterized by its lush, green environment and high average rainfall. Kauaʻi is approximately 550 square miles and is approximately 30 miles in diameter. A 75-mile coastal state highway circumnavigates nearly the entire island (USFWS 1989). A 2-mile County road (Kīlauea Road) connects the Refuge to the Kuhio Highway, state route 56. The Refuge is situated in the mokuʻaina (district) of Koʻolau near Kīlauea Town (Hawaiʻi Department of Education 2001). The Daniel K. Inouye Kīlauea Point Lighthouse is situated on the northernmost point in the Hawaiian Island chain.

3.1 Climate

3.1.1 General Climate

Climatic conditions on the island of Kauaʻi are dominated by northeasterly tradewinds approximately 70 percent of the year. Tradewinds bring warm, tropical, moisture-laden air to Kauaʻi. As a result of the steep topography, the northern and eastern (windward) sides of Kauaʻi have heavier rainfall than the drier south and west (leeward) sides. Traditionally, only two seasons were recognized in Hawaiʻi: *kau*— the warm season occurring from May to October that is characterized by northeast winds and an overhead sun, and *hoʻoilo*— the cold season, occurring from October to April and characterized by cooler temperatures, rain, variable winds and a lower sun (Seimers 2009, Juvik and Juvik 1998). Temperatures during the winter months on Kauaʻi range from 65 ºF to 81 ºF. Summer temperatures range from 72 ºF to 88 ºF (USFWS 2007). Average annual air temperature is approximately 73 ºF (Berg et al. 1997).

Prevailing ocean currents surrounding the island influence weather patterns by moderating the surface air temperatures as a result of differential heat absorption and advection of heat. Ocean currents in the Hawaiian Islands are moderated by the North Pacific anticyclone, a clockwise gyre that extends from the tropics to the North Pacific (Juvik and Juvik 1998, Lau and Mink 2006). Storm-generated ocean swells are common throughout the year. The north and west shores are pounded by fierce North Pacific winter storms.

Kīlauea Point NWR is directly exposed to the northeast tradewinds. A variable 10–20 mile-per-hour (mph) tradewind blows across the Refuge during most of the year. During strong wind conditions, which are not uncommon, the winds increase to 20–35 mph (USFWS 1989).

Rainfall in the main Hawaiian Islands averages 75–90 inches a year. However, extreme variation in rainfall across the islands is a result of orographic lifting. The wide range of rainfall patterns results in a diversity of environmental settings, ranging from rain forests (more than 100 inches) to mesic forests (50–100 inches) to semiarid deserts (less than 50 inches). As tradewinds drive the warm, moist air up on the windward side of an island, the air is cooled. On Kauaʻi, air is forced up the steep slopes of Mount Waiʻaleʻale and its highest peak, Kawaikini (Blay and Seimers 2004). As air rises and cools, it cannot hold as much moisture and condensation and so precipitation occurs.

Often referred to as one of the wettest places on Earth, the plateau of Kaua‘i reaches elevations of 5,148 feet at Wai‘ale‘ale and 5,243 feet at Kawaikini and is directly exposed to tradewinds ascending abruptly over precipitous pali (cliffs). Average annual rainfall at Wai‘ale‘ale is 444 inches (Juvik and Juvik 1998). Water drains across the Olokele Plateau into the Alaka‘i Swamp. The rain shadow effect is demonstrated by the dry, semi-arid, leeward, west side of the island (Blay and Seimers 2004). Average rainfall for Waimea Town on Kaua‘i’s west side is 12–15 inches per year. In contrast, Kīlauea Town receives an average of 50–60 inches per year (USFWS 2007). Average annual rainfall at Kīlauea Point is 67.4 inches with the highest rainfall occurring November to March and the least amount of rainfall in the summer months (USFWS 1989). The Kīlauea area historically has experienced periods of exceptional rainfall. The most extreme instance of record occurred in Kīlauea during the storm of January 24–25, 1956. The Kīlauea Sugar Plantation Office recorded over 38 inches of rain in a 24-hour period (NCDC 2001).

On Kaua‘i, there are differences between winter and summer rainfall. About 58 percent of rain typically falls during the 6 months between November and April, the remaining 42 percent between May and October (USFWS 2005).

There are four classes of disturbances that create major storms: cold fronts, low pressure systems, true tropical storms, and instances of severe weather attributed to low pressure systems in the upper atmosphere (NCDC 2001).

Long periods of rainfall in the winter are a result of Kona storms or low pressure systems from the west (Seimers 2009). Cold fronts associated with low pressure systems move north of the Hawaiian Islands in the prevailing westerly winds between October and April. This results in severe cloud cover, heavy rains, and occasional thunderstorms. Because of its northwesterly location, Kaua‘i receives more cold front storms than the other islands and can receive up to 20 cold fronts per year (NCDC 2001, Juvik and Juvik 1998).

Episodic oceanic and atmospheric events such as the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) also influence climate in the islands during specific intervals. In El Niño years, average sea surface temperatures in the central and eastern equatorial Pacific Ocean are warmer than average and the easterly trade winds in the tropical Pacific are weakened. La Niña is characterized by the opposite—cooler than average sea surface temperatures and stronger than normal easterly trade winds. These changes in the wind and ocean circulation can have global impacts to weather events. ENSO usually results in light tradewinds and drier conditions in the western Pacific (Duffy 1993). During previous ENSO years in Hawai‘i, average rainfall has dropped below historical averages (Chu and Chen 2005).

Like ENSO, PDO is characterized by changes in sea surface temperature, sea level pressure, and wind patterns. PDO is described as being in one of two phases: warm (positive) and cool (negative). During a warm phase, sea surface temperatures near the equator and along the coast of North America are warmer, while in the central north Pacific they are cooler. During a cool phase, the patterns are opposite. Within Hawai‘i, winter rainfall is negatively correlated with PDO (i.e., warm phase PDO winters tend to be warmer and drier than average while cool phase PDO winters tend to be cooler and wetter than average) (Chu and Chen 2005). A single warm or cool PDO phase lasts 20–30 years. The triggering cause of PDO phase shift is not understood.

Hurricanes are not uncommon in the Hawaiian Islands. In 1950, Hurricane Hiki was the first recorded hurricane in Hawaiʻi and passed within 150 miles northeast of Kauaʻi. Kīlauea Lighthouse recorded sustained windspeed of 68 mph. In 1987, Hurricane Nina passed the northern coast of Kauaʻi, and in 1959, Hurricane Dot had the highest wind gust recorded of 103 mph at Kīlauea Lighthouse (Wilson 1980). Two recent hurricanes caused damage to the Refuge. Winds of over 90 mph were registered from Hurricane Iwa in 1982 (USFWS 1989). The eye of Hurricane ʻIniki passed directly over Kauaʻi on September 11, 1992. With 145 mph winds, Hurricane ʻIniki was classified as a Category 4 hurricane on the Saffir-Simpson scale (NCDC 2001). It was the most devastating hurricane recorded in Hawaiʻi's history (Juvik and Juvik 1998). Though no major wildlife losses were recorded (with the exception of some shearwater chicks and young boobies), infrastructure was significantly damaged or destroyed. This included damage to the Kīlauea Lighthouse lens room and Fresnel lens, office building, two residences and detached garages, visitor center, environmental education building, and maintenance buildings. Additionally restored native coastal vegetation on Kīlauea Point was washed or blown away. The Refuge was closed to the general public from 1992 to 1994 as a result.

3.1.2 Climate Change

The terms “climate” and “climate change” are defined by the Intergovernmental Panel on Climate Change (IPCC). The term “climate” refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2007). The term “climate change” thus refers to a change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (Ibid).

The greenhouse effect is a natural process by which greenhouse gases (GHG) such as water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) absorb infrared radiation emitted by Earth's surface, by the atmosphere itself, and by clouds. These gases also trap heat within the surface-troposphere system (IPCC 2007), heating Earth's surface and the lower atmosphere. CO_2 is produced in the largest quantities, accounting for more than half of the current impact on Earth's climate.

There is consensus in the scientific community that Earth's climate has been rapidly changing and that changes in atmospheric composition are the primary drivers (Bierbaum et al. 2007, USGCRP 2009, EPA 2012). Although climate variations are well documented in Earth's history, even in relatively recent geologic time, the current warming trend differs from shifts earlier in geologic time in two ways. First, this climate change appears to be driven primarily by human economic activities, such as deforestation and the burning of fossil fuels, which results in a higher concentration of atmospheric GHG. Second, atmospheric CO_2 and other GHG, levels of which are strongly correlated with Earth's temperature, are now higher than at any time during the last 800,000 years (USGCRP 2009). Prior to the start of the Industrial Revolution in 1750, the amount of CO_2 in the atmosphere was about 280 parts per million (ppm). As of January 2014, atmospheric CO_2 was approximately 397.8 ppm (NOAA 2014).

Results of scientific analyses presented by the IPCC show that most of the observed increase in global average temperature since the mid-20th century cannot be explained by natural variability in climate, and is “very likely” (defined by the IPCC as 90 percent or higher probability) due to the observed increase in GHG concentrations in the atmosphere as a result of human activities, particularly carbon dioxide emissions from use of fossil fuels (IPCC 2007, Solomon et al. 2007). According to the Fourth Assessment Report by the IPCC, global temperatures on 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 and 2003 (Solomon et al. 2007).

Global climate models offer a variety of projections based on different emission scenarios. Projected increases in global average surface temperature range from 1.1 ºF to 7.2 ºF by 2100, relative to 1980–1999 levels (IPCC 2007). However, IPCC is considered to be a relatively conservative source of climate change projections (Watson 2010, Scherer 2012). Pursuant to the assessment of the U.S. Global Climate Research Program, global average temperature is projected to increase 2.0 ºF to 11.5 ºF by 2100.

Climate Change in Hawaiʻi

The global climate system affects regional and local-scale climate conditions in the Pacific Islands, including Hawaiʻi. Detailed in the following sections, projected impacts to the region encompassing the Refuge include shifting rainfall patterns, changing frequencies and intensities of storms and drought, decreasing baseflow in streams, rising air and ocean temperatures, rising sea levels, and changing ocean chemistry (Leong et al. 2014). Small island groups are particularly vulnerable to climate change, sea level rise (SLR), and extreme events. The following characteristics contribute to this vulnerability: small emergent land area compared to the large expanses of surrounding ocean, limited natural resources, high susceptibility to natural disasters, and inadequate funds to mitigate impacts (IPCC 2007, Mimura et al. 2007). Thus, Hawaiʻi is considered to have a limited capacity to adapt to future climate changes.

Atmospheric Events and Precipitation

Precipitation in Hawaiʻi, which includes sea level precipitation and the added orographic effects, shows a steady and significant decline of about 15 percent over the last 15–20 years (Diaz et al. 2005, Chu and Chen 2005). These data are also supported by a steady decline in stream flow beginning in the early 1940s (Oki 2004). However, rain intensity (the type of rainfall that contributes to stream overflow and flooding and is not beneficial for aquifer replenishment) has increased by approximately 12 percent from 1958 to 2007 (Fletcher 2010).

The impact of climate change on water resources is dependent on shifts in precipitation amounts, evaporation rates, storms, and atmospheric processes such as ENSO and PDO. Based on the evidence of the history of ENSO and PDO events, it is likely that these cycles will continue far into the future. However, the potential influence of anthropogenic climate change on ENSO and PDO is unknown. While ENSO events have increased in intensity and frequency over the past decades, some longer-term records have not shown a direct link to climate change 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 suggest that this trend is likely to increase rapidly in the next 50 years. Alternatively, other models predict more "La Niña-like" conditions in the Hawaiian Islands (Walther et al. 2002, Buddemeier et al. 2004, Timm 2008).

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 such as Hawai‘i.

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, and agricultural water (Giambelluca et al. 1996, Solomon et al. 2007, Parry et al. 2007). Global climate modeling projects that net precipitation at sea level near the Hawaiian Islands will decrease in winter by about 4–6 percent near the Hawaiian Islands, with no significant change during summer (IPCC 2007). Downscaling output from global climate models suggest that wet-season (winter) precipitation will decrease by 5–10 percent, while dry-season (summer) precipitation will increase by about 5 percent by the end of the century under a moderate emissions scenario (Timm and Diaz 2009).

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 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 rainfall events of 4 inches per day and a 15–18 percent increase in rainfall intensity over large areas of the Pacific.

Rising Temperatures

A study examining temperature trends over an 88-year period (1919–2006) based on measurements from 21 temperature stations within Hawai‘i showed a long-term increase in temperature and an accelerated rate of increase in the last few decades (0.08 °F/decade for the full record versus about 0.3 °F/decade since 1975) (Giambelluca et al. 2008). In general, warming trends are lower for summer (May–October) and higher for winter (November–April), compared with the annual trends. Additionally, as with the annual trends, warming in both seasons has been greater for high elevation (i.e., greater than 0.5 miles or 800 meters above sea level) stations and for the most recent period. Temperature variation appears to have been tightly coupled to PDO, perhaps through regional sea surface temperature (SST) variation; however, since 1975, the air temperature trend has risen at a faster rate than can be explained by PDO and local SST trends.

These temperature fluctuations have the potential to impact precipitation and existing moisture zones which can influence forest structure composition. A change in forest structure could impact how well vegetation collects water from the atmosphere and during rainfalls and how much of this water gets infiltrated through the ground into aquifers and streams.

Sea Level Rise

According to the IPCC, the oceans are now absorbing more than 80 percent of the heat added to Earth’s climate system. This absorption has caused average global ocean temperatures to increase and seawater to expand. Additionally, the transfer of water mass from the land to the ocean from the heating and melting of ice-sheets, ice caps, and alpine glaciers also influences ocean levels. Scientific evidence suggests that the current, accelerated rate of global change began between the mid-1800s and 1900s (Church and White 2006, Jevrejeva et al. 2008, Church and White 2011). Based on satellite altimeter measurements, the rate of globally averaged SLR since the early 1990s has been estimated to be 0.134 ± 0.016 inches per year (Nerem et al. 2010). This is twice the estimated rate for the 20th century as a whole based on tide-gauge reconstructions (reviewed by Bindoff et al. 2007). Sea-level projections using semi-empirical models based on statistical relationships between observed SLR and global temperature, coupled with projections of future global temperature, yield estimates of global SLR ranging from roughly 3 to 5 feet by 2100 (Rahmstorf 2007, Vermeer and Rahmstorf 2009, Grinsted et al. 2010).

Near Pacific Island ecosystems, local SLR is influenced by the rate and extent of global SLR, as well as changes in episodic events, such as ENSO, PDO, and storm-related conditions (Marra et al. 2012). 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).

Sea level around the Hawaiian Islands is rising by 6 to 14 inches per century (EPA 1998, Giambelluca 2008). The University of Hawaiʻi Sea Level Center has estimated that between 1905 and 2006 mean sea level rose about 0.0417 inches per year. A similar estimate was derived from shallow core measurements of a fringing reef crest at Hanauma Bay, which concluded that Oʻahu is subsiding at a rate of 0.0394–0.0787 inches per year. Although most of this rise is due to isostatic sinking of the tectonic plate, global warming induced sea level increases have the potential to intensify this rise (Nakiboglu et al. 1983, Caccamise et al. 2005).

Globally, the potential for wetland loss due to inundation has been estimated at 22 percent, of which 70 percent is due directly to SLR and other human factors. It is estimated that a rise of about 1.5 feet in sea level could lead to the loss of 50 percent of North American coastal wetlands. Inundation effects include changes in wetland communities, salinization of freshwater areas, movement of species, increased vulnerability of stressed species to disease, and changes in soil composition (Bedoya et al. 2008).

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. For example, paleoecological studies have shown that the distribution of vegetation is highly influenced by climate. The reproductive physiology and population dynamics of amphibians and reptiles are highly influenced by environmental conditions such as temperature and humidity. For example, whether a sea turtle is male or female 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 could have an effect on seabirds and waterbirds through increased heat stress leading to mortality or inundation of breeding sites due to SLR or storm surge (Duffy 1993, Walther et al. 2002, Baker et al. 2006, Young et al. 2012).

Warming has caused species to shift toward the poles or higher altitudes and changes in climatic conditions can alter community composition. Increases in CO_2 levels can impact plant photosynthetic rates, reduce water stress, decrease nutrient content, and lower herbivore weights. Climate change can increase the loss of species. Some of the characteristics that make species vulnerable include small population sizes, restricted or patchy ranges, occurrences at either high or low-lying areas, with limited climatic ranges, and narrow or specific habitat requirements—all characteristics of endangered species in Hawai‘i. 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).

The Hawaiian Islands were recognized in a report as one of ten places to save for endangered species in light of climate change (ESC 2011). Climate change has the potential to influence two important ecological issues in the State of Hawai‘i: endangered species and pest species. Species decline has 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. For example, 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).

The Service is supporting regional Landscape Conservation Cooperatives. These cooperatives are public-private partnerships that recognize conservation challenges transcend political and jurisdictional boundaries and require a more networked approach to conservation—holistic, collaborative, adaptive, and grounded in science to ensure the sustainability of America’s land, water, wildlife, and cultural resources. The local version of these Landscape Conservation Cooperatives is the Pacific Islands Climate Change Cooperative (PICCC), headquartered in Honolulu, Hawai‘i, and 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, and nongovernmental conservation organizations and academic institutions, forming a cooperative partnership that determines the overall organizational vision, mission, and goals.

At the Refuge, climate change could, among other things, reduce the areal extent of beaches, including the small and secluded beach in the Kīlauea (East) Cove which is used by foraging shorebirds (e.g., ‘ulili, ‘akekeke, and kōlea), roosting seabirds (e.g., ‘iwa and ‘ā [brown boobies and red-footed boobies]), and by ‘īlio-holo-i-ka-uaua and honu as a haul-out site for resting and potentially for pupping and/or nesting; and, in the Kāhili Quarry area, by Refuge visitors for recreation. There may also be effects on Refuge vegetation communities and the wildlife they support; on the near-shore ocean environment which supports marine life preyed upon by Refuge sea and shore birds, and enjoyed by Refuge visitors; and on the waterway that drains to the ocean through Kīlauea River and adjacent riparian and wetland habitats. Additionally, high-island refuges like Kilauea Point could become increasingly important to sea and shore birds if the areal extent of their breeding, foraging, loafing, and other habitats on low-islands in the mid-Pacific Ocean are reduced or displaced as a result of sea-level rise.

Additionally, national wildlife refuges will be exploring options for more effective engagement with visitors on this topic. The 2010–2011 National Visitor Survey collected information about visitors’ levels of personal involvement in climate change as it relates to fish, wildlife, and their habitats, and the visitors' beliefs regarding this topic (Sexton et al. 2011). Items draw from the "Six Americas" framework for understanding public sentiment toward climate change (Leiserowitz, Maibach, and Roser-Renouf 2008) and from literature on climate change message frames (e.g., Nisbet 2009). Such information provides a baseline for understanding visitor perceptions of climate change within the context of fish and wildlife conservation that can further inform related communication and outreach strategies.

For Kīlauea Point NWR, the majority of visitors believe the following regarding climate change as it relates to fish, wildlife, and their habitats:

- Future generations will benefit if we address climate change effects;
- It is important to consider the economic benefits to local communities when addressing climate change effects; and
- We can improve our quality of life if we address the effects of climate change.

The majority of visitors do *not* believe:

- There has been too much emphasis on the catastrophic effects of climate change.

Forty-two percent of visitors indicated that their experience would be enhanced if Kīlauea Point NWR provided information about how they could help address the effects of climate change on fish, wildlife, and their habitats. Framing the information in a way that resonates most with visitors may result in a more engaged public who will support strategies aimed at alleviating climate change pressures (Sexton et al. 2011).

3.2 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 (Lau and Mink 2006).

Rainfall contributes roughly 2.88 million gallons per day (mgd) to the water budget of Kaua‘i Island (County of Kaua‘i 2001). This rainwater recharges two vital water resources: groundwater and surface water.

Groundwater, which occurs beneath the surface, is the primary water resource in Hawai‘i. The major fresh groundwater systems are freshwater-lens or dike-impounded systems, which are below the water tables (USGS 2000). Groundwater can occur as a thin basal lens, as well as high-level aquifers where freshwater does not float on seawater (Juvik and Juvik 1998).

Surface water is water flowing in stream channels, lakes, ponds, or wetlands. This water originates from precipitation (e.g., direct rainfall, fog drip), surface runoff derived from rainfall, and groundwater seepage. Streams are classified as intermittent or perennial based on flow conditions. Perennial streams are streams that have continuous flow all year, whereas intermittent streams are those which normally cease flowing during certain times of the year. The longest flowing stream on Kaua‘i is the Waimea River/Po‘omau Stream, a perennial stream which flows 19.5 miles. Perennial streams, which are generally sustained by groundwater in aquifers, are usually restricted to the windward sides of islands that receive more rain (Juvik and Juvik 1998).

Prior to European settlement, water was controlled by the konohiki (headman) as part of the ahupua‘a system. Water was considered sacred; it was a gift from Kane I ka wai ola (Procreator in the water of life), and delivered by Lono makua (the Rain Provider). The wai (water) was “life” for the farmer as it was necessary for kalo (taro), which was grown in the streams, valleys and springs.

Today, the use of water resources in the Hawaiian Islands is regulated by the State Water Code, Chapter 174C, and governed by the State Commission on Water Resource Management (CWRM). This agency issues permits to regulate the use of surface and ground water. Between 1988 and 1989, water users in Hawai‘i were required to register their water sources and declare their water uses to CWRM (CWRM 1992). A water right is a legal entitlement to use a certain amount of water from a particular source for a beneficial use. Outside designated water management areas landowners have the right to “reasonable use” of underlying groundwater and riparian water, providing it does not harm the uses of other users (Miike 2004). Specific water rights for descendants of Native Hawaiians who inhabited the Hawaiian Islands prior to 1778 are discussed in Section §174C-101 of the State Water Code.

The Refuge is located in the Kīlauea watershed, which is a little over 8,000 acres. There are no hydrological features (e.g., streams, tributaries, ponds, lakes, groundwater) on the fee-owned areas of the Refuge. However, in the non–fee-owned and adjacent areas of the Refuge, there are several streams and freshwater ponds. To the east is Kīlauea River, a perennial stream that is 4 miles long and empties out to Kīlauea Bay via Kāhili Beach (also known as Rock Quarry Beach). It begins as two main streams coming off the Kamo‘okoa Ridge and from Mount Namahana (Halualanai and Pu‘u Ka Ele streams) and converges southwest of the Refuge to become Kīlauea River. This river has an average flow of 8.21 cubic feet per second (USFWS 2007). There are also two waterfalls along the river makai (ocean side) of Kūhiō Highway. Intermittent tributaries run off Kīlauea River and include Kaluamakua and Wailapa. Additional intermittent streams to the east include Kulihaili and Pīla‘a. To the west of the Refuge, Niu is categorized as a nonperennial stream, while Pu‘ukumu is a perennial stream and has a stream gage (USGS station number 16097900). Along the northern boundary of the Refuge are coastal waters, which are State-owned and managed. According to the State Department of Health’s water quality classification, the coastal waters directly below the Refuge are classified as Marine Waters Class A (EPA 1988):

> It is the objective of this class of 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.

According to the Federal Emergency Management Agency’s Flood Insurance Rate Maps, Refuge lands and surrounding areas are zoned X, which is the flood insurance rate zone that corresponds to areas outside the 500-year floodplain, areas within the 500-year floodplain, and to areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 100-year flood by levees. No based flood elevations or depths are shown within this zone. The Kīlauea River is in both Zones AE and VE; however, the Refuge sits well above this. Zone VE is the flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. The 34- to 36-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone. Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the flood insurance studies by detailed methods. In most instances, whole-foot base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone (DLNR 2011).

3.3 Topography and Bathymetry

The Kīlauea River Valley provides drainage for the nearby mountains, mainly Kamoʻokoa ridge. The fee-owned part of the Refuge is higher in elevation, with the highest point on Crater Hill at 568 feet, as indicated by the USGS marker. Kīlauea Town itself is a flat plain.

3.4 Geology and Geomorphology

Kauaʻi, which is approximately 550 square miles, consists of a single great shield volcano that is deeply eroded and partly veneered from much later volcanic activity. The shield volcano was created by the extrusion from lava of the Waimea Canyon Volcanic Series during the late Pliocene Epoch. Following the cessation of the main volcanic-building event, there was renewed volcanic activity with the extrusion of the post-erosional Kōloa Volcanic Series. Rocks of the Kōloa Volcanic Series are generally characterized as thick flows of dense basalt extruded from dozens of vents and are associated with pyroclastic materials that form low cinder cones at the vent (Blay and Siemers 2004). Kauaʻi is unique among Hawaiian volcanoes because it lacks an obvious rift zone and also has a large caldera complex with a graben (depressed block of land bordered by parallel faults) (Juvik and Juvik 1998). Kauaʻi is also the oldest of the main Hawaiian Islands, with substrates aging from 3.8 to 5.6 million years.

Kīlauea Point is a volcanic cone complex that was formed later, during the vents of Kōloa volcanics (3.65–0.52 million years ago). It is the remnant of the former Kīlauea volcanic vent that last erupted about 500,000 years ago. Two islands, both formerly portions of this volcanic crater, lie off the coast (Mokuʻaeʻae and Makapili). Crater Hill is the highest peak, rising 568 feet from sea level. Due to coastal erosion, only about one-third of the Kīlauea volcano complex still exists, but at one time probably had a diameter of at least 1.2 miles (Blay and Siemers 2004). The east (Mōkōlea Point) and west flanks drop away approximately 200 feet. Slopes range from 10–70 percent (USFWS 1989).

According to the Kauaʻi County General Plan, the Refuge is also considered an important land form according to its heritage resources map.

3.5 Soils

The soils of Kīlauea Point and the adjoining Crater Hill consist primarily of Līhuʻe Silty Clay. Mōkōlea Point, Makapilli Rock, and the ocean cliff surrounding Kīlauea Point are exposed bedrock consisting of basalt and andesite. The soil type (Līhuʻe-Puhi association) is deep, nearly level to steep, well-drained soils that have a fine textured or moderately fine textured subsoil (Foote 1972). Adjacent areas to the Refuge are comprised primarily of oxisols (Līhuʻe-Puhi association, which make up about 12 percent of the island), which contain no more than 10 percent weatherable minerals, and low cation exchange capacity. Oxisols are always a red or yellowish color, due to the high concentration of iron (III) and aluminum oxides and hydroxides. In addition, they also contain quartz and kaolin, plus small amounts of other clay minerals and organic matter (Hue et al. 2010). The elevation of the Līhuʻe-Puhi soil association ranges from near sea level to 800 feet. Areas along the coast as well as bordering Kīlauea River are categorized as rough mountainous land, rough broken land, rock outcrop association (which makes up 50 percent of the island). Such soils are well-drained to excessively drained, very steep to precipitous lands of mountains and gulches. The elevation of this soil association ranges from near sea level to 5,170 feet (Foote 1972).

Kīlauea town and the surrounding area have a history of agriculture (e.g., ranching, sugar plantation). These uses may have impacted present day soils (e.g., chemicals, soil composition). For instance, in the 1920s, Kīlauea Sugar Company planted ironwood to prevent wind erosion and stop the salt air from abrading cultivated crops. Introduction of this new vegetation type to the area may or may not have affected soils (USFWS 1989).

3.6 Fire

Unlike the continental United States where fire can play a large role in ecosystem function and species adaptations, fire is a relatively infrequent disturbance regime in Hawaiian ecosystems. The two primary sources of natural fires are lava flows and lightning strikes (Mueller-Dombois and Lamoureux 1967, Mueller-Dombois 1981, Smith and Tunison 1992). Most ecologists agree that natural fire has not played a significant ecological or evolutionary role in most Hawaiian ecosystems. Most native vegetation is not conducive to fire spread, producing low fuel loads and/or litter of relatively low flammability. When fires did occur, they probably did not spread quickly or extensively due to the patchiness inherent in native habitats. While fires certainly occurred, they were not a formative force in the distribution or type of vegetation found in native Hawaiian habitats. However, early Polynesians used fire to clear much of the native forests of Hawai‘i for agricultural purposes. In the past 200 years, a vast array of nonnative plants and animals have been imported and released into the Hawaiian landscape. The contemporary fire regime in the alien dry grasslands is one of moderate intensity, high frequency (less than 35 years) stand replacement fires that perpetuate the dominant grasses. Under this fire regime, burns are typically complete with little patchiness except under low fire intensity weather conditions, where rock outcrops limit fuel loading, or where fires burn into mixed fuels or another vegetation type. With very few exceptions, fires in these systems benefit alien species and exclude natives. No native species has ever been shown to successfully compete with alien grasses after successive fires.

Most of the vegetation at KPNWR is degraded coastal woodlands (scrub, shrub, and forest) with large open areas of grass. Due to the mild climate, the vegetation on and adjacent to the Refuge experiences a year-round growing season. The exposed nature and strong winds of many areas on the Refuge increase chances of wildfire onsite.

A Cooperative Fire Protection Agreement between the Kaua‘i County Fire Department and the KNWRC was established for initial attack, suppression, and mop-up of wildfires within Refuge lands on Kaua‘i. No prescribed burning has occurred on the Refuge; only small piles of vegetation debris have been burned.

The KNWRC has a Wildland Fire Management Plan that was completed in 2004. Small-scale prescribed burns might be occasionally necessary as a method of disposal of woody debris. Prescribed burns would also require individual burn prescriptions. A Hawai‘i State Department of Health (HDOH) burn permit may also be necessary for each prescribed burn to minimize effects on air quality. The prescribed fire season is expected to be from September to February. Conditions for the permit would exclude specified time periods (“no-burn” days) as broadcast by the National Weather Service.

3.7 Environmental Contaminants

In 2011, a contaminants assessment was conducted for the Refuge, and it concluded that no major contaminant issues existed at that time (USFWS 2011). Historically, however, contaminants did exist on the Refuge. Built in 1913 as a navigational aid for commercial shipping between Hawai‘i and Asia, Kīlauea Lighthouse guided ships and boats safely along Kaua’i’s rugged north shore for 62 years. The lighthouse contains a unique Fresnel lens that weighs about 4.5 tons and was designed to “float” on mercury and pressurized air. In 1998 a mercury leak was discovered by a maintenance worker while chipping rust off the ceiling between the second and third floors. In October 1998 the mercury was cleaned by a hazmat team and properly disposed of. A follow up inspection showed that mercury was no longer present in the clean-up zone or surrounding areas (Paglinawan 1998).

A Formerly Used Defense Site (FUDS) exists on the Refuge but should no longer be a source of contaminants. Previous records, studies, and interviews indicate the Kīlauea Radar Station was constructed by the U.S. Army Corps of Engineers shortly after the outbreak of World War II between 1941and 1942. Records indicate that the station was one of three radar installations located on the island of Kaua‘i. The station was constructed on the highest point of the Crater Hill parcel and included two tunnels (one for radio and one for radio operations), an electrical generation plant, and a 200-foot radar tower. Records indicate after the war, former landowner Kīlauea Plantation used one of the tunnels as a storage area for explosives. An underground tank used to hold petroleum products was removed from the site (Dept. of the Army 1991).

An internal Service environmental compliance audit report was performed in August 2010 for KPNWR. The purpose of the audit was to assess compliance status with Federal, State, and local environmental regulations. This also included compliance with all DOI and Service policies, Executive orders, and any other applicable requirements. Eight findings related to some management categories (hazardous, toxic, pesticide, petroleum/oil/lubricants) were identified for corrective action (mostly related to improving storage, labeling, and training).

3.8 Air Quality

Due to the tradewinds experienced year-round on Kaua‘i, as well as the low population and development on the island, air quality is not considered a problem. However, due to an active volcano on the island of Hawai‘i, air quality is periodically affected by vog (volcanic smog) depending on the eruption and prevailing winds, although Kaua‘i is the least impacted, being farthest away from Hawai‘i Island. The HDOH, which began monitoring activities in 1957, manages several air quality monitoring stations found on O‘ahu, Maui, and Hawai‘i Islands. These stations monitor pollutants to assess air quality compliance with State and Federal standards (standards can be found at http://hawaii.gov/health/environmental/air/cab/index.html, link “Federal and State Ambient Air Quality Standards).

Air quality regulations in the U.S. are based on a set of air quality standards, which are the National Ambient Air Quality Standards. These standards are set to protect the public health and welfare and determine if areas are in attainment or nonattainment. HDOH monitors carbon monoxide, hydrogen sulfide, nitrogen dioxide, ozone, fine particulate matter (10 and 2.5 micrometers), lead, and sulfur dioxide. Only O‘ahu, Maui, and Hawai‘i Islands are monitored for these pollutants. There is a monitoring station on Kaua‘i, but it is a special purpose monitoring station, located at Niumalu, that monitors specifically for cruise ship emissions. This station was made operational in 2010. A previous monitoring station was also located in Līhuʻe, but only monitored for particulate matter 10 and was closed in 2007 (Kihara pers. comm. 2011).

Air quality concerns on Kauaʻi center on the west side, where a major power generation facility and most of the large-scale agriculture and military facilities are found. The Air Quality Index (based on measuring ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide) for Hawaiʻi is considered to be satisfactory with air pollution posing little to no risk. In 2009, the State was in attainment of all National Ambient Air Quality Standards (excluding exceedances due to volcanic activity). A 5-year trend analysis of ambient air quality shows that, with the exception of particulate matter 10 (due to fireworks and construction activities), recorded pollutants are well below both State and Federal standards (DOH 2010).

Additional air quality-related emissions involve GHG. In 2007, it was estimated that approximately 24,270,000 metric tons of GHG emissions were produced in Hawaiʻi, with transportation and electric power comprising 88 percent of the total emissions. Kauaʻi contributed 3 percent to the total State emissions, with a majority of this 3 percent composed of the transportation and electric power sectors (DBEDT 2008). These estimates do not include fuels that were exported, used on international aircraft or ship operations, or used by the military in the State. Additionally, Hawaiʻi is developing means to reduce its GHG emissions. In 2007, the State of Hawaiʻi enacted Act 234, which set a goal to reduce GHG emissions to 1990 levels by 2020.

An internal Service environmental compliance audit report was performed in August 2010 for Kīlauea Point NWR. The purpose of the audit was to assess compliance status with respect to Federal, State, and local environmental regulations. This included compliance with all DOI and Service policies, Executive orders, and any other applicable requirements. The August 2010 audit showed no major findings of violations of air emissions management.

3.9 Water Quality

On Refuge-owned lands, there are no hydrological features, so water quality is not assessed. However, Kīlauea River (which runs through the boundary of the Refuge on non-Refuge owned lands) is listed on the EPA 303(d) List of Impaired Waters for turbidity (HDOH 2008).

Heavy rainfalls are a factor for water quality because during such floods and storms, debris and sediments are washed downriver.

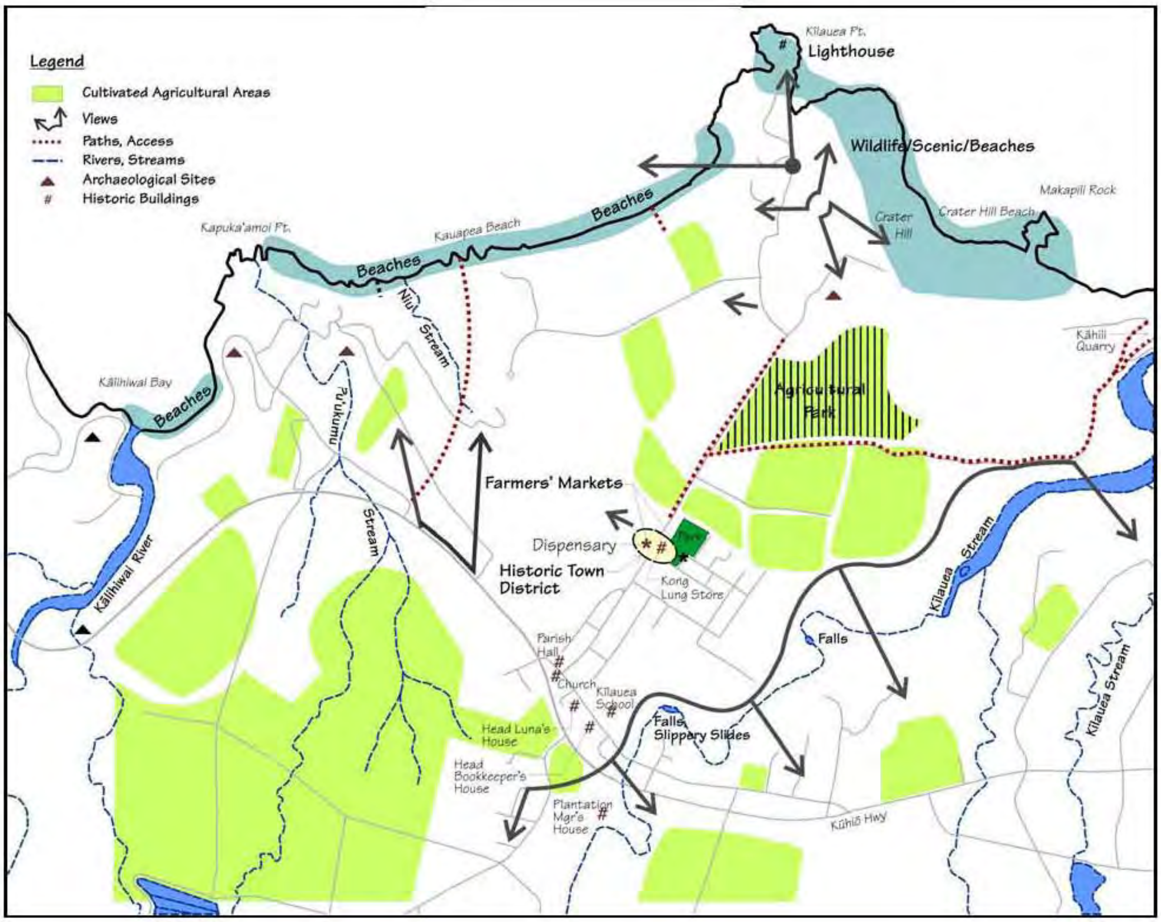
An internal Service environmental compliance audit report was performed in August 2010 for Kīlauea Point NWR. The purpose of the audit was to assess compliance status with respect to Federal, State, and local environmental regulations. This also included compliance with all DOI and Service policies, Executive orders, and any other applicable requirements. The August 2010 audit showed no major findings of violations of water quality management.

3.10 Visual Quality

The dramatic views of the coastline from the areas open to the public on the Refuge are commonly photographed by visitors. The lighthouse and the peninsula on which it stands are also commonly photographed sites (both from the ground and aerially) with images often used for tourism and sight-seeing/attractions related purposes.

The Kīlauea town plan also identifies views as part of Kīlauea's assets (Figure 3-1) and a desire to retain Kīlauea's rural charm and scenic landscapes.

Figure 3-1. Kīlauea Assets Map (County of Kaua'i 2006).



3.11 Surrounding Land Uses

Under the State Land Use Law (Act 187), Hawai'i Revised Statute Chapter 205, all lands in the State are classified into four districts: Agriculture, Rural, Conservation, and Urban. Conservation Districts, under the jurisdiction of the Hawai'i Department of Land and Natural Resources, are further divided into five subzones: Protective, Limited, Resource, General, and Special (Hawai'i Administration Rules, Title 13, Chapter 5). The other three districts are under the jurisdiction of the counties.

Most of the land in the Kīlauea area is private property, with some County (about 95 acres) and few State (a little over 4 acres) properties. Lands to the south of the Refuge are part of Kīlauea town, which includes residential areas, schools, a County park, and commercial properties (e.g., stores, restaurants, markets). Areas of Kīlauea (lands west, south, and east of the Refuge) include high-end properties with large residential estates priced in the millions. Most of Kīlauea is zoned as agriculture with Kīlauea town proper (or commercial core) zoned Urban. Within the larger Kīlauea area are orchard operations to small farms specializing in organic produce (County of Kauaʻi 2006). Most of the Kīlauea area is identified as prime agricultural land under the State's agricultural lands of importance.

Areas directly along the coast are zoned Conservation. Areas on and adjacent to the Refuge are also zoned as special management areas under the Coastal Zone Management Program (see figures in Chapter 1 for location maps and Chapter 5 for further information on towns). The Kauaʻi Public Land Trust (which is now part of the Hawaiian Islands Land Trust) also owns lands, for the purpose of conservation, within the Refuge boundary.

Within the expanded Refuge boundary, adjacent waterways (e.g., Kīlauea River) provide recreation (e.g., fishing, kayaking) and a beach area (Kāhili) that is used for picnicking, swimming, surfing, etc. The Hawaiʻi Department of Land and Natural Resources manages the fisheries and aquatic resources in the Kīlauea River.

The coastal waters around the Refuge are also part of the Humpback Whale National Marine Sanctuary which is jointly administered by the State and NOAA. Directly north and to the west of Mokuʻaeʻae Rock/Sea Stack is a State marine managed area (bottomfish restricted fishing area).

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