Big Island Impacts:
Effects of Current and Potential Future Land Use on Water Quality, Carbon Emissions, and Wildlife at Kohala Institute

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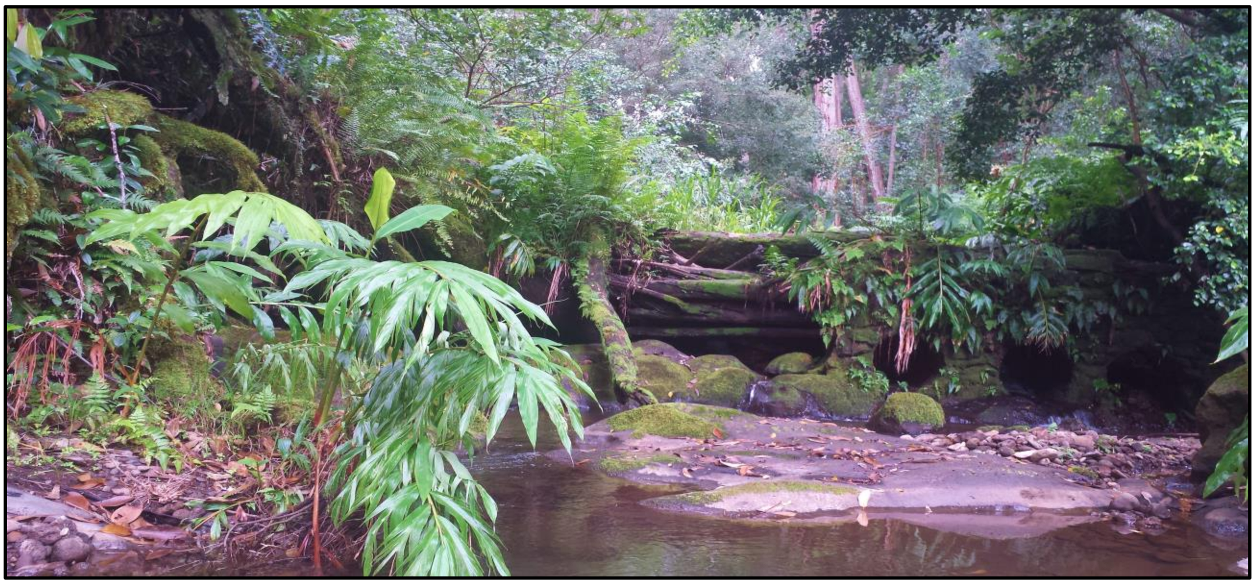
May 2017



Master's Group Project
Bren School of Environmental Science & Management
University of California, Santa Barbara

Faculty Advisor
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BREN SCHOOL
ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

KOHALA INSTITUTE

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Effects of Current and Potential Future Land Use on Water Quality, Carbon Emissions, and Wildlife at Kohala Institute

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

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Signature Page

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Report is authored by MESM students and has been reviewed and approved by:

DR. FRANK DAVIS

May _______, 2017

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Contents

List of Figures

List of Tables

List of Abbreviations

ACD	Above-ground carbon density
AGB	Above-ground biomass
BCD	Below-ground carbon density
BGB	Below-ground biomass
C	Carbon
CH_4	Methane
cm	Centimeters
CN	Curve number
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
DARE	Department of Agriculture and Resource Economics
DAS	Department of Animal Sciences
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GHG	Greenhouse gas
HELCO	Hawaii Electric Light Company
HIPAg	Hawaii Institute of Pacific Agriculture
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilograms
KI	Kohala Institute
kWh	Kilowatt hour
LCA	Life cycle assessment
LiDAR	Light detection and ranging
m	Meters
N_2O	Nitrous oxide
N-SPECT	Nonpoint Source Erosion Comparison Tool
SOM	Soil organic matter
t	Metric tons
TN	Total nitrogen
TP	Total phosphorus
TWh	Terawatt hour

Abstract

The Big Island of Hawaii supports some of the most unique ecosystems in the world, but these ecosystems have been highly altered by human activities. Kohala Institute (KI), a 501(c)(3) non-profit, is tasked with stewarding 2,418 acres on Hawaii Island and providing economic opportunities for the local community. We assessed how five alternative future land use scenarios—Baseline, Pasture, Agriculture, Forest, and Riparian Buffer—impact KI's water quality, carbon footprint, and wildlife habitat. Pasture and cropland contributed the most to total runoff and pollutant loadings of total phosphorus (TP), nitrogen (TN), and sediment. Conversion of forest to pasture contributed the most to carbon emissions, and the decrease in forest and shrub contributed the most to habitat loss and degradation for the endangered Hawaiian hawk, Hawaiian hoary bat, and Hawaiian goose. Undesirable environmental impacts associated with expanded agricultural activities on the property can be reduced by using best management practices and mitigation strategies. This report is intended to help KI minimize their environmental impacts when determining future land uses as their organization continues to grow.

Executive Summary

Kohala Institute (KI), a 501(c)(3) non-profit, was founded in 2016 and manages 2,418 acres on Hawaii Island. Their land consists of several deep gulch systems, large tracts of forest, wide pasture lands, several acres of taro and row crops, over one-hundred-year-old macadamia nut groves, and several developed areas, including the historic Bond District, KI offices, and KI Grace Center. Their property extends from the ocean to roughly 2,000ft in elevation and receives an ample supply of rainfall throughout the year (Gerrish, 2003a). Their mission, "to provide opportunities for people to connect with the land and universal values for a better world" (Kohala Institute, 2014), aims to provide economic opportunities for the local Hawaiian community while acting as a steward for the land by performing sustainable land management. Many land managers struggle with this balance between environmentally responsible land use and economic productivity.

This project investigates the impacts to water quality, carbon emissions, and wildlife habitat from the expansion of anthropogenic activities on KI's property, and recommends strategies for reducing these impacts. KI is interested in expanding their agricultural activities and pasturelands, while also continuing to develop several other pilot projects (i.e., Kohala Mountain Fish, KI tours, and KI microgrid). To model and assess the impacts from these expansions, Big Island Impacts created five land use scenarios, each with a 20 year planning horizon, to capture varying degrees of future development:

1. <u>Baseline</u>: No changes to current land activities.
2. <u>Pasture</u>: Expand pasture land by 645 acres and improve the road network.
3. <u>Agriculture</u>: Maintain changes from the previous scenario *and* expand agriculture land with 38 acres of row crops and 30 acres of orchards.
4. <u>Forest:</u> Maintain changes from the previous scenario *and* preserve or restore 100 acres of forest land.
5. <u>Riparian Buffer</u>: Maintain changes from the previous scenario *and* preserve or restore natural vegetation within 50-meter riparian buffers.

However, before KI can expand any of their current land use activities they must be able to access desired portions of their property. To understand KI's current accessibility and recommend improvements to it, their road network was mapped and ArcGIS was used to assess the time it takes to travel from KI's headquarters, the GRACE Center, to every other location on their property. The results indicated that access to KI's southernmost portion of their property was limited to travel on foot and exceeded 30 minutes in travel time, making it both inconvenient and inaccessible to the equipment necessary for land conversion. Using these results as a baseline, new roads were proposed, which reduced travel time by up to 50% and allowed the entire property to be accessed by vehicle. These new roads were incorporated into the alternative scenarios.

Next, the impacts to water quality under each scenario were analyzed. Row cropping was shown to contribute the most to total runoff and pollutant loadings (i.e., nitrogen, phosphorus, and sediment) per acre, followed by developed land and pasture land. The Riparian Buffer Scenario saw a decrease in phosphorus, nitrogen, and sediment pollutant loadings from the Baseline Scenario due to the vegetated riparian buffers limiting the expansion of agriculture and pasture lands. It is important to note that pollutant and runoff loadings generated were based on default values provided by the National Oceanic and Atmospheric Administration (NOAA) because KI

lacked local water quality data. While these results provide a first-look into water quality impacts, collecting on-site data should be KI's first priority before implementing best management practices for water quality protection.

An analysis of KI's carbon emissions was also performed for the five land use scenarios. This assessment estimated the carbon emissions from land use conversion, cattle, purchased electricity, and erosion, as well as the amount of carbon sequestered by vegetation on KI's property. Under the Baseline Scenario, cattle were the largest emitters of CO_2, with electricity and erosion the second and third largest contributors. Under the four alternative scenarios, emissions increased dramatically, primarily due to the large amounts of forest cleared for the expansion of pasture land; land use conversion accounted for over 90% of total emissions under the Pasture, Agriculture, Forest, and Riparian Buffer Scenarios. Erosion and sequestration had a minimal effect on total emissions, contributing less than 1% and mitigating approximately 1% of total emission, respectively. These results indicate that the simplest method for reducing emissions is to minimize the amount of forest cleared. However, other strategies to reduce total emissions are also explored.

Finally, to assess how KI's land use activities will impact species of concern likely to be found on KI's property, a wildlife habitat analysis was performed for all five land use scenarios. Three species of concern were selected based on their risk of extinction, likelihood of occurrence at KI, and terrestrial habitat: the Hawaiian hawk, the Hawaiian hoary bat, and the Hawaiian goose. When compared to the Baseline Scenario, suitable habitat for all three species declined under the Pasture, Agriculture, Forest, and Riparian Buffer Scenarios. The Hawaiian hawk and Hawaiian hoary bat were especially affected, as they rely on forest for habitat, while the Hawaiian goose was marginally affected, as it prefers shrub land—and large amounts of forest were converted to pasture land under the Pasture, Agriculture, Forest, and Riparian Buffer Scenarios, but only small amounts of shrub land were converted under these scenarios.

This project indicates which land use activities have the largest impacts to water quality, carbon emissions, and wildlife habitat. The results indicate that the expansion of any anthropogenic land uses will have negative effects on the three impact categories. However, 'no action' is often not a realistic option for a land use manager. Therefore, mitigation strategies were recommended to decrease KI's impacts should they decide to implement any of the proposed increases of anthropogenic land use on their property.

Part 1. Background

1.1 Objectives

Land managers often face difficult decisions when trying to determine how to utilize their land. These decisions are further complicated when considering not only economic factors, but environmental ones as well. The purpose of the Big Island Impacts group project was to assist Kohala Institute (KI) in identifying the best potential uses for their land by analyzing the effects to water quality, carbon emissions, accessibility, and wildlife under current and proposed land uses.

The project has three primary objectives:

1. Determine current and proposed land uses, as well as land characteristics of KI's property.

2. Analyze the effects to KI's water quality, carbon footprint, and wildlife habitat under five different land use scenarios over a 20-year planning horizon.

    a) <u>Baseline Scenario:</u> No changes to current land use activities.

    b) <u>Pasture Scenario:</u> Expand pasture land and improve road network.

    c) <u>Agriculture Scenario:</u> Maintain changes from the previous scenario *and* expand agricultural land.

    d) <u>Forest Scenario:</u> Maintain changes from the previous scenario *and* preserve or restore forest land.

    e) <u>Riparian Buffer Scenario:</u> Maintain changes from the previous scenario *and* preserve or restore natural vegetation within the riparian buffers.

3. Recommend land uses and management practices to minimize KI's water quality impacts, carbon emissions, and habitat degradation.

1.2 A History of the ʻIole Ahupuaʻa

Kohala Institute (KI) is a 501(c)(3) non-profit that stewards 2,418 acres in Kapaʻau, Hawaii. This land includes one of the few remaining intact ahupuaʻa, called ʻIole, and the Bond Historic District, which consists of the Bond Homestead, Kohala Girls School, and Kalahikiola Church. An ahupuaʻa is a traditional Hawaiian division of land that prioritizes the conservation of natural resources available to maintain sustainable levels of resource use; there were some 1,625 ahupuaʻa in ancient Hawaii (Ku'uipo Losch & Kamahele, 2008). The ʻIole ahupuaʻa has a long agricultural history and purportedly contained the two favorite taro patches (loʻi kalo) of King Kamehameha I, who unified the islands and established the Kingdom of Hawaii in 1810 (Potter, Kasdon, & Rayson, 2003). The presence of abundant springs, which allowed for the irrigation of taro and other Hawaiian staples, played an important role in the agricultural history of ʻIole (Morgan, 1981). ʻIole also once possessed many of the ecosystems that are unique to Hawaii (mesic forests, coastal shrub lands, and dry forest); however with the arrival of foreigners, much of the island was converted to sugarcane.

In 1841, Elias Bond, a protestant missionary from Maine, settled near present day Kapaʻau and established what is now referred to as the Bond Historic District (Morgan, 1981). In 1863, Bond approached Castle & Cooke, a business associated with the Protestant Mission, about setting up a sugarcane company to provide the local Hawaiians with work (Morgan, 1981). Part of Bond's and his neighbor's land became the center for the Kohala Sugar Company, which would go on to operate for over a 100 years (Morgan, 1981). In 1906, during the peak of the Kohala Sugar Company's power, they controlled over 13,500 acres of sugar plantations on the Island of Hawaii and built the Kohala Ditch to bring water from the wetter highlands to the dryer lowlands (Morgan, 1981). During the late-1800s, Elias Bond's son, Benjamin, began cultivating the first macadamia nut trees on the property (Morgan, 1981). Benjamin's son, Kenneth, took an active interest in the macadamia nut trees and expanded the macadamia nut orchards to 60 acres in 1939 (Morgan, 1981).

In the 1930s, plantation workers began to successfully form unions and press for better wages and rights (McAvoy, 2016). After World War II, U.S. tariffs and quota protections for sugar began to decrease with the advent of large-scale trade liberalization (McAvoy, 2016). Consequently, sugarcane plantations in Hawaii suffered and their owners sought alternative profit-generating activities (McAvoy, 2016). During the mid-1950s, the Kohala Sugar Company brought in, cultivated, and sold *Rauvolfia vomitoria* to a pharmaceutical company in an effort to boost revenues; however, the Kohala Sugar Company closed down in 1975 (Morgan, 1981). Originally from Africa, *R. vomitoria* contains a potent anti-psychotic, resperin (D. Waterman, personal communication, July 27, 1956). Today, *R. vomitoria* has become one of the most invasive plant species found on the Island of Hawaii (D. Waterman, correspondence with W. Yee, July 27, 1956).

During this same period of time, the ʻIole Development Corporation formed in 1967 to hold trust over the Bond Estate (Morgan, 1981). It began leasing land to ranchers and expanding the existing macadamia nut orchards from 60 to 460 acres (Iole Development Corporation, 1989). From 1998-2008, the 2,418 acres of land were purchased by Bennett Dorrance Jr., and then donated to the private New Moon Foundation, established in 1999, to steward the lands and create positive community impacts. As part of an effort to involve community partners in managing the land and supporting local agriculture, New Moon Foundation leased large tracts of their land for cattle grazing and turned over management of the extensive macadamia nut orchards to Island Harvest

Inc. In 2016, Kohala Institute (KI), a new public charity, was given a master lease of all 2,418 acres, with the goal of carrying out the New Moon Foundation's mission.

1.3 The Client: Kohala Institute

Kohala Institute (KI) maintains stewardship over the property to this day. Presently, KI is a nonprofit organization operating on the Big Island of Hawaii. Their mission is to "provide opportunities for people to connect with the land and universal values for a better world" (KI 2016). They are concerned with the closely interrelated issues of traditional Hawaiian culture and environmental conservation — respect for one another, and respect for the land. KI has identified several distinct objectives for their activities, which guided the development of this project.

KI hopes to serve as a platform for community engagement, which they currently implement through Collaboration for Solutions. Collaboration for Solutions is an innovative approach to civic engagement where diverse stakeholders build relationships with one another by utilizing place-based experiences and expert facilitation to find mutually beneficial outcomes. This objective informs KI's thinking when developing strategic projects. KI also hopes to continue the traditional Hawaiian land use practice of the *ahupuaʻa*, or watershed-based management, in order to remain as environmentally sustainable as possible throughout all of their various activities.

This is an exciting time for KI, as many of their strategic projects are just now gaining momentum and will undoubtedly continue to grow. KI is in the process of implementing an ambitious five-year strategic plan that is focused on creating a model for a "21st Century Ahupua'a", which integrates responsible natural resource management, financial sustainability, and sustainable living outreach programs ("What We Do," 2017). This plan includes the development of an innovative fish farm – Kohala Mountain Fish Company – with a hatchery, grow tanks, and processing facility; a land and water management tour – KI Tours – showcasing best practices for land conservation; a microgrid consisting of an hydroelectric plant, solar panels, and energy storage; and, a 30-acre agricultural park – KI Farms – demonstrating successful and sustainable methods of growing food to meet Hawaii Island's food security needs (Kohala Institute, 2014). All of these projects are presently in the pilot stage.

Currently, the majority of the property is leased to cattle ranchers and Island Harvest. However, much of the leased cattle land is currently unusable due to invasive plant growth; invasive plants are also threatening Island Harvest's macadamia nut yields. Despite the recent flurry of development on KI's property, the vast majority of the land is still being used as it has been for the past 40 years — for cattle grazing and agriculture.

The Big Island Impacts group project assessed the impacts from KI's current and potential land use on water quality, carbon emissions, and wildlife to help inform their land use decisions moving forward.

1.4 Physical Setting

Introduction

Kohala Institute (KI) resides over four distinct watersheds: the Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds (“Watersheds,” 2016). Currently, 89% of KI’s property and 86% of the four watersheds are overrun by invasive plant species, which include, but are not limited to, *Psidium guajava* (Common Guava), *Caesalpinia decapetala* (Mysore Thorn), *Macfadyena unguis-cati* (Cat’s Claw Creeper), *Psidium cattleianum* (Strawberry Guava), *Rauvolfia vomitoria* (Poison Devil’s Pepper), and *Elaeocapus grandis* (Blue Marble Tree) (MacAdam-Somer, Laws, Blansett, & Cohen, 2016; “National GAP Analysis,” 2001, “Watersheds,” 2016). The invasive plants have prevented the land from being used for economically productive uses, namely agriculture and cattle grazing; only 12% of KI’s property and 10% of the four watersheds are currently used for agricultural purposes (McAvoy, 2016; Morgan, 1981; “National GAP Analysis,” 2001, “Watersheds,” 2016).

Location

The Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds are located on the north side of the Big Island of Hawaii near the towns of Hawi and Kapaʻau. These watersheds have a total surface area of 7,488 acres; extend 7 miles in length from mauka (i.e., mountain-side) to makai (i.e., ocean-side); and span 2 miles in width from east to west (Fig. 1.4.1). The longest tributary in these watersheds is the Kapaʻau Gulch (Fig. 1.4.1). It is 7.2 miles in length, passes through KI’s property, and drains into the Pacific Ocean (Fig. 1.4.1) (“Hydrography: National Hydrography Dataset, Watershed Boundary Dataset,” 2016, “Watersheds,” 2016).

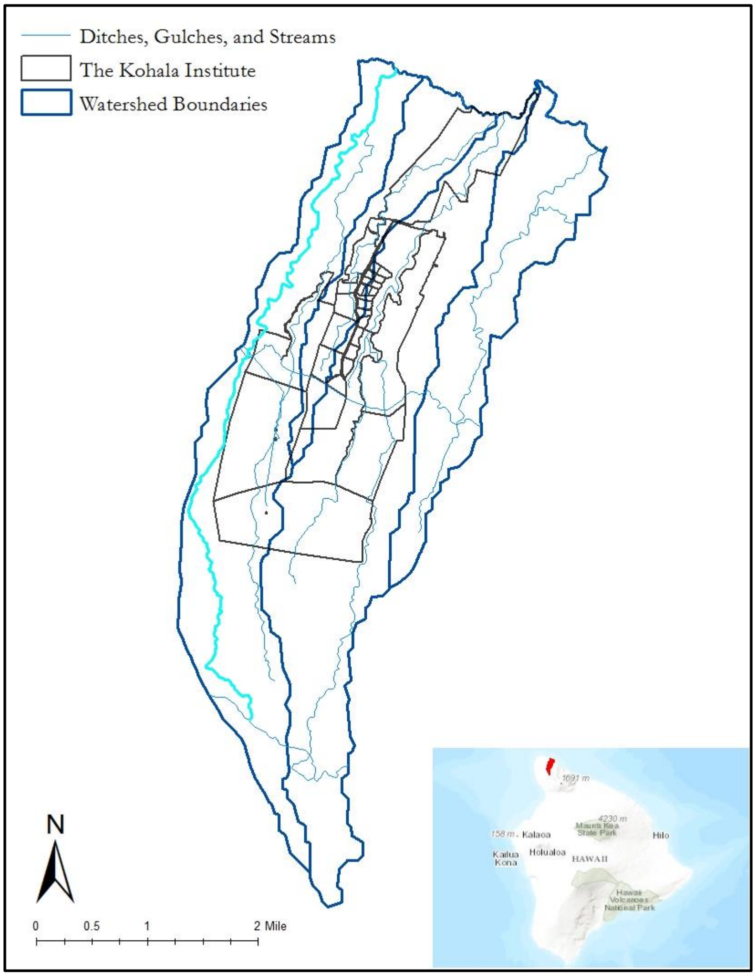

Figure 1.4.1. The locations of the Kohala Institute (KI), the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right), and their ditches, gulches, and streams. The four watersheds are indicated in red in the location map in the bottom-right-hand corner. The Kapa'au Gulch, the longest stream in the watershed area, is indicated in light blue in the main map. Sources: Hawaii Statewide GIS Program, the Kohala Institute, USGS Hydrography Dataset, and Esri Topographic Basemap.

Topography

The headwaters (i.e., the beginning) of the Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds are located in the south in the Kohala Mountains, where water travels approximately 7 miles northeast to discharge into the Pacific Ocean (Fig. 1.4.2). The peak of the watershed area resides in the Wainaia watershed at 1,031 meters above sea level, where water travels about 3.6 miles north to an elevation of 448 meters above sea level (Fig. 1.4.2). From there, water continues to travel northeast to an elevation of about 0.68 meters below sea level where it drains into the Pacific Ocean (Fig. 1.4.2). As seen in Figure 1.4.2, there are three discharge locations in this watershed area, one of which is located on KI's property (Fig. 1.4.2).

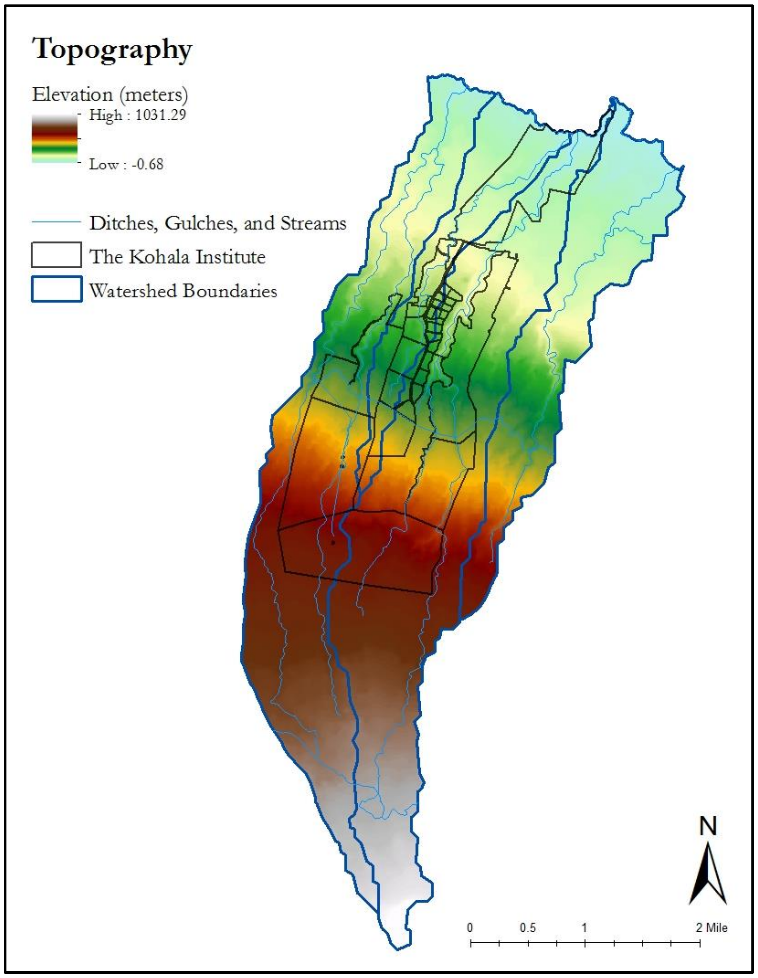

Figure 1.4.2. Elevations of the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right) and their ditches, gulches, and streams ranging from -0.68 meters below sea level by the Pacific Ocean to 1,031.29 meters above sea level in the mountains. Sources: Hawaii Statewide GIS Program, the Kohala Institute, USGS Hydrography Dataset, and USGS National Elevation Dataset (NED).

Climate

The Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds vary significantly in terms of climate and span multiple Koppen climate classification zones. The majority of the watershed area is characterized by a warm, humid, tropical climate with the mauka-side receiving ample rainfall brought by northeasterly tradewinds (Gerrish, 2003b; Miller, 1978). According to an historical 30-year rainfall dataset, higher levels of precipitation can be seen in the headwaters of the watersheds, which are located at the higher elevations in the Kohala Mountains (Fig. 1.4.3) (T.W. Giambelluca et al., 2013). Precipitation generally increases as elevation increases (Fig. 1.4.3) (T.W. Giambelluca et al., 2013). Over the last 30 years, the average annual rainfall in this watershed area has been 63.6 inches (Eggleston, 2017). The driest and wettest years during this 30-year time period were seen in 1997 and 1999 with 33.2 inches and 109.3 inches of rainfall, respectively (Eggleston, 2017).

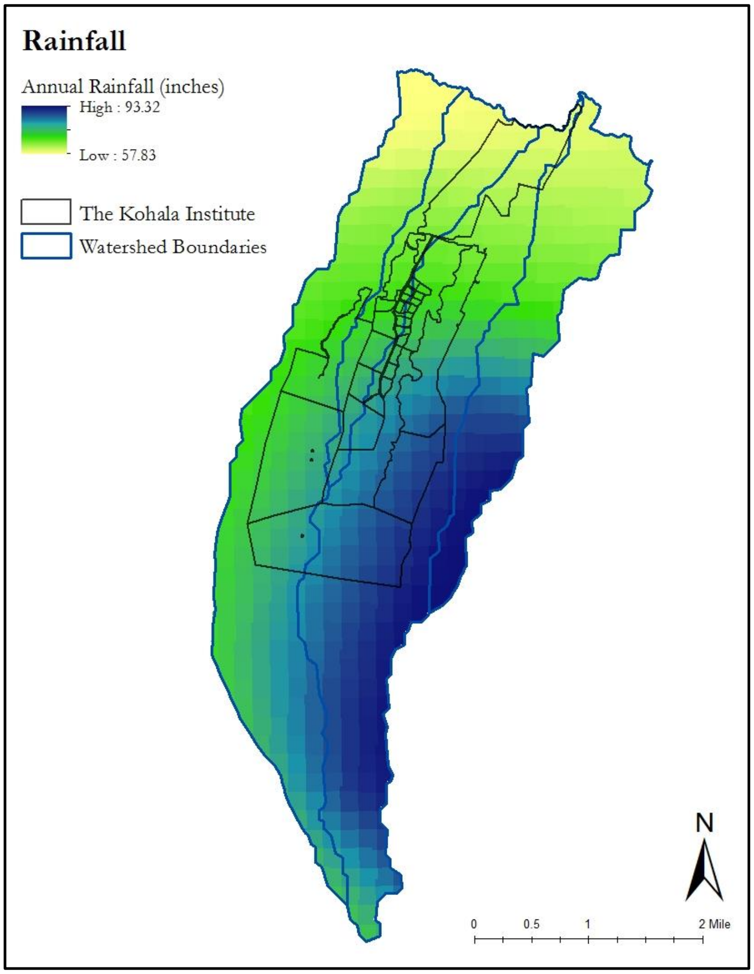

Figure 1.4.3. Average annual rainfall in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right) from 1978-2007. Sources: Hawaii Statewide GIS Program, Giambelluca et al., 2013, and the Kohala Institute.

On KI's property, the average annual rainfall is about 60~~.7~~ inches at lower elevations near the coastline and about 93~~.3~~ inches at higher elevations near the Kohala Mountains (T.W. Giambelluca et al., 2013). By contrast, the average annual temperature within these watersheds generally increases as proximity to the coastline increases (Fig. 1.4.4). The average annual temperature in this watershed area is about 23°C (i.e., 73°F) at lower elevations near the coastline and about 17°C (i.e., 63°F) at higher elevations near the Kohala Mountains (Fig. 1.4.4) (T.W. Giambelluca et al., 2014). On KI's property, the average annual temperature is about 75°F at lower elevations near the coastline and about 67°F at higher elevations near the Kohala Mountains (Gerrish, 2003c).

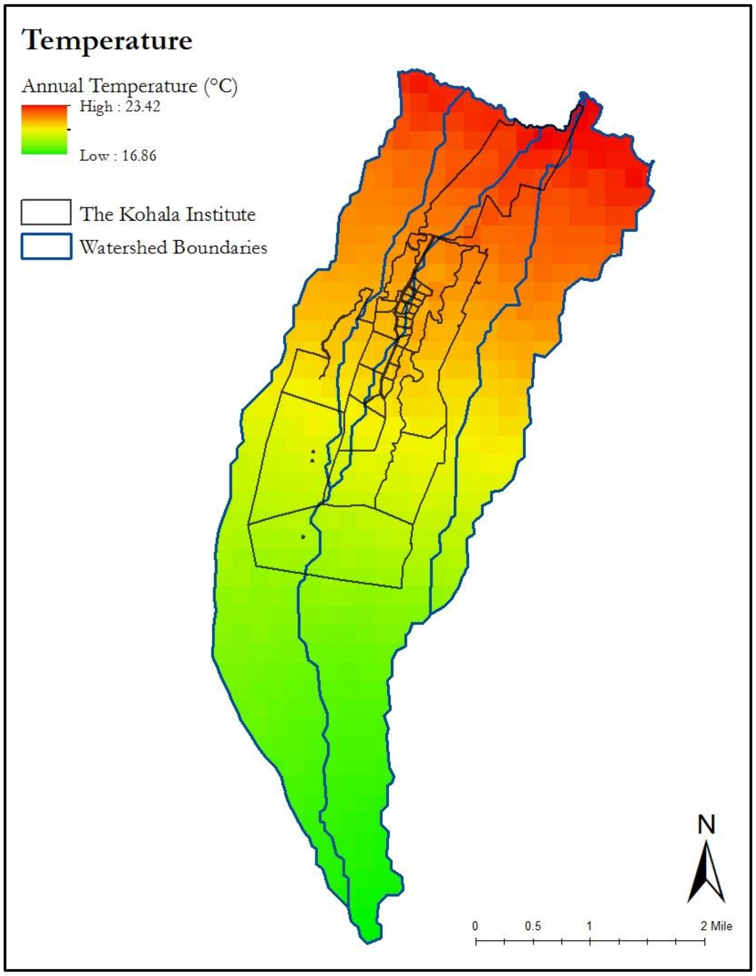

Figure 1.4.4. Average annual temperature in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right) from 1978-2007. Sources: Hawaii Statewide GIS Program, Giambelluca et al., 2014, and the Kohala Institute.

Geology

The northwestern movement of the Pacific Plate over the Hawaiian hotspot (i.e., a weak spot in the Earth's crust where magma from the mantle escapes from the ocean's surface) formed the Hawaiian Islands. The Big Island of Hawaii was formed by five different volcanoes, listed oldest to youngest: Kohala, Mauna Kea, Hualalai, Mauna Loa, and Kilauea. The Kohala volcano formed the North Kohala region of the Big Island approximately 500,000 years ago, making it the oldest geologic area on the island with an elevation of 1,670 meters (Gerrish, 2003b; "Kohala: Hawaii's Oldest Volcano," 1998).

The Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds are comprised of three distinct rock types, the majority of which are lava flows from volcanic ash (Fig. 1.4.7). Benmoreite lava flows comprise some portions of the eastern and southern regions of the Wainaia and Halelua watersheds, respectively (Fig. 1.4.7). Scoria cones only comprise a small area at the southernmost tip of the Wainaia watershed (Fig. 1.4.7) ("Geological Units," 2016).

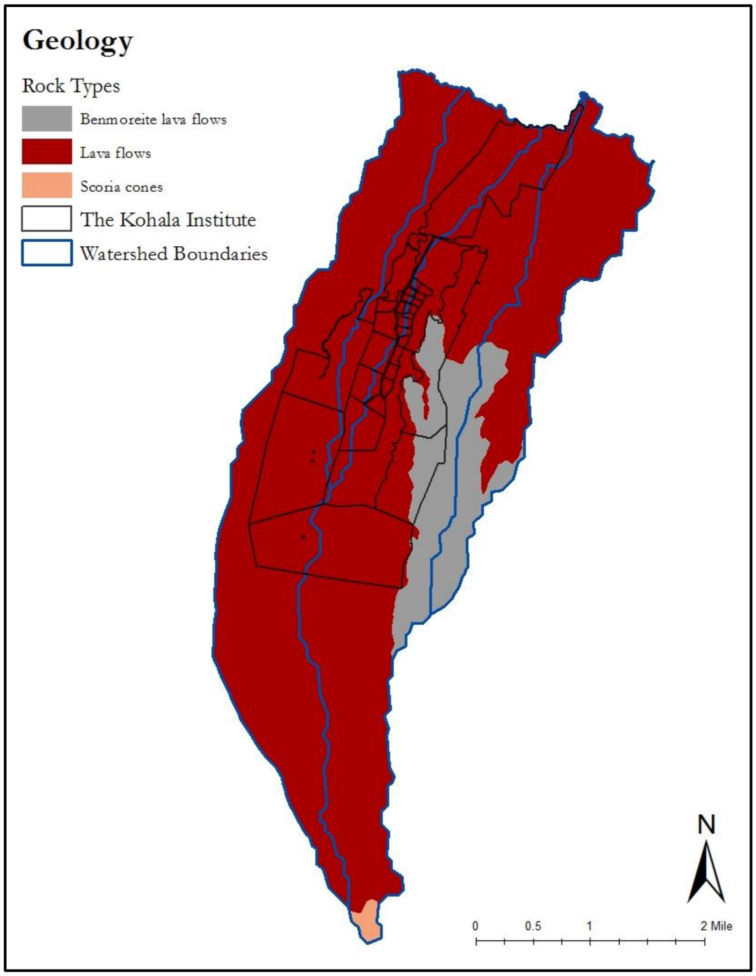

Figure 1.4.7. Rock types in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right). Sources: Hawaii Statewide GIS Program and the Kohala Institute.

These watersheds are also comprised of three distinct rock compositions: 1) alkali and tholeiitic basalt, 2) benmoreite, and 3) hawaiite and mugearite (Fig. 1.4.8). The alkalic and tholeiitic basalt rock compositions are found in the lower-elevation coastal regions of the watersheds. By contrast, the benmoreite, hawaiite and mugearite rock compositions are found in the mid- and upper-elevation mountainous regions of the watersheds (Fig. 1.4.8) ("Geological Units," 2016).

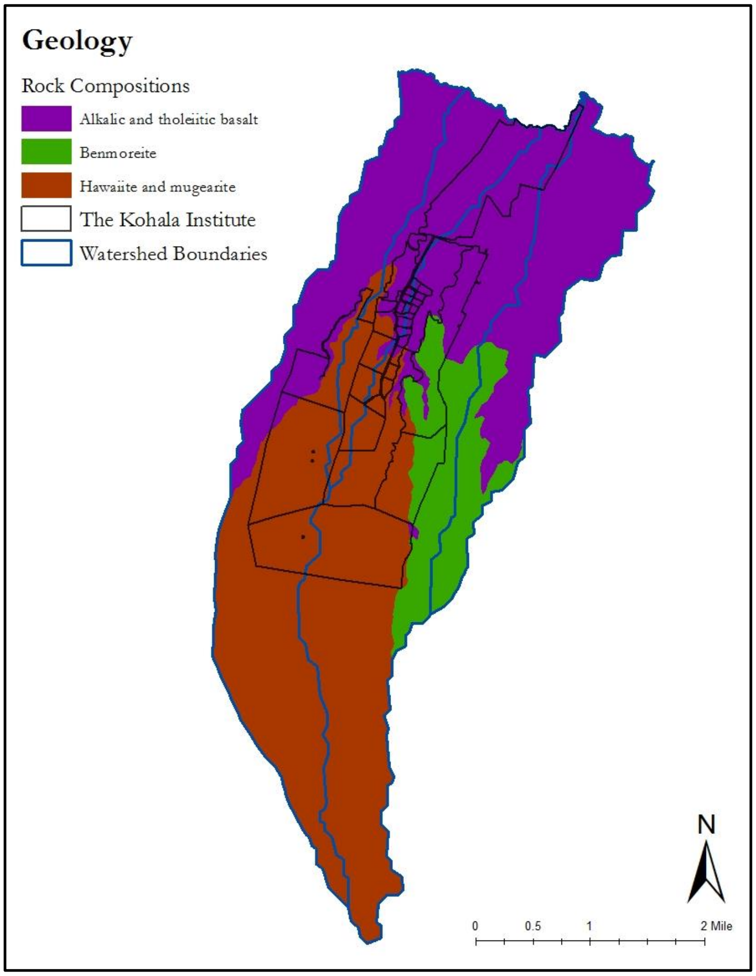

Figure 1.4.8. Rock compositions in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right). *Sources: Hawaii Statewide GIS Program and the Kohala Institute.*

Soil Characteristics

In the Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds, soils have fast and moderate rates of permeability (i.e., the ability to allow liquids to pass through) (Fig. 1.4.9) ("Hawaii Soil Atlas," 2014). These silty/clay/loam soils are also moderately-well- and well-drained, and have k-factors (i.e., coefficients reflecting soil erodibility) that range from 0.05 to 0.17 (Fig. 1.4.9) (Gerrish, 2003b; "Soil Survey Area (SSURGO)," 2016, "Watersheds," 2016). Soils with these low k-factor values (i.e., those ranging from 0.05 to 0.2) are typically high in clay and/or sand content, which makes them very resistant to detachment, transportation from rain, and, therefore, erosion ("K Factor," 2002).

These soils have also been categorized into three hydrologic groups: B, C, and D (Fig. 1.4.9) ("Soil Survey Area (SSURGO)," 2016, "Watersheds," 2016). Soils in group B have a moderate infiltration rate (i.e., the ability to absorb rainfall or runoff) and runoff potential (i.e., the ability to generate surface runoff) when saturated; soils in group C have a moderate/high runoff potential and a low infiltration rate when saturated; and soils in group D have a high runoff potential and a very low infiltration rate when saturated (Nielsen & Jr., 1998). Lastly, because these soils were created primarily from volcanic ash, topsoil in these watersheds is highly acidic (Gerrish, 2003b).

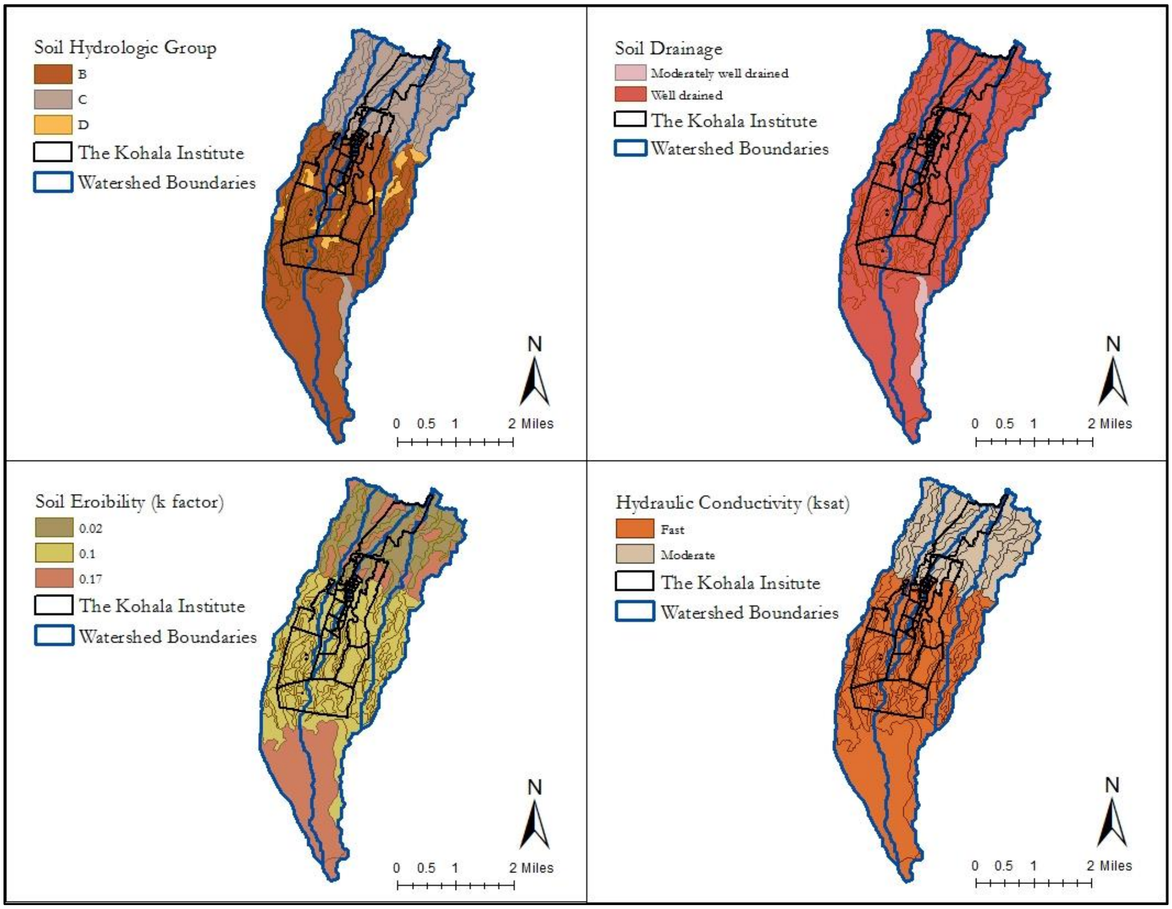

Figure 1.4.9. Soil hydrologic groups, drainage, erodibility (k factor), and permeability (ksat) of the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right). Source: USGS SSURGO, Hawaii Statewide GIS Program, and the Kohala Institute.

Hydrology

The Halelua, Hapahapai, Pali Akamoa, and Wainaia watersheds have similar hydrologic characteristics where rainfall is the only source of water to the area (County of Hawai‘i, Department of Water Resources, 2010). Each watershed has its own ephemeral stream, and associated tributaries, that flow to the northeast into the Pacific Ocean from the Kohala Mountains (Fig. 1.4.10) (“Hydrography: National Hydrography Dataset, Watershed Boundary Dataset,” 2016, “Watersheds,” 2016).

In many of these streams, the majority or all of the streamflow comes from man-made structures (e.g., Kohala Ditch, Bond Tunnel), which transport water from the wetter, higher-elevation areas to the drier, lower-elevation areas (Morgan, 1981). Sometimes, water is only able to flow through the upper reaches of these streams and not the lower reaches because of a soil infiltration rate that is greater than the streamflow; during these instances, water and soil carried with it do not reach the Pacific Ocean (Gerrish, 2003c).

These four watersheds primarily overlie the Hawi Aquifer (i.e., a basaltic and volcanic rock aquifer), but a small portion of the Hapahapai and Wainaia watershed headwaters overlie the Mahukona Aquifer, which is located on the mauka-side of the watersheds (Fig. 1.4.10) (“DLNR

Aquifers (Poly),” 2016, “Watersheds,” 2016). The watersheds have many diversions and ditches that bisect them for agricultural and domestic water supply purposes. The Halelua Gulch is a first-order stream (i.e., the smallest stream in a watershed; a headwater stream) with one impoundment along its 4.5-mile length. The Hapahapai Gulch is a second-order stream (i.e., the second-smallest stream in a watershed that is formed by the convergence of two first-order streams; a headwater stream) with a waterfall and six impoundments along its 5.6-mile length. The Pali Akamoa Gulch is a first-order stream with one impoundment along its 3.4-mile length. The Waiania Gulch is a second-order stream with a small lake and eight impoundments along its 5.3-mile length. Since there are no streamflow gauges in these watersheds, except in the Bond Tunnel, streamflow is unknown and difficult to estimate (County of Hawaiʻi, Department of Water Resources, 2010).

Overall, these watersheds recharge local groundwater and support a variety of aquatic and terrestrial organisms (County of Hawaiʻi, Department of Water Resources, 2010). However, because many of these gulches are severely trampled by cattle and pigs, have steep slopes, and a lack of ground cover caused by strawberry guava and rose apple shading out sunlight, significant sheet and rill erosion occur in these gulch systems (Gerrish, 2003b). On most agricultural lands (e.g., pasture, cultivated crops), there is sufficient groundcover by grasses that attenuate soil erosion. Some exceptions include pasture areas located on the mauka-side of the watersheds where there are concentrated populations of cattle, and older macadamia nut orchards located at lower elevations of the watersheds that are populated with larger macadamia nut trees, which prevent groundcover from growing due to shading (Gerrish, 2003c).

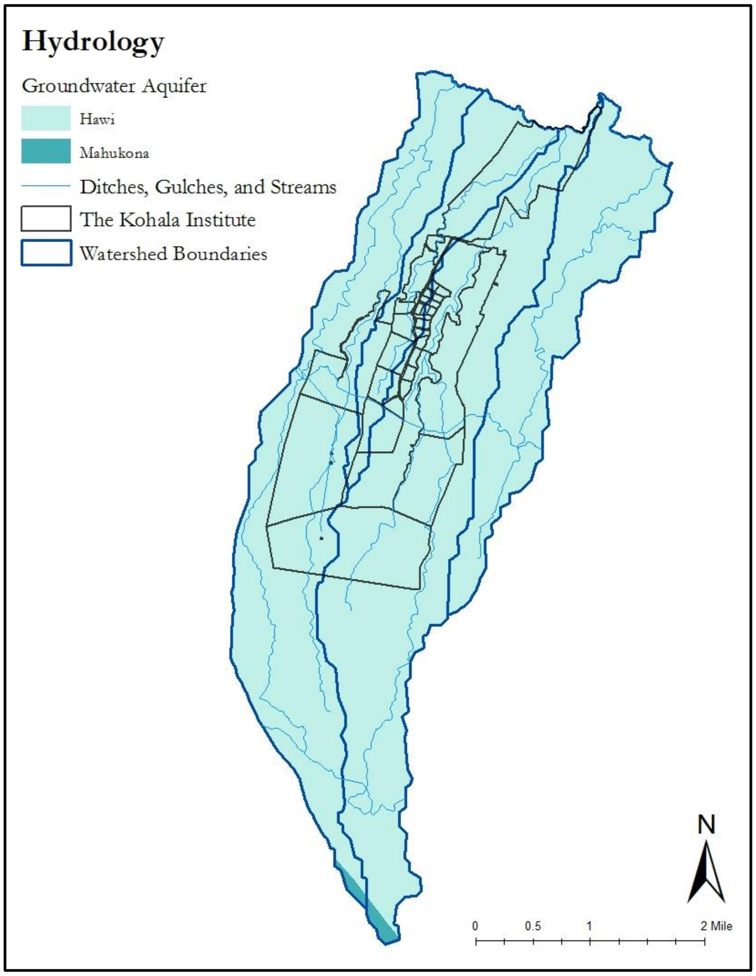

Figure 1.4.10. Hydrological features of the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right). Sources: Hawaii Statewide GIS Program, State Department of Land and Natural Resources, USGS Hydrography Dataset, and the Kohala Institute.

Land Cover

According to the 2005 Coastal Change Analysis Program (C-CAP), developed by the National Oceanic and Atmospheric Administration (NOAA), and spatial data collected at KI, the 7,488 acres of the Halelua, Hapahapai, Pali Akamoa and Wainaia watersheds are comprised of 12 distinct land cover types (Table 1.4.1; Fig. 1.4.11) ("C-CAP Land Cover Atlas," 2005, "Watersheds," 2016). Pasture and agriculture are the predominant anthropogenic land cover types at the watershed- and KI-scale (Fig. 1.4.11) ("C-CAP Land Cover Atlas," 2005, "Watersheds," 2016). Forest, which is primarily comprised of invasive plant species, is concentrated in the central regions of the watersheds and KI's property, and becomes more sparsely vegetated at the lower-coastal and higher-mountainous elevations (Fig. 1.4.11 and 1.4.12) ("C-CAP Land Cover Atlas," 2005, "National GAP Analysis," 2001, "Watersheds," 2016). Since only 7.00% of the watershed area is developed at low-, medium-, and high-intensities, the watershed area is considered to be mostly rural, as opposed to urbanized (Fig. 1.4.11) ("C-CAP Land Cover Atlas," 2005, "Watersheds," 2016).

Table 1.4.1. 2005 coastal change analysis program (C-CAP) land cover classifications, their areas, and percent of total area in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds. Sources: Hawaii Statewide GIS Program, the Kohala Institute, and NOAA C-CAP.

Land Cover Type	Acres	Percent of Total Area (%)
Pasture	3,299	44.24%
Forest	2,357	31.61%
Agriculture	725	9.72%
Low Intensity Developed	472	6.33%
Shrub	447	6.00%
Developed Open Space	61	0.82%
Medium Intensity Developed	46	0.62%
Grassland	31	0.42%
Bare Land	8	0.11%
Water	5	0.07%
High Intensity Developed	3	0.04%
Palustrine Emergent Wetland	2	0.02%

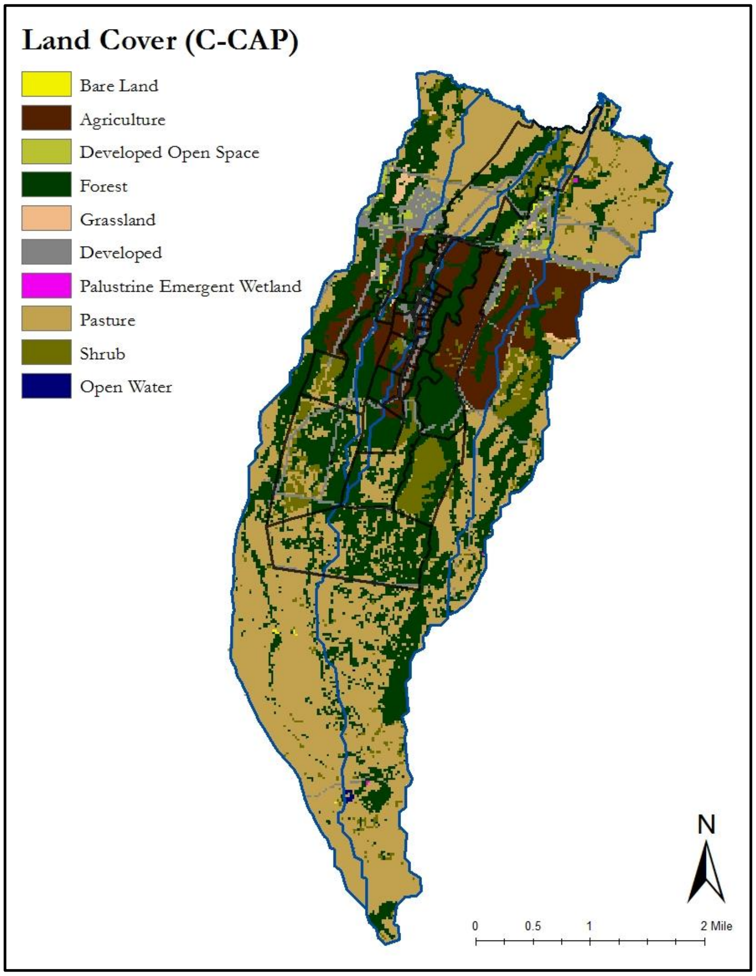

Figure 1.4.11. 2005 coastal change analysis program (C-CAP) land cover classifications in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right; outlined by blue lines). Black lines outline the Kohala Institute (KI). *Sources: Hawaii Statewide GIS Program, the Kohala Institute, and NOAA C-CAP.*

Biological Assets

North Kohala and Kohala Institute Lands

As previously stated, approximately 86% of the watershed area and 89% of KI's property are overrun by invasive plant species (Fig.1.4.12) ("National GAP Analysis," 2001, "Watersheds," 2016); this is a common ecological theme in the North Kohala region of the Big Island (Cowie, Imada, Allison, & Arakaki, 1999). Over the years, North Kohala has been highly modified by humans, especially for agricultural purposes, so there are scarce populations of native plant and animal species left in this region (Cowie et al., 1999; Gerrish, 2003b). Major habitats of KI's lands include, but are not limited to, macadamia nut orchards, gulches, freshwater habitats (i.e., streams, ponds), roadside vegetation, and forests, all of which are populated with various types of vertebrates (i.e., birds, mammals, reptiles), mollusks (i.e., snails, slugs), arthropods (i.e., insects), and plant species (Cowie et al., 1999):

- Vertebrates found in the North Kohala region of the Big Island include thirteen bird species, three mammalian species, and one reptilian species (Cowie et al., 1999). However, of the six bird and mammalian species that have an "endangered species" status under the Endangered Species Act (ESA), only three are likely to be found in North Kohala and one, the nēnē goose (*Nesochen sandvicensis*), is likely to be an irregular visitor. Moreover, one bird species found in the area, the pueo (*Asio flammeus sandwichensis*), maintains a "species of concern" status under the ESA (Cowie et al., 1999).

- Mollusks found in the North Kohala region of the Big Island include nine alien, land snail, and land slug species. None of these mollusk species are listed under any category of the ESA (Cowie et al., 1999).

- Over 90 species of arthropods can be found in the North Kohala region of the Big Island, but more than 90% of these arthropods are alien species (Cowie et al., 1999). Of the native arthropod species found in this area, none are listed under any category of the ESA (Cowie et al., 1999).

- Approximately 200 plant taxa have been found in the North Kohala region of the Big Island (Cowie et al., 1999). Most of these plant species are non-native to the area because and are now thriving as naturalized weeds (Cowie et al., 1999). Of the few native plant species found in this area, none are listed under any category in the ESA (Cowie et al., 1999).
  Only 12% and 5% of plant species found on New Moon Foundation lands are native and endemic, respectively. Endemic plant species are found primarily within the gulch systems, including their slopes, in the southeastern corner of KI's property. Despite their relatively small presence in the area, these endemic plant species are still considered to have "biodiversity value" since they only grow naturally in Hawaii, provide habitat for other valued Hawaiian organisms (e.g., insects, invertebrates, microorganisms), and can serve as locally-adapted seed or spore sources for native ecosystem restoration projects (Gerrish, 2003b).

According to a 2003 baseline botanical survey of the area, the ʻIo (*Buteo solitaries*) (i.e., the "endangered" Hawaiian Hawk under the ESA) was seen flying over KI's lands. At most, six ʻIo were seen flying over the area in one day from September to October 2002. Despite these sightings, it is unknown whether the KI's lands provide resources or habitat for the ʻIo, but it was assumed that the ʻIo were flying in the area in search for food (Gerrish, 2003c, 2003b).

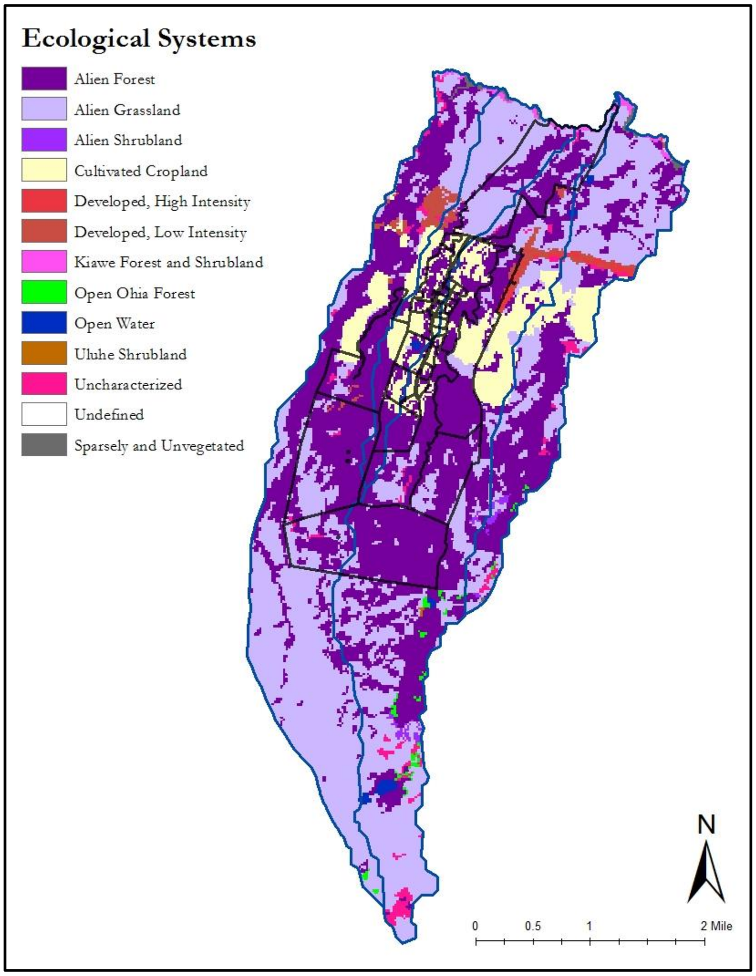

Figure 1.4.12. Ecological systems in the Hapahapai, Pali Akamoa, Wainaia, and Halelua watersheds (left to right; outline by blue lines). Black lines outline the Kohala Institute (KI). *Sources: Hawaii Statewide GIS Program, USGS GAP Analysis, USGS Hydrography Dataset, and the Kohala Institute.*

Part 2. Analysis

2.1 Conceptual Framework & Scenarios

The Big Island Impacts group project assessed the potential environmental impacts brought on by current and hypothetical future land use activities at Kohala Institute (KI) by modeling changes in water quality, carbon emissions, and wildlife habitat. This approach was developed because to be the most informative for KI, this study needed to both consider a wide range of environmental impacts across all areas of concern, and accurately depict the implementation of current land uses and proposed land use changes that were within the scope of reality for KI.

With these goals in mind, the group project objectives were identified and a sequence of distinct project phases were developed. First, the analyses of interest were selected; then, land characteristics were identified; and lastly, a series of land use scenarios were developed to perform the analyses of interest and compare environmental impacts of each scenario.

First, the analyses of interest were selected. This study ultimately included assessments of:

a) Accessibility;
b) Water quality;
c) Carbon emissions; and
d) Wildlife habitat availability.

These components were chosen because the latter three categories (i.e., water, carbon, and wildlife) were identified as the most important issues of concern to KI. Within a watershed, non-point source pollution represents the largest contributor to water quality degradation; therefore, a water quality analysis was performed to assess how changes to non-point sources of pollution would affect water quality under the various scenarios. Additionally, land use change and the combustion of fossil fuels are the two largest contributors to climate change, therefore an analysis of how carbon sources and sinks would change under the various scenarios was performed. Finally, habitat fragmentation and loss brought on by the expansion of anthropogenic land use activities, such as development, is a key driver of biodiversity loss. Thus, an analysis of how land use change would impact wildlife habitat availability and possible species of concern at KI under the various scenarios was performed.

However, before any of these topics could be assessed, accessibility throughout KI's property needed to be assessed and improved – limited access throughout the property currently prevents KI from fully implementing any of the alternative land use scenarios being investigated in the water, carbon, and wildlife analyses. Because of this, an additional accessibility analysis was integrated into the study to determine the locations and benefits of new and restored roads. The results of this preliminary accessibility analysis were incorporated into the design of the alternative land use scenarios.

Therefore, all four analyses (i.e., accessibility, water, carbon, and wildlife) were necessary in helping KI gain a better understanding of the full scope of the current and potential environmental impacts from- their existing and proposed land use activities.

Once the analyses of interest were determined, KI's current land cover types and land cover conversions under the alternative scenarios needed to be identified. For each analysis, the land cover types were used as parameters in a baseline and several alternative scenarios.
The current land cover types seen on KI's property include:

a) Forest land (-i.e., comprised primarily of alien species)
b) Shrub land (-i.e., comprised primarily of alien species);
c) Pasture land (i.e., non-native grasses and land cleared for cattle grazing);
d) Agricultural land (i.e., macadamia nut orchards and a farm); and
e) Developed land (i.e., buildings such as the homestead, office, the new GRACE center, cabins, paved roads and parking lots).

After the current land cover types were determined under the Baseline Scenario, the land cover changes seen in the alternative land use scenarios were identified. These scenarios needed to be feasible for KI to realistically carry out, while also being significant enough to demonstrate the differing environmental impacts seen under different land uses. Three initial alternative scenarios – Pasture Scenario, Agriculture Scenario, and Forest Scenario – were decided upon based on KI's current land use activities, goals for future projects, and overall mission. These scenarios represent an iterative approach in which KI added on an additional project to each subsequent scenario.

Once the three alternative scenarios were identified, the water, carbon, and wildlife analyses were performed on these scenarios. The results were then compared to the Baseline Scenario results to establish an understanding of how potential environmental impacts under the alternative scenarios differ from those seen under the Baseline Scenario. However, after the results were analyzed, one last alternative scenario – Riparian Buffer Scenario – was developed to expand upon and incorporate lessons learned from these results.

All five scenarios — the Baseline, Pasture, Agriculture, Forest, and Riparian Buffer Scenarios — are described in greater detail below. Refer to the Tables 2.1.1 and 2.1.2 for the new acreages and percentages of each land type under each alternative scenario.

Table 2.1.1. Scenario acreages. Land cover types by acreage within each of the five planning scenarios.

	Baseline	Pasture	Agriculture	Forest	Riparian
Forest land	1,123	603	603	698	772
Shrub land	234	67	67	67	171
Pasture land	581	1,226	1,148	1,054	912
Agricultural land	298	288	366	366	329
Developed land	194	260	260	260	261
Total*	2,430	2,444	2,444	2,445	2,445

Table 2.1.2. Scenario percentages. Land cover types by percent of total acreage within each of the five planning scenarios.

	Baseline	Pasture	Agriculture	Forest	Riparian
Forest land	46%	25%	25%	29%	32%
Shrub land	10%	3%	3%	3%	7%
Pasture land	24%	50%	47%	43%	37%
Agricultural land	12%	12%	15%	15%	13%
Developed land	8%	11%	11%	11%	11%
Total*	100%	100%	100%	100%	100%

*Note: total acreages vary slightly across scenarios as a result of the process of converting land cover polygons to raster grids for analysis in ArcGIS.

Baseline Scenario

The Baseline Scenario makes no changes to KI's current land cover types or their current land use activities. This scenario was intended to determine KI's current environmental impacts since they had not been assessed in-depth prior to this study. It was also used to determine how water quality, carbon, and wildlife impacts would change under the various alternative scenarios. It is important to note that the Baseline Scenario did not include the new roads proposed in the accessibility analysis.

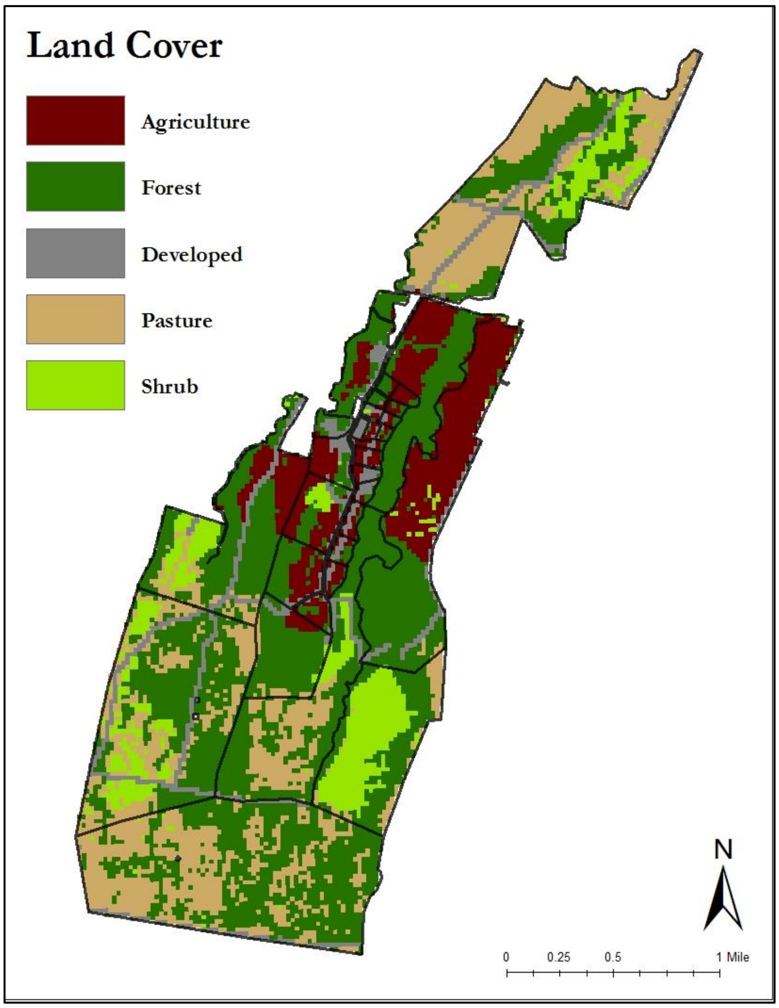

Figure 2.1.1. Baseline scenario map. Under the Baseline Scenario, no changes have been made to current land uses or land cover types. The property consists of 24% Pasture land, 12% Agricultural land, 8% Developed land, 46% Forest land, and 10% Shrub land.

Pasture Scenario

The Pasture Scenario represents what KI would look like if cattle grazing on the property was maximized in areas licensed out for cattle grazing. Cattle grazing is currently KI's largest land use. However, many areas on the property that are licensed out for cattle grazing are not able to be fully utilized by the cows because the areas have been overgrown with alien forest and shrub species; in this scenario, these areas were converted to bare land in Year 1 and then reclassified as pasture in Years 2-20. The Pasture Scenario also included the new roads proposed in the accessibility analysis and doubled the size of the aquaculture facility.

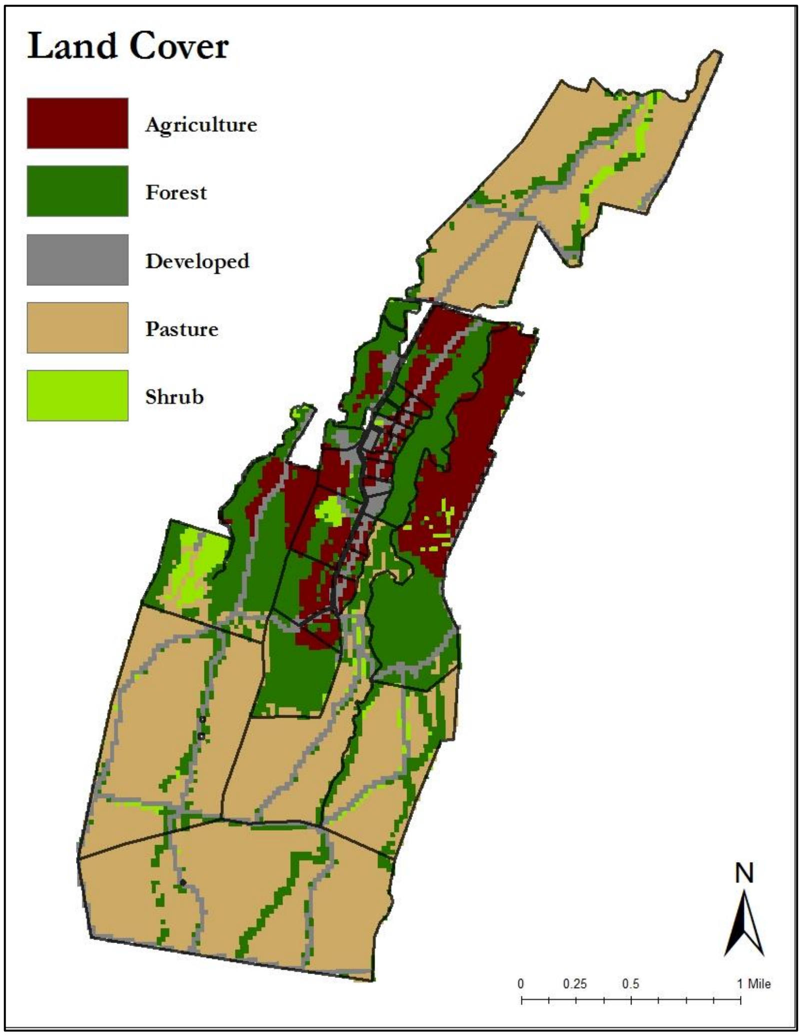

Figure 2.1.2. Pasture scenario map. Under the Pasture Scenario, approximately 645 acres have been converted from Alien Vegetation (i.e., Forest or Shrub land) to Pasture land, and new roads have been incorporated. The property is now 50% Pasture land, 12% Agricultural land,11% Developed land, 25% Forest land, and 3% Shrub land.

<u>Agriculture Scenario</u>

The Agriculture Scenario represents what KI would look like if cattle grazing was maximized *and* additional agricultural areas were created. KI currently has two types of agriculture on their property: macadamia nut orchards and a produce farm. However, they hope to expand their current agricultural activities to include several new types of orchards – coconut, breadfruit, and moringa – as well as additional row crops on the new, makai-side (i.e. the ocean side) agricultural regions of the property. In this scenario, the licensed areas for cattle were fully converted to pasture, with the exception of an approximately 80-acre plot of land on the makai side of the property that was designated for these new orchards and row crops. This area was specifically sited for agriculture due to its relatively larger, flatter, contiguous area, with respect to the rest of the geographically-heterogeneous property, as well as its accessibility to the property's water sources. 80 acres were selected for this new agricultural area based on the recommendation of HIP Ag (Hawaii Institute of Pacific Agriculture, a local natural farming organization). The Agriculture Scenario also included the new roads proposed in the accessibility analysis and doubled the size of the aquaculture facility.

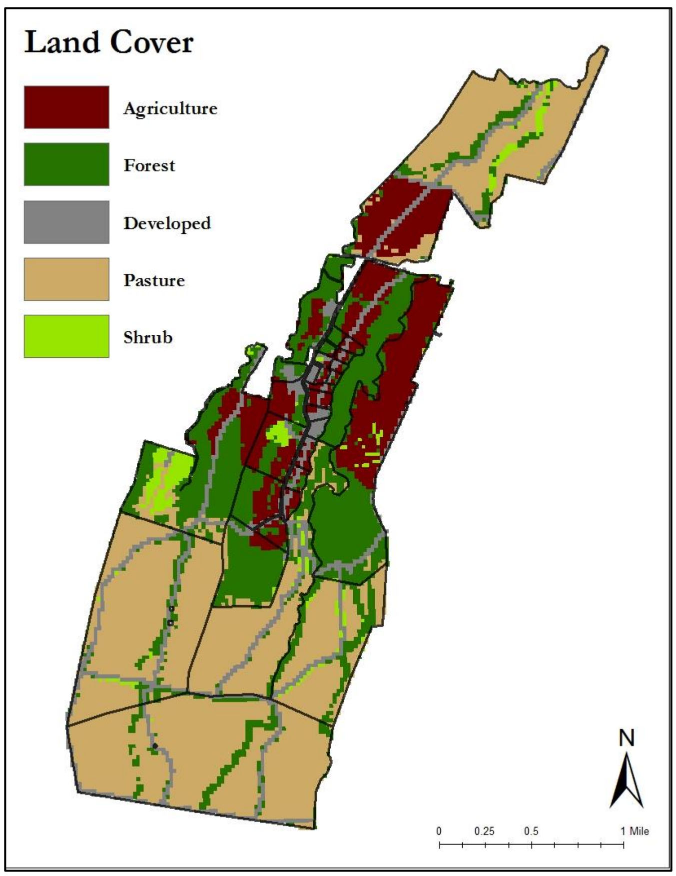

Figure 2.1.3. Agriculture scenario map. Under the Agriculture scenario, approximately 565 acres have been converted to Pasture land, 80 acres have been converted to Agricultural land, and the road network has been improved. The property is now 47% Pasture land, 15% Agricultural land, 11% Developed land, 25% Forest land, and 3% Shrub land.

Forest Scenario

The Forest Scenario represents what KI would look like if cattle grazing was maximized, additional agricultural areas were created, *and* the property's remaining patch of native forest was prioritized for conservation. Although KI's property has been highly modified throughout its entire land use history and almost all of it is now dominated by alien forest/shrub species and anthropogenic land uses, there is still one remnant of native forest located in the southeastern corner of the property. In this scenario, the licensed areas for cattle were fully expanded, with the exception of the 80-acre agricultural area from the previous scenario and a new 100-acre plot of forest surrounding the native plant community. 100 acres was selected on the recommendation of KI, who hopes to form a partnership with the University of Hawaii, Hilo, where 100 acres of forest would be managed with experimental forestry practices. The Forest Scenario also included the new roads proposed in the accessibility analysis and doubled the size of the aquaculture facility. These new roads would be especially imperative to reach the location of the forest plot for effective management and conservation purposes.

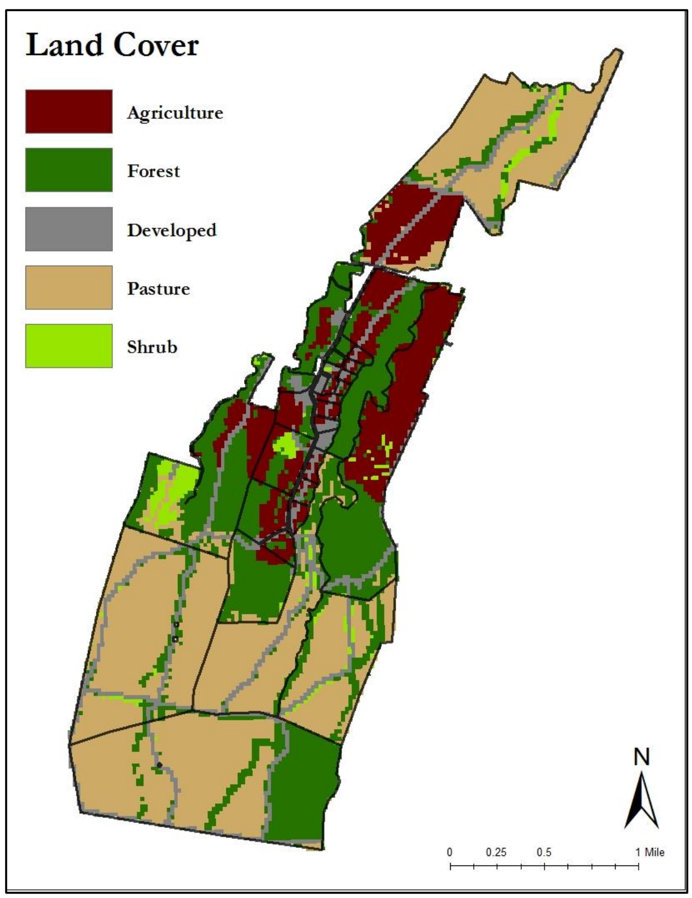

Figure 2.1.4. Forest scenario map. Under the Forest scenario, approximately 465 acres have been converted to Pasture land, 80 acres have been converted to Agricultural land, 100 acres have been maintained or converted to Forest land, and the road network has been improved. The property is now 47% Pasture land, 15% Agricultural land, 11% Developed land, 29% Forest land, and 3% Shrub land.

Riparian Buffer Scenario

The Riparian Buffer Scenario represents what KI would look like if cattle grazing was maximized, additional agricultural areas were created, the property's remaining patch of native forest was prioritized for conservation, *and* vegetated riparian buffers were established in KI's gulch systems to mitigate some potential environmental impacts. This scenario was designed *after* assessing the environmental impacts from the other three alternative scenarios. It was intended to explore how our client might be able to fulfill their land use goals (i.e. pasture expansion, agricultural additions, and native forest preservation) while *also* minimizing the resulting environmental impacts brought on by these land use changes (Kondolf, Kattelmann, Embury, & Erman, 1996). In this scenario, the vegetated riparian buffers did not contain pasture or agriculture land cover types as they would defeat the purpose of a riparian buffer, but existing development (i.e., buildings, roads) was kept intact as it is important, permanent infrastructure that KI needs. By leaving these riparian buffers primarily naturally vegetated, water quality, carbon storage, and wildlife habitat impacts should be minimized.

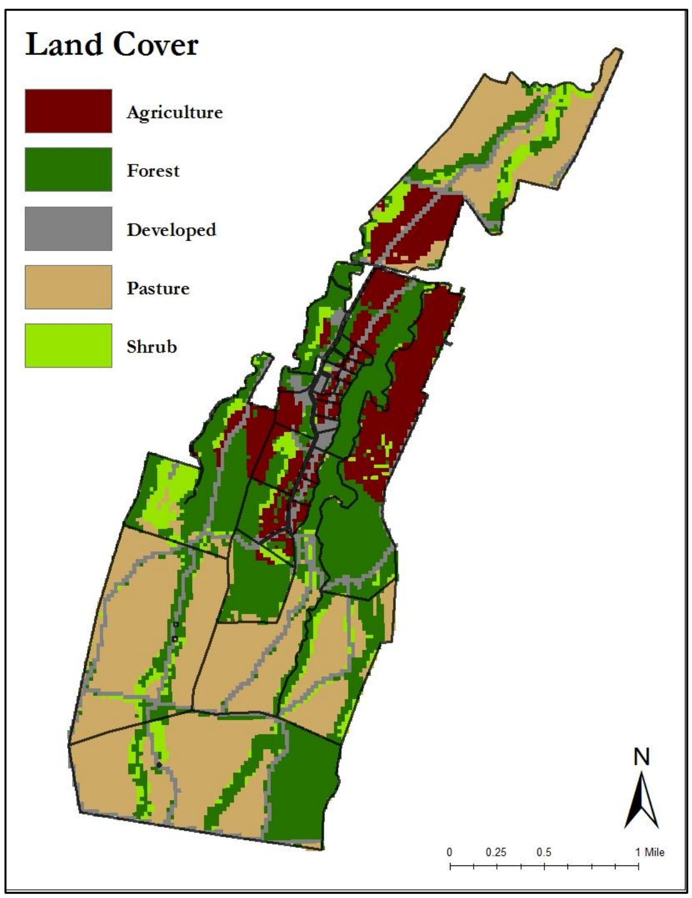

Figure 2.1.5. Riparian buffer scenario map. Under the Riparian Buffer Scenario, approximately 330 acres have been converted to Pasture land, 40 acres have been converted to Agricultural land, and 275 acres have been retained or converted to Forest land or Shrub land. The property is now 37% Pasture land, 13% Agricultural land, 11% Developed land, and 32% Forest land, and 7% Shrub land.

Buffer sizes were determined based on the following equation from (Kondolf et al., 1996):

$$Buffer\ width = potential\ tree\ height\ in\ area * e\char`^(1 + average\ slope\ of\ the\ gulches)$$

wherein the potential tree height of the region was determined to be 15 meters (Gerrish 2003), and the average slope of the gulches was determined to be a steep 20%. The probability of KI's gulch systems being degraded by current and future land use disturbances is proportional to the proximity of land use activities to the gulch systems, slope of the gulches and the surrounding area, and soil erodibility (Kondolf et al., 1996). Because some KI land use activities are sited in close proximity to these steep gulch systems, this KI-specific vegetated riparian buffer will be beneficial in mitigating negative environmental impacts from KI's current and future land use disturbances by preserving and restoring parts of existing forest and shrub lands, which are able to filter water pollutants (e.g., phosphorus, nitrogen, sediment) before they enter KI's gulch systems (Kondolf et al., 1996). In addition, these vegetated buffers will help prevent cattle from accessing the steep gulches, which are especially vulnerable to erosion (Gerrish, 2003a).

This equation yielded a buffer of 50 meters on each side of the gulches, preserving or restoring 100 meters total vegetation along all of KI's gulch systems. The riparian buffer scenario also included the new roads proposed in the accessibility analysis and doubled the size of the aquaculture facility, but omitted conversions to pasture or agriculture within the newly buffered regions.

2.2 Accessibility

Introduction

Access to the property is perhaps the single greatest deterrent to KI's current land use activities. To analyze accessibility, this analysis mapped the current road network, created a cost surface raster for the full property, and implemented a cost-distance function to calculate the travel time to different locations on the property. Two accessibility analyses were performed: a baseline analysis using KI's current functional road network, and a potential future analysis using KI's full road network if several currently-defunct roads were to be repaired. Results indicated that the rehabilitation of the road network could significantly improve overall access, especially in the most difficult-to-reach regions on the mauka side of the property.

Big Island Impacts' client is in a period of great transition, but their current transportation infrastructure is failing to keep up. In the next few years, KI hopes to scale up their organization's current activities (such as cattle grazing) to a more economically viable level, as well as launch several new strategic projects (such as new agricultural crops) on the land.

Unfortunately, KI is severely limited in their planning by the property's present lack of accessibility. New projects cannot be sited on large portions of the property because the act of physically getting to them is too prohibitive. Even some of KI's existing activities are currently being inhibited by a lack of access. At the time of this study, the road network was unmapped, unmaintained, and fully impassable in several locations — in one case, leading to the complete inaccessibility of a leased parcel of land.

For this reason, increasing access to the property is a top priority of the client, and will be a necessary first step before additional planning i.e. to implement the land use changes presented in the Pasture, Agriculture, Forest, and Riparian Scenarios) can take place.

This spatial analysis, performed in ArcGIS 10.4.1, sought to establish a clear baseline of accessibility, upon which KI can adjust their current activities to maximize their current land uses; plan their future activities; and potentially make future plans to rehabilitate, expand, and improve the existing road network. It had several distinct components:

1. Map and display the current road network utilized by KI;
2. Establish a travel cost surface for KI's property based on slope and land cover type;
3. Perform a cost distance function which calculates the travel time as a measure of accessibility to KI's property; and
4. Explore the potential accessibility benefits of repairing KI's road network to its full capacity.

Data

Table 2.2.1. Accessibility analysis data sources. The Accessibility Analysis incorporated spatial data provided by the client, generated through Big Island Impacts group member field work, and obtained from a variety of publicly available sources.

Data	Description	Source
Kohala Institute (KI)	Polygons defining property boundaries	The Kohala Institute
Topography	2007 digital elevation model (DEM) 30-meter resolution	University of Hawaii at Manoa, School of Ocean and Earth Science and Technology (SOEST)
Land Cover	Describes vegetation and land uses in 2005 and 2017 30-meter resolution	National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) and KI
Roads	Polylines defining roads on and intersecting KI	County of Hawaii, KI, Field Data Collection

Methods

The first step in analyzing the accessibility of KI's property was to map the current road network. First, major roads were recorded in the field using a handheld GPS smartphone application and imported into digital mapping software. Roads were preliminarily recorded by Big Island Impacts group project members in Summer 2016 using the *GPS Tour* Android application, imported into Google Earth, and then transformed from KML into ArcGIS-friendly formats for mapping and analysis. Additional road data were recorded by group members again in Winter 2016 using the *Collector for ArcGIS* Android application, and then imported directly into ArcGIS Online.

As they were recorded, roads were assigned a Road Condition attribute value of either Asphalt, Gravel, Dirt, or Grass. Select roads were also timed while being mapped, to obtain a value for Travel Speed (MPH) possible on each Road Condition, which would later be incorporated into the travel time analysis.

Unfortunately, not all roads could be mapped in the field within the limited time periods. Some roads were impassable due to vegetation regrowth, fallen trees, boulders, or muddy conditions. These road features that could not be mapped were digitized using the Create Features function in ArcGIS by either tracing an Esri Aerial Imagery basemap in ArcGIS or approximating their location under the guidance of KI staff (i.e. in locations where tree canopy cover blocked the view of the roads in aerial photos).

Lastly, major roads (such as the 270 highway that crosses through KI's property) were obtained from publicly-available GIS data through the Hawaii Statewide GIS Program, and then combined into the existing road data layer using the Merge function. KI's road network is displayed below in Figure 2.2.1.

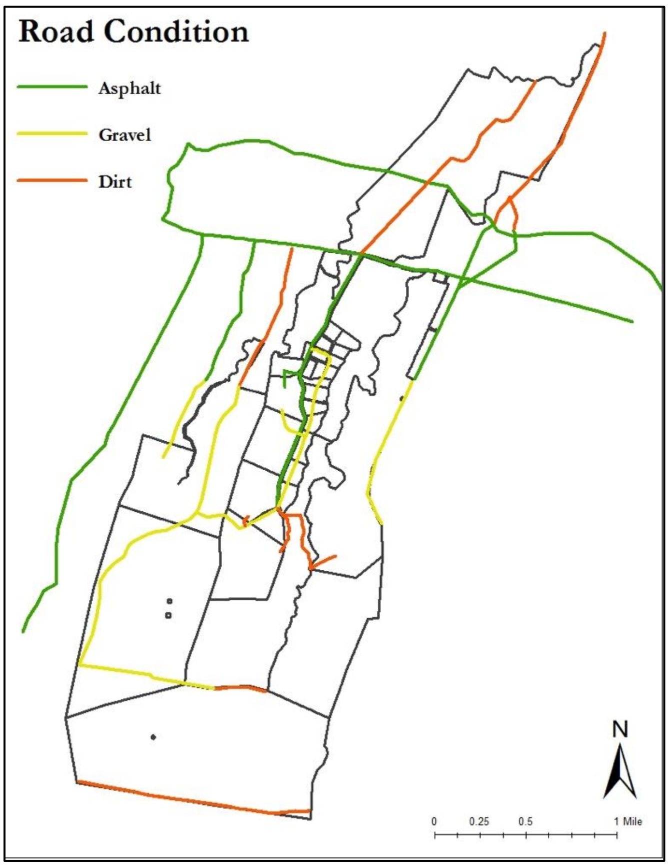

Figure 2.2.1. Current KI Road Conditions. KI's current road network consists of Asphalt, Gravel, and Dirt roads. Access is extremely limited on the southernmost (mauka) side of the property.

After the existing road network had been mapped, the potential future road network for the alternate analysis needed to be designed. Once the new road network had been designed, it was drawn using the Create Features tool in ArcGIS. The new road network is displayed in Figure 2.2.2 on the next page. Roads were identified for the new road network based on several criteria:

1. Roads that had previously existed but are presently inaccessible (due to vegetation overgrowth, fallen trees, boulders, flooding during heavy rains, etc.);
2. Pathways that are commonly used but not technically maintained as roads (primarily through the Pasture land regions of the mauka side); and
3. New roads that would be imperative to create in order to access proposed future projects on the land (such as the native forest site in the Forest and Riparian Scenarios).

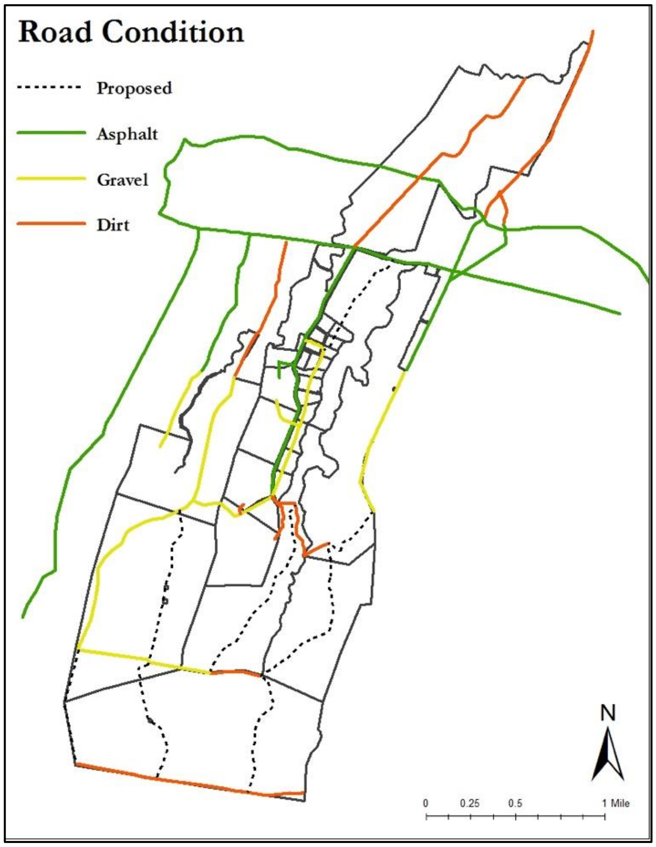

Figure 2.2.2. Future KI Road Conditions**.** KI's potential future road network also consists of Asphalt, Gravel, and Dirt roads. Access is improved on the southernmost (mauka) side of the property.

After all of the roads had been mapped, the next step was to create a continuous travel cost surface. Continuous cost surfaces are raster datasets that contain a value for the degree of difficulty of passing through each cell of the raster. Cost surface rasters are very useful for determining various measures of accessibility over a landscape, such as the least-cost path from an origin to a destination (Moller & Nielsen, 2007). Cost surfaces that are created as raster datasets may be based on a single criterion, or on multiple criteria layered together. In many studies, slope is the only variable considered since vertical distance is considered the most prohibitive factor in movement (van Leusen, 1998). However, a variety of other variables can be implemented to suit the needs of a particular analysis (Howey, 2006).

For KI, a cost surface raster was created by calculating travel times using two inputs: the slope of the land and the land cover type, since these are the two greatest determining factors in analyzing speeds at which movement over the property is possible. Each distinct road and land cover type was assigned a travel time cost value obtained by inverting the speed at which one could travel through it. These values were then multiplied by the tangent of the slope used as a resistance modifier.

When KI land managers need to reach a portion of the property not immediately accessible by road, they can either drive or walk to their location. Most land cover types can simply be driven over if necessary, such as pasture land, or carefully navigated through, such as the widely-spaced macadamia nut orchards that comprise most of KI's Agricultural land. The only land cover type on KI's property that cannot be driven through at all is the dense forest land.

For each given road condition and land cover type, a cost value was assigned based on the maximum possible velocity of travel (in MPH) over that surface type. These velocities were obtained from Big Island Impacts group member field data when possible and relevant literature when field data could not be collected. These travel velocities are presented in Table 2.2.2 below.

Then, the inverses of the travel velocities were taken to reflect the inverse relationship between potential speed of travel and degree of difficulty of passing over a surface. Finally, the inverse velocities were converted from seconds-per-foot to thousandth-seconds per foot, in order to obtain integer values for the raster GIS analysis. These inverse velocities are also included in Table 2.2.2.

To obtain a unified road and land cover raster with these new values, the existing KI Roads shapefile was converted to a raster, then mosaicked with the existing CCAP land cover type raster into a new road/land cover raster, which was finally reclassified to the new cost values. This process was repeated twice — once with the existing road network as-is, and one with the potential road network fully repaired — to yield two different land cover travel cost rasters: one for the baseline analysis, and another for the potential future analysis. Refer to figures A2.2.1 and A2.2.2 in the Appendix for diagrams of this process.

Table 2.2.2. Travel cost for various road and land cover types. Original velocities are given in MPH, converted to feet per second, inverted and rescaled to integer values.

Land cover type	Travel velocity (Miles/Hour)	Travel velocity (Feet/Second)	Rescaled value (1000^{th} Sec/Ft)	Mode of Transportation
Asphalt roads	15	22	45	Driving
Gravel roads	10	14.67	68	Driving
Dirt roads	5	7.3	136	Driving
Pasture, hay, grass, & cultivated land	3	4.4	227	Driving
Scrub/shrub land	2	2.9	340	Walking or Driving
Evergreen forest	1	01.47	681	Walking

To account for slope effects on travel cost, slope was next used as a multiplier in a raster calculation with the land cover raster. First, the DEM was input into the Slope tool to obtain the study area's slope in degrees. However, the relative difficulty of travelling up slopes does not increase in a linear pattern, so the raw degree values were insufficient (Howey, 2006). A more accurate representation of the relative cost of traveling upslope was obtained by using the tangent of the slope (Bell & Lock, 2000).

Therefore, the tangent of slope was multiplied by the land cover time-cost values to represent the increasing difficulty and consequential decreased speed brought on by travelling up or down slopes. The following equation was used:

$$(Land\ cover\ value) * (1 + \tan(slope))$$

Again, this process was completed twice — once with the baseline road/land cover raster, and once with the alternative future road/land cover — to obtain two different cost surface rasters for the baseline and future accessibility analyses. Refer to Figure A2.2.3 in the Appendix for an illustration of the increasing difficulty of traveling over slopes.

Once the travel cost surface rasters had been created, they were utilized to implement a cost-distance analysis to assess overall accessibility on the property. The Cost Distance function in ArcGIS involves exploring all of the possible routes outward from a source over a "friction" gradient representing the difficulty of travel (Atkinson, Deadman, Dudycha, & Traynor, 2005). In this case, the friction gradient was represented by the travel cost surfaces that were just created, and the GRACE Center was used as the source point, since all activities on the property must begin at this location.

Utilizing an embedded equation called Dijkstra's algorithm to travel over the cost surface raster, the cost distance function outputs another raster, wherein each cell now contains a measure of the accumulated least-cost distance from the source to that cell (Stahl, 2005). Since the cost values were assigned in terms of time-per-distance, integrating the costs over the least-cost distances yields time values as outputs of the function. Cost-distance functions were performed using both the baseline and alternative cost surfaces, to produce two different cost-distance rasters. The travel time values contained in these rasters could then be assessed as a measure of current access and increased access, if KI were to repair its road network in places where it has failed. Refer to figures A2.2.4 and A2.2.5 in the Appendix for diagrams of this process.

Results & Discussion

The preliminary travel time analysis indicated, as anticipated, that access was most limited in the southernmost end of the property. Whereas most of the property can be accessed within 10-15 minutes of leaving the Grace Center, the remote reaches of the mauka side can take up to 45 minutes to access, making them incredibly inconvenient to reach. This is due to the fact that there are not roads in this region, so in order to reach them, staff must hike out from the nearest road, which takes significantly longer.

Travel times that were calculated based on KI's current road network are presented below in Figure 2.2.4.

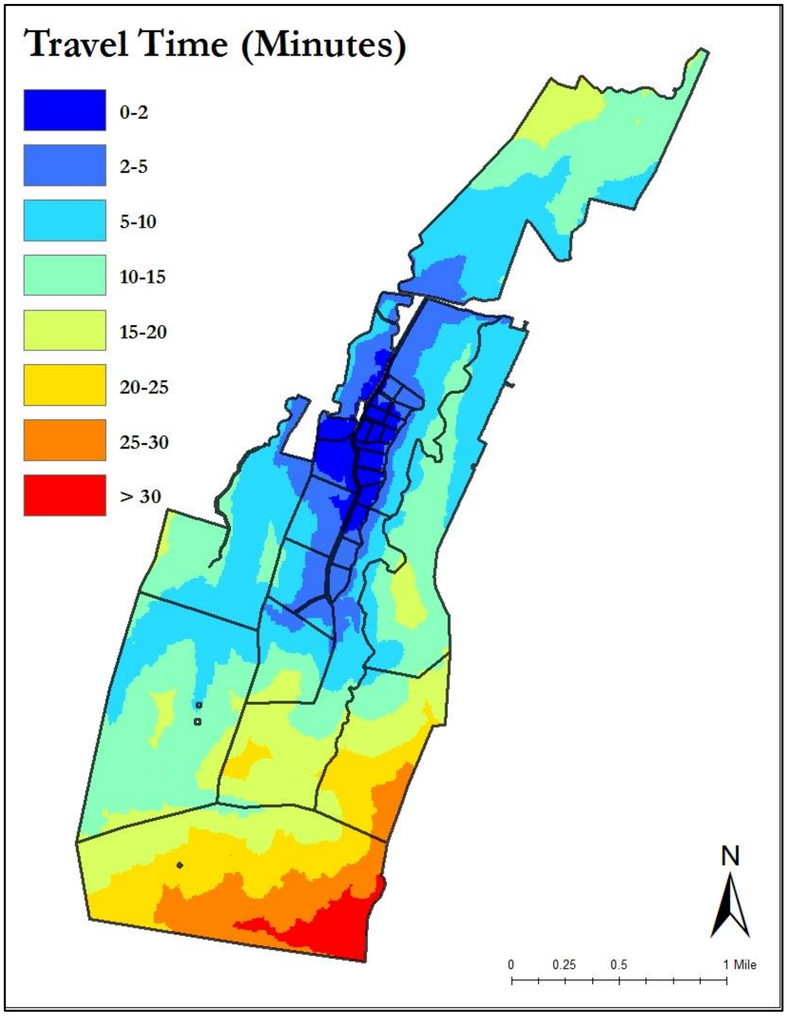

Figure 2.2.4. Preliminary travel times. The accessibility analysis with KI's current road network revealed that the southeastern end of the property is the most inaccessible, with travel times up to three times greater than the majority of the property.

When the newly-built and repaired roads were incorporated into the accessibility analysis, access to the most difficult-to-reach portions of the property improved dramatically. In this scenario, almost all of the property can be reached within 15-20 minutes, with only a very small portion takeing 25-30 minutes to access. Since most of the roads changed in the new road network were located on the mauka side of the property, the makai side (where access was already manageable) remains relatively unchanged.

Travel times that were calculated based on KI's potential future road network are presented below in Figure 2.2.5.

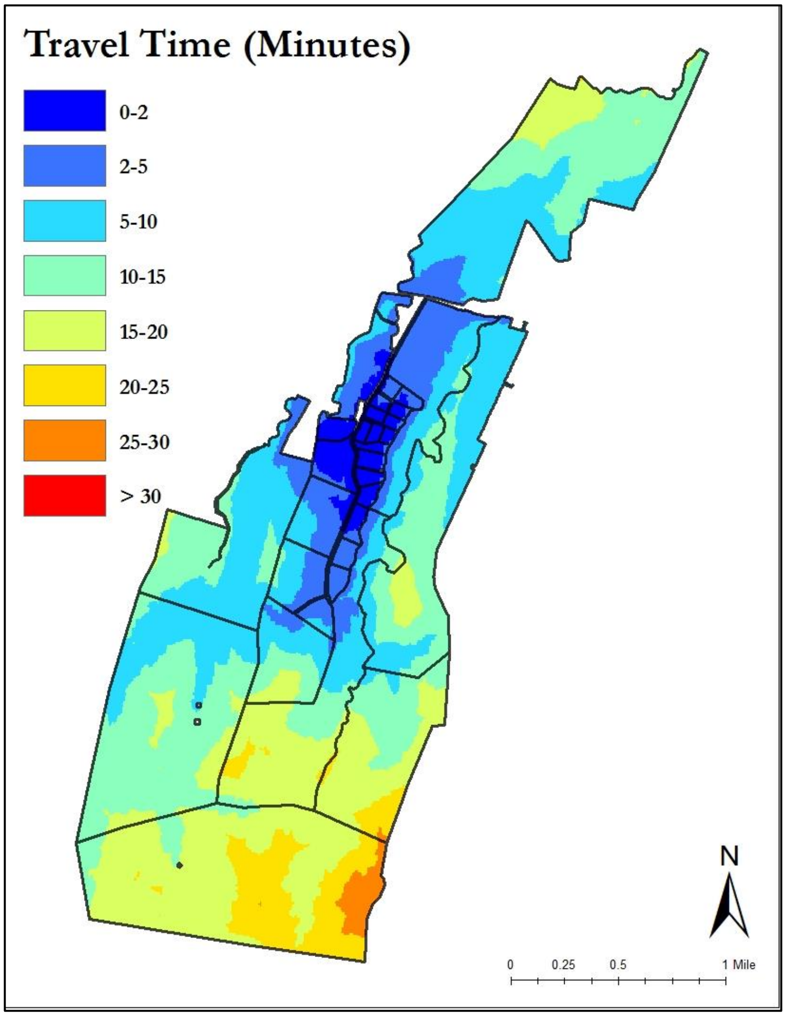

Figure 2.2.5. Potential future travel times. The accessibility analysis with KI's potential future road network revealed that access to the southeastern end of the property could be substantially improved with the repair and addition of several roads.

This accessibility analysis demonstrated the significant improvement in access that could be achieved with just a few roads being repaired, maintained, or created. Time savings of over 10 minutes or 50% improvements were possible in the most remote areas of the property.

Differences in travel times that were calculated between KI's existing and potential future road network are displayed below in Figure 2.2.6.

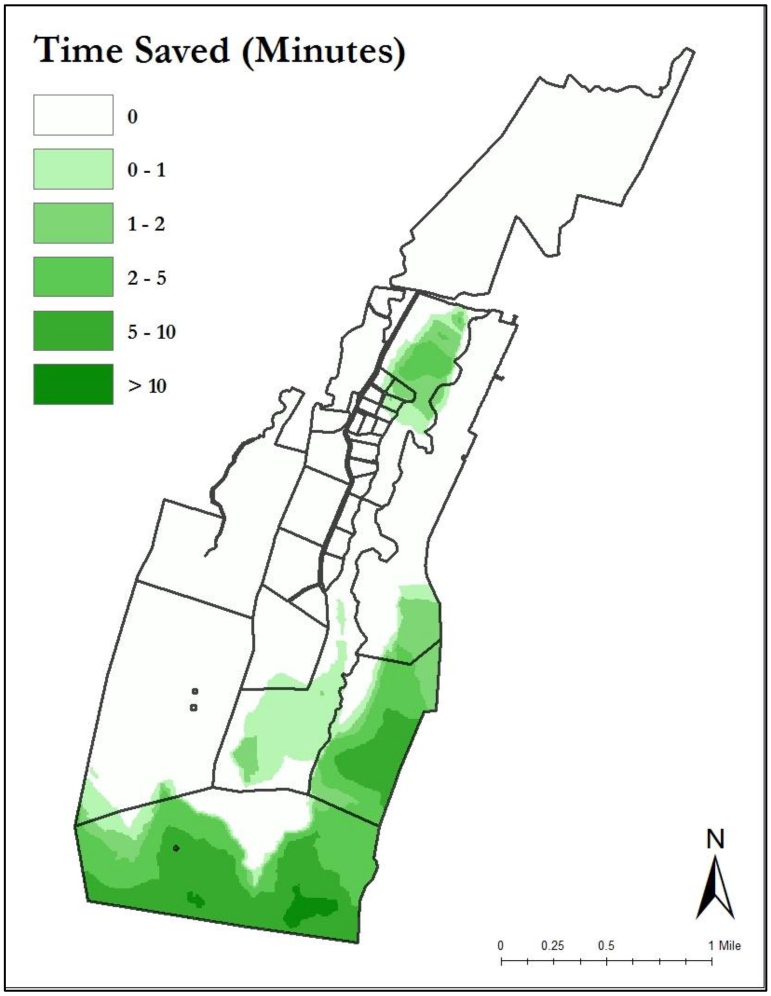

Figure 2.2.6. Potential future time savings. When the current and future travel time rasters were compared, significant time savings were revealed. Most of the time savings are concentrated in the southeastern end of the property where access was most restricted to begin with.

These potential time savings could be incredibly valuable to KI if they were to actually begin implementing strategic projects on this side of the property. The time saved could translate directly to other metrics, such as money saved when paying workers, productivity possible in a given workday, and so on. Even more important is the fact that these regions can now be reached with vehicles, equipment, and heavy machinery, which was impossible before The ability to access this region of the property with vehicles and heavy machinery is necessary for any large scale land conversion to occur.

2.3 Water Quality Assessment

Introduction

The Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) evaluates how different land use activities (i.e., sources of nonpoint pollution) and precipitation scenarios impact coastal watershed quality (Michaud & Stewart, 2012; *User's Manual for OpenNSPECT, Version 1.2*, 2014). OpenNSPECT is the open-source, plug-in version of N-SPECT that is compatible with the open-source geographic information system (GIS) software, MapWindow GIS (*User's Manual for OpenNSPECT*, *Version 1.2*, 2014). This tool was originally developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) for the Waianae Ecological Characterization project, and is currently being used to predict and compare changes in water quality between existing and proposed land use scenarios in Hawaii and abroad (Michaud & Stewart, 2012; "Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT)," 2010, *Technical Guide for OpenNSPECT*, *Version 1.2*, 2014).

OpenNSPECT was utilized for this water quality assessment for various reasons, which include:

- Original design intent: N-SPECT was specifically designed for water quality specialists, coastal managers, and local stakeholders to predict, address, and compare water quality impacts under different land use scenarios in coastal watersheds of Hawaii (Easson, Francis, & Janaskie, 2008; "Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT): Technical Guide," 2008). Therefore, OpenNSPECT is ideal for this water quality assessment because Kohala Institute (KI) resides over four coastal watersheds on the Big Island of Hawaii.

- Widespread usage: Since its development, N-SPECT and OpenNSPECT have been utilized to predict, address, and compare water quality impacts in other U.S., Caribbean, Central American, and South Pacific coastal watersheds around the world ("Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT)," 2010).

- Data limitations: Spatial data for watershed modeling in Hawaii are limited. OpenNSPECT is compatible with these data limitations and only requires key data inputs that are available for Hawaii (i.e., DEM, rainfall, soil, land cover, R-factor) to give users a good idea of how water quality could be impacted in their areas of interest from existing and proposed land use scenarios (Michaud & Stewart, 2012).

- Open-source: OpenNSPECT and MapWindow GIS are both open-source (*User's Manual for OpenNSPECT*, *Version 1.2*, 2014), which make them easy to obtain and allow KI to utilize these GIS software programs and decision-making tools independently in the future.

Since KI and its watersheds are highly rural, the primary pollutants that cause water quality degradation (e.g., eutrophication) in rural areas were analyzed: total runoff, phosphorus (TP), nitrogen (TN), and sediment. Using OpenNSPECT 4.8.1 and ArcMap 10.4.1, total annual runoff, TP, TN, and sediment loadings were calculated for each land use scenario (i.e., Baseline Scenario, Pasture Scenario, Agriculture Scenario, and Forest Scenario) under three different precipitation scenarios over the 20-year planning horizon. During this water quality assessment, four research questions were investigated:

1. How do total runoff, TP, TN, and sediment loadings differ across land use scenarios over the 20-year planning horizon?

2. How sensitive are model results to the total number of rain days (i.e., number of days in a year with enough rain to generate surface runoff) in each land use scenario over the 20-year planning horizon?

3. How do TP and TN concentrations differ across land use scenarios and precipitation scenarios over the 20-year planning horizon?

Methods

Water quality analyses were executed using OpenNSPECT version 1.2 and ArcGIS 10.4.1. All input spatial datasets were projected into the NAD83 UTM5N coordinate system and clipped to Kohala Institute's (KI) watershed boundaries (Table 2.3.1). Input spatial datasets in the raster (i.e., grid) format were already in or resampled to a 30-meter resolution (Table 2.3.1), as recommended by the National Oceanic and Atmospheric Administration (NOAA).

Data

Refer to Table 2.3.1 on the next page for the data inputs required for the water quality analysis.

Table 2.3.1. Input spatial datasets used by the OpenNPSECT model.

Dataset	Description	Source
Curve Number (CN)	The amount of rainfall (%) that turns into suface runoff in an area.	OpenNSPECT (default values)
Elevation	2007 digital elevation model (DEM; 10m).	University of Hawaii at Mānoa, School of Ocean and Earth Science and Technology (SOEST), Coastal Geography Group
K-factor	Coefficients representing soil erodibility.	Esri SSURGO Downloader 2014
Land Cover	2005-2017 standardized land cover and vegetation types for U.S. coastal regions (30m).	National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (CSC)
Pollutant Coefficient	Average pollutant concentrations (mg/L) for each NOAA Coastal Change Analysis Program (C-CAP) land cover type.	OpenNSPECT (default values)
Rainfall	Average annual rainfall raster (250m).	University of Hawaii at Mānoa, Geography Department
Rainfall Erosivity Factor (R-Factor)	Capacity of rainfall to cause detachment of soil particles.	NOAA OpenNSPECT website
Soil	2015 Soil Survey Geographic Database (SSURGO) shapefile.	Esri SSURGO Downloader 2014
Watershed Boundaries	2016 watershed unit boundary shapefile.	Hawaii Statewide GIS Open Data Portal

Land Cover Data

This 2005 land cover dataset was updated only on KI's property where land cover changes were known. These land cover changes were mapped by manual interpretation of recent imagery using Google Earth and ArcMap 10.4.1,. land cover maps for the four alternative land use scenarios (i.e., Pasture Scenario, Agriculture Scenario, Forest Scenario, Riparian Buffer Scenario) were rasterized from input shapefiles in OpenNSPECT (Michaud & Stewart, 2012).

Rainfall Data

The 250-meter grid was derived by interpolating rain gauge data collected from 1978-2007 (Thomas W. Giambelluca et al., 2011). Because of the interpolation process, the level of rainfall uncertainty at KI is relatively low and ranges from 1.29 to 4.84 inches (Thomas W. Giambelluca et al., 2011).

R-Factor Data

The 30-meter R-factor (i.e., rainfall/runoff erosivity factor; a coefficient reflecting how easily a soil is eroded by rainfall) grid is in the units of feet-tonfeet-inch/acre-hour-year (*Technical Guide for OpenNSPECT, Version 1.2*, 2014).

Soil Data

OpenNSPECT uses two key attribute fields in the dataset to assign curve numbers (CN) and estimate soil erodibility: the "hydrological soil group" and "k-factor" (i.e., a coefficient representing soil erodibility) (Michaud & Stewart, 2012).

Pollutant Coefficient Data

Pollutant coefficients (i.e., average pollutant concentrations in mg/L), which vary by land cover type, were derived from a national land cover pollutant runoff dataset based on event mean concentrations (EMC), and compiled by the U.S. Environmental Protection Agency (US EPA) (Table A2.3.2) (Michaud & Stewart, 2012). For KI, comprehensive, up-to-date, local water quality data are lacking. Therefore, these default pollutant coefficients were used in this water quality assessment, as recommended by NOAA (Michaud & Stewart, 2012; *Technical Guide for OpenNSPECT, Version 1.2*, 2014).

Calculating Annual Runoff, Phosphorus, Nitrogen, and Sediment with "Local Effects Only"

For each land use scenario, OpenNSPECT ran using the "Local Effects Only" option where output rasters (i.e., grids) indicated the total annual amounts of runoff (L), TP (mg), TN (mg), and sediment (mg) that were generated in each cell (i.e., locally) on KI's property without contributions from upstream cells (Michaud & Stewart, 2012; *Technical Guide for OpenNSPECT, Version 1.2*, 2014). OpenNSPECT determined local annual runoff loadings on KI's property by using the initial abstraction grid and the average annual rainfall raster (*Technical Guide for OpenNSPECT, Version 1.2*, 2014; see the "Calculating Annual Runoff" section in Appendix 2.3). Then, the local annual runoff raster (L) was multiplied by the pollutant concentration grid (mg/L; Table A2.3.2) to calculate local annual TP and TN loadings (mg) in each cell on KI's property without contributions from upstream cells (*Technical Guide for OpenNSPECT, Version 1.2*, 2014). Local annual sediment loadings in each cell on KI's property, without contributions from upstream cells, were calculated by OpenNSPECT using the RUSLE equation ((*Technical Guide for OpenNSPECT, Version 1.2*, 2014; see the "Calculating Annual Sediment Loadings with RUSLE" section in Appendix 2.3). After using the "Raster Calculator" tool in ArcMap 10.4.1 to sum these annual outputs of total runoff, TP, TN, and sediment loadings over the 20-year model run for each land use scenario and each precipitation scenario, the "Zonal Statistics as Table" tool was used in ArcMap 10.4.1 to calculate the contributions of each land cover type to total pollutant loadings on KI's property.

Results & Discussion

The following subsections provide answers to the four research questions that were proposed for this water quality assessment:

1. How do total runoff, TP, TN, and sediment loadings differ across land use scenarios over the 20-year planning horizon?

2. How sensitive are model results to the total number of rain days (i.e., number of days in a year with enough rain to generate surface runoff) in each land use scenario over the 20-year planning horizon?

3. How do TP and TN concentrations differ across land use scenarios and precipitation scenarios over the 20-year planning horizon?

Differences in Total Runoff, TP, TN, and Sediment Loadings by Land Use Scenario

Total runoff, phosphorus (TP), nitrogen (TN), and sediment loadings were compared as percent differences from the Baseline Scenario, as recommended by NOAA, because the best utilization of OpenNSPECT is through the comparison of relative differences in runoff and pollutant loadings between land use scenarios rather than the comparison of specific output values (i.e., liters of runoff, mg of pollutants) from each land use scenario (Eslinger, 2017; Mausio, 2017).

From this water quality assessment, it was found that all four alternative land use scenarios (i.e., Pasture Scenario, Agriculture Scenario, Forest Scenario, and Riparian Buffer Scenario) increased total runoff loadings from the Baseline Scenario – the Agriculture Scenario increased total runoff loadings the most from the Baseline Scenario by 3.15-4.5%, followed by the Forest Scenario by 2.93-4.23%, the Pasture Scenario by 2.03-2.68%, and the Riparian Buffer Scenario by 0.92%-1.14% (Table 2.3.2). TP, TN, and sediment loadings also increased in the Pasture, Agriculture, and Forest Scenarios from the Baseline Scenario (Table 2.3.2); however, TP, TN, and sediment loadings decreased in the Riparian Buffer Scenario from the Baseline Scenario by as much as -7.7%, -1.6%, -3.5%, respectively, due to the addition of 50-meter vegetated riparian buffers protecting KI's gulches (Table 2.3.2).

Overall, the Agriculture Scenario increased total runoff, TP, TN and sediment loadings the most from the Baseline Scenario (Table 2.3.2). By contrast, not only did the Riparian Buffer Scenario increase total runoff loadings the least (i.e., 1-1.5%), it was also the only alternative land use scenario able to decrease TP, TN, and sediment loadings from the Baseline Scenario (Table 2.3.2).

Table 2.3.2. Percent differences in total runoff, total phosphorus (TP), total nitrogen (TN), and sediment loadings from the Baseline Scenario to the Pasture Scenario, Agriculture Scenario, Forest Scenario, and Riparian Buffer Scenario. The first precipitation scenario (i.e., row) has the minimum number of rain days (i.e., 227 rain days) over the 20-year planning horizon. The second precipitation scenario (i.e., row) has the median number of rain days (i.e., 301 rain days) over the 20-year planning horizon. The third precipitation scenario (i.e., row) has the maximum number of rain days (i.e., 363 rain days) over the 20-year planning horizon. Since RUSLE uses the R-factor (i.e., a coefficient for rainfall erosivity) instead of the number of rain days to calculate sediment loadings, sediment loadings did not change between the three precipitation scenarios (i.e., all percent differences will be 0).

Changes (%) in Total Runoff, Phosphorus, Nitrogen, and Sediment Loadings Relative to the Baseline

Pollutant	# of Rain Days	Baseline	Pasture	Agriculture	Forest	Riparian Buffer
Runoff	Minimum Number of Rain Days (n = 227)	0	2	3	3	1
	Median Number of Rain Days (n = 301)	0	2	4	3	1
	Maximum Number of Rain Days (n = 363)	0	3	5	4	1
Phosphorus	Minimum Number of Rain Days (n = 227)	0	1	2	1	-8
	Median Number of Rain Days (n = 301)	0	1	3	1	-7
	Maximum Number of Rain Days (n = 363)	0	1	4	2	-7
Nitrogen	Minimum Number of Rain Days (n = 227)	0	2	4	3	-2
	Median Number of Rain Days (n = 301)	0	2	4	3	-1
	Maximum Number of Rain Days (n = 363)	0	2	5	4	-1
Sediment	Minimum Number of Rain Days (n = 227)	0	0	19	18	-3
	Median Number of Rain Days (n = 301)	0	0	19	18	-3
	Maximum Number of Rain Days (n = 363)	0	0	19	18	-3

Differences in Total Runoff, TP, TN, and Sediment Loadings by Precipitation Scenario

Total runoff, phosphorus (TP), nitrogen (TN), and sediment loadings were also compared as percent differences from the 20-year planning horizon with the median number of rain days (n = 301), as recommended by NOAA (Eslinger, 2017; Mausio, 2017). From this water quality assessment, it was found that total runoff, TP, and TN loadings varied notably between the three precipitation scenarios (i.e., 20-year planning horizons with a minimum (n = 227), median (n = 301), and maximum (n = 363) number of rain days) (Table 2.3.3). Depending on the number of rain days seen over the 20-year planning horizon, total runoff, TP, and TN loadings increased by as much as 17% and decreased by as much as 19% in all five land use scenarios (Table 2.3.3). Since the RUSLE equation used the R-factor (i.e., a coefficient for rainfall erosivity) instead of the number of rain days to calculate annual sediment loadings, sediment loadings did not differ between the three precipitation scenarios (Table 2.3.3).

Table 2.3.3. Percent differences in total runoff, phosphorus (TP), nitrogen (TN), and sediment loadings from the precipitation scenario with the median number of rain days (i.e., 301 rain days) over the 20-year planning horizon. Since RUSLE uses the R-factor (i.e., a coefficient for rainfall erosivity) instead of the number of rain days to calculate sediment loadings, sediment loadings did not change between the three precipitation scenarios (i.e., all percent differences will be 0).

Changes (%) in Total Runoff, Phosphorus, Nitrogen, and Sediment Relative to the Median Number of Rain Days

Pollutant	Scenario	Median Number of Rain Days (n = 301)	Minimum Number of Rain Days (n = 227)	Maximum Number of Rain Days (n = 363)
Runoff	Baseline	0	17	-19
	Pasture	0	16	-19
	Agriculture	0	16	-18
	Forest	0	16	-18
	Riparian Buffer	0	16	-19
Phosphorus	Baseline	0	15	-16
	Pasture	0	15	-16
	Agriculture	0	14	-15
	Forest	0	15	-15
	Riparian Buffer	0	14	-15
Nitrogen	Baseline	0	16	-17
	Pasture	0	16	-17
	Agriculture	0	15	-17
	Forest	0	15	-17
	Riparian Buffer	0	15	-17
Sediment	Baseline	0	0	0
	Pasture	0	0	0
	Agriculture	0	0	0
	Forest	0	0	0
	Riparian Buffer	0	0	0

Differences in Pollutant Concentrations by Land Use Scenario and Precipitation Scenario

It is important to note that estimated total phosphorus (TP) and nitrogen (TN) concentrations from OpenNSPECT must be validated for accuracy with real-time, water quality monitoring data. However, these TP and TN concentration estimations are still valid to use when comparing relative differences in pollutant concentrations between land use scenarios and precipitation scenarios (Eslinger, 2017; Mausio, 2017). From this water quality assessment, it was found that average pollutant concentrations (mg/L) for both TP and TN did not notably differ between each land use scenario and precipitation scenario (Table 2.3.4).

Table 2.3.4. Average concentrations (mg/L) of total phosphorus (TP) and nitrogen (TN) by land use scenario and precipitation scenario. The first precipitation scenario (i.e., row) has the minimum number of rain days (i.e., 227 rain days) over the 20-year planning horizon. The second precipitation scenario (i.e., row) has the median number of rain days (i.e., 301 rain days) over the 20-year planning horizon. The third precipitation scenario (i.e., row) has the maximum number of rain days (i.e., 363 rain days) over the 20-year planning horizon.

Pollutant Concentrations (mg/L) by Land Use Scenario and Precipitation Scenario

Pollutant	# of Rain Days	Baseline	Pasture	Agriculture	Forest	Riparian Buffer
Phosphorus	Minimum Number of Rain Days (n = 227)	0.23	0.24	0.24	0.25	0.24
	Median Number of Rain Days (n = 301)	0.23	0.25	0.24	0.25	0.24
	Maximum Number of Rain Days (n = 363)	0.23	0.25	0.25	0.25	0.24
Nitrogen	Minimum Number of Rain Days (n = 227)	1.78	1.97	1.96	1.96	1.94
	Median Number of Rain Days (n = 301)	1.79	1.98	1.97	1.98	1.95
	Maximum Number of Rain Days (n = 363)	1.80	1.99	1.98	1.99	1.96

As with all models, OpenNSPECT has its limitations. First, OpenNSPECT's default pollutant coefficients can be seen as "too broad" and not representative of KI's specific land cover types at the local scale (Michaud & Stewart, 2012). However, previous users of OpenNSPECT in Hawaii have confirmed that the model is "well-suited" for estimating total runoff and pollutant loadings at both the local and watershed scale (Michaud & Stewart, 2012). According to Dr. Dave Eslinger, an oceanographer at NOAA, the benefit of acquiring and using local pollutant coefficients is to determine the accuracy of OpenNSPECT estimates with real-time, local water quality data (Eslinger, 2017). However, the derivation of local pollutant coefficients for OpenNSPECT would not only require Kohala Institute (KI) to obtain comprehensive water quality data, it would also require a high risk, complex comparison of pollutant coefficients as numerous assumptions and distinct conditions would have been made in the creation of both the default and locally-derived pollutant coefficient datasets (Eslinger, 2017). OpenNSPECT is also unable to model water quality impacts when best management practices (BMPs) are included in land use management scenarios (Michaud & Stewart, 2012). While this feature is not present in OpenNSPECT, coastal watershed, water resource, and land use managers have still been able to recommend BMPs from OpenNSPECT's results (Michaud & Stewart, 2012).

Using OpenNSPECT, this water quality assessment was able to provide a first look into how KI's water quality could possibly change under different land use scenarios and precipitation scenarios. It was revealed that the Agriculture and Forest Scenarios increased total runoff and pollutant loadings the most from the Baseline Scenario (Table 2.3.2). Since these alternative land use scenarios include an addition of 80 acres of row crop agriculture and orchards that have higher amounts of exposed soils and lower levels of groundcover, they induce higher amounts of soil, water, and nutrient loss from the Baseline Scenario (Table 2.3.2). Under these alternative scenarios, it was also found that sediment loadings increased the most, by nearly 20%, relative to other water quality pollutant loadings (Table 2.3.2), which is concerning because the Wainaia Gulch resides on KI's property. Since 2002, the Wainaia Gulch has been listed as an impaired state water body under the federal Clean Water Act for exceedances in turbidity, meaning that the Wainaia Gulch has water quality problems related to the murkiness or clarity of its water (Hawaii State Department of Health, 2012, 2017; Koch, Harrigan-Lum, & Henderson, 2004). While OpenNSPECT was not able to directly measure levels of turbidity for this assessment, it is known that turbidity problems are often caused by higher amounts of sediment entering these water bodies of concern. Therefore, if KI decides to implement certain land use activities in the future that do not promote soil conservation (e.g., row crop agriculture and orchards), then an existing water quality problem on their property that has been present for the last fifteen years could be exacerbated even further.

Fortunately, it appears that water quality impacts from these alternative scenarios can be mitigated if best management practices, such as vegetated riparian buffers, cover crops, and tillage management, are implemented by KI. As seen in the Riparian Buffer Scenario, where 50-meter vegetated riparian buffers around KI's gulch systems limited the expansion of anthropogenic land uses in water-quality-degradation-prone areas, increases in total runoff and pollutant loadings were minimized and reduced, respectively, from the Baseline Scenario. However, depending on the total number of rain days (i.e., number of days with sufficient rainfall to generate surface runoff) that occur over the 20-year planning horizon, total runoff and pollutant loadings increased by as much as 17% and decreased by as much as -19% in all five land use scenarios (Table 2.3.3). This is concerning because if KI's gulch systems are assigned total maximum daily loads (TMDLs) – the maximum thresholds of allowable daily pollutant loadings that still protect water bodies from water quality degradation – in the future, it could put KI at risk of being out-of-compliance or further out-of-compliance with state water quality standards.

By contrast, total phosphorus (TP) and nitrogen (TN) concentrations did not vary notably between land use scenarios or precipitation scenarios (Table 2.3.4). This is relatively good news, as the current state water quality report did not find that KI's water bodies were being impaired by TP or TN concentrations under the Baseline Scenario (Hawaii State Department of Health, 2017). Still, KI should not only implement BMPs (e.g., vegetated riparian buffers, cover crops) to protect its gulch systems from further water quality degradation caused by 1) the existing and potential expansion of anthropogenic land uses and 2) fewer-than-average annual rain day events that increased total runoff and pollutant loadings in all five land use scenarios, they should also implement independently long-term autosampler measurement programs to collect the comprehensive, real-time water quality data needed for monitoring their water quality impacts now and in the future.

2.4 Carbon Sources & Sinks

Introduction

Global warming is being heralded as a significant threat to human health, ecosystem services, and biodiversity (IPCC, 2014). As stated by the World Health Organization, "Between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhea and heat stress" ("Climate change and health," 2016). Additionally, a study from UC Berkeley concluded that by 2100 global warming will reduce the average person's income by 23%, with poorer countries seeing disproportionately large reductions in their average incomes than wealthier countries (Maclay, 2015). The meat industry, especially beef cattle production, is one of the largest contributors to global greenhouse gas emissions, larger even than transportation (Steinfield et al., 2006). Land use conversion to accommodate more pasture and crop land is another significant contributor to global warming (Steinfield et al., 2006).

Billions of tons of carbon are stored within the vegetation and soil around the globe, with the tropics containing the largest percentage of the world's carbon stock, approximately 25% (Carvalhais et al., 2014). The Kohala Institute's (KI) property supports large amounts of vegetation, and the soil is rich in carbon due to high concentrations of aluminum and iron oxides (O. Chadwick, personal interview, February 20, 2017). KI also leases large tracts of their land, 580ac, for cattle grazing. Given that KI is interested in expanding their pasture and agricultural activities, which would both lead to increased beef cattle and necessitate land use conversion, we decided to investigate how the Kohala Institute's carbon emissions would change if these interests were implemented.

Current sources and sinks of emissions at KI needed to be quantified to determine how land use change would alter KI's carbon footprint; specifically, sources and sinks within the terrestrial ecosphere were assessed, since KI's property and activities all take place on land. According to the Intergovernmental Panel on Climate Change (IPCC), there are five carbon pools in the terrestrial ecosphere: above ground biomass, below-ground biomass, litter, woody debris, and soil organic matter (Vashum & Jayakumar, 2012). CO_2 stored for short periods of time is not beneficial to ameliorating the affects of climate change, thus the focus was on the storage of carbon for decades or longer. Of these five categories, woody above-ground biomass (AGB), below-ground biomass (BGB), and soil organic matter (SOM) all represent long term sinks of CO_2 (Riebeek, 2011); AGB, and SOM also contain the majority of carbon within the terrestrial environment, 36.7% and 42.6%, respectively ("Carbon Storage in Forests," 2015) (Vashum & Jayakumar, 2012). So, the analysis of KI's carbon footprint focused on AGB, BGB, and SOM, as well as emissions from land use conversion, cattle, purchased electricity, and erosion.

Methods

Because of a lack of site-specific data needed to determine the carbon stored within the vegetation on Kohala Institute's (KI) property, an extensive literature review was conducted to find estimates on the amount of carbon stored within the above ground biomass (AGB) and below ground biomass (BGB) of areas physically and climaetically similar to KI's property. These proxy values were then applied to the broad C-CAP land cover types identified at KI. The agriculture land cover type was further subdivided to better capture the differences between the various types of cultivation occurring on the property: row crops, macadamia orchards, coconut orchards, breadfruit orchards, moringa orchards, and permaculture. A similar process was used to estimate sequestration rates for the various land cover types. Finally, soil samples collected at KI by Dr. Oliver Chadwick were used to estimate the amount of carbon stored within the top meter of soil for the entire property.

Once the approximate amount of carbon stored within the various land cover types was known, the emissions from future from land use conversion and erosion could be calculated—e.g., once the amount of carbon stored within an acre of forest was estimated, the amount of CO_2 released from the conversion of that acre of forest into pastureland could be determined. Similarly, emissions from erosion, which resulted from the transport of soil to the ocean, could be calculated once the estimates of the amount of carbon stored within the soil were determined. The soil at KI is rich in sequestered carbon due to high concentrations of iron and aluminum oxides; carbon binds tightly to iron and aluminum oxides making it relatively stable for long periods of time. Soil carbon bound up in this way resists moderate disturbance from human activity, e.g. tilling or cattle grazing, but if the soil is moved into the ocean by wind or water erosion the resulting change in pH will release any carbon stored in the soil into the atmosphere as CO_2 (O. Chadwick, personal interview, February 20, 2017).

Next, the emissions generated from the cattle on KI's land and from KI's electricity consumption were estimated and added to the emissions from land use conversion and erosion to get the total emissions for each land use scenario. Finally, the amount of CO_2 sequestered under each scenario was subtracted from the total emissions to get net emissions. It is important to note that in this report a carbon stock refers to the amount of carbon contained within a land cover type (e.g. carbon contained within an acre of forest), while sequestration refers to the rate at which carbon will be added into a land cover type (e.g. how much carbon is removed from the atmosphere and stored with a tree each year).

$$Net\ Emissions = (land\ use\ conversion\ emissions + cattle\ emissions + electricity\ emissions + erosion\ emissions) - \ sequestration$$

Because of the lack of primary data, only the sequestration rates from forest growth, coconut orchards, and moringa orchards could be estimated: KI's breadfruit trees, macadamia orchards, shrubs, row crops, permaculture, pastureland, and soil sequestration rates could not be estimated.

Soil Carbon Stock

Soil samples taken on KI's property by Dr. Oliver Chadwick in 1998 within Island Harvest's macadamia orchards were used to estimate the bulk dry weight of soil, in g/cm^3, and percentage carbon (C) of the soil, for a series of soil profiles down to 350 cm on KI's property. However, only the data from the top meter of the soil was used since the carbon content of soil decays exponentially with increasing depth (O. Chadwick, private meeting, February 20, 2017); the soil samples taken by Dr. Chadwick's followed this trend. Refer to figure 2.4.2 in Appendix 2.4 for Soil Sample data.

Next, the bulk weight of each soil profile was multiplied to its corresponding carbon percentage. The resulting products were summed to obtain the total C stored within a cubic centimeter of soil to a depth of one meter, 0.18g C/cm^3/meter depth. Refer to table 2.4.1 in Appendix 2.4 for soil calculations.

When converted from cm^3 to m^3 and from grams C to kg C, a value of 180kg C/m^3 was obtained. This estimate was then multiplied by the area of KI's property, approximately 2,418 acres, and converted to metric tons (t) C to get 1,768,640t C/meter depth for the entire property; it was assumed that all existing developed land had removed the soil down to a depth of one meter during construction, and thus subtracted the amount of carbon stored within the soil of this area, 193ac, from the previously calculated soil carbon stock.

Finally, the total carbon stock of KI's soil, 1,628,052t C, was converted to tons CO_2 using a conversion factor of 3.67 to obtain a total of 5,974,950t CO_2/meter depth of KI's property.

Table 2.4.1. KI Soil Carbon Stock. The total amount of carbon dioxide contained within the soil of an acre and all of KI's property to a meter depth.

Amount of CO_2 sequestered per acre per meter depth	2,673t
Amount of CO_2 sequestered per meter depth of KI's property	5,974,950t

Forest Carbon Stock

A literature review was conducted to determine above-ground carbon density (ACD) and below-ground carbon density (BCD) per hectare of KI's forests. The studies used to estimate the ACD and BCD of KI's forests employed the use of LiDAR to sample canopy height for their perspective study areas and then related this canopy height to biomass data gathered in the field; allometric equations (i.e. equations that relate the height and diameter of a tree to its mass) were then used to calculate an estimate of ACD, with error decreasing with the size of the study area (Hughes, Asner, Mascaro, Uowolo, & Baldwin, 2014 & Asner et al., 2016).

Ultimately, the average ACD of lowland wet forests near Hilo, Hawaii (128 $\pm$ 59 t C/ha) was used as a proxy value for the ACD of KI's forests. This proxy value was chosen since the forests near Hilo sites had similar physical and climactic characteristics to the forests found on KI's property (Hughes et al., 2014). However, there were major difference in precipitation between these two areas, with Hilo's lowland wet forests receiving nearly twice the annual average precipitation as KI's property. The age of substrate also differed between the two sites: the oldest substrates in the study area around Hilo were 1,500 years old (Hughes et al., 2014), whereas the soils at KI are nearly 120,000 years old (Gerrish, 2003a).

Next, this proxy value was converted from metric tons of carbon into metric tons of CO_2 by multiplying the average ACD, 128 t C/ha, by a factor of 3.67 to get 470 t CO_2/ha, (190t CO_2/ac). However, given the large uncertainty of the average ACD, $\pm$88 t C/ac, a sensitivity analysis was performed by analyzing the minimum, maximum, and average carbon stocks per acre of forest—102t CO_2/ac, 277t CO_2/ac, and 190t CO_2/ac, respectively. Finally, these values were multiplied by the forested area of KI's property, 1,123ac, to get the estimated minimum, maximum, and average total amount of carbon dioxide sequestered, 115,084 t CO_2, 311,893 t CO_2, and 213,488 t CO_2, respectively. However, the amount of carbon stored within the below ground biomass (BGB) of KI's forest needed to be assessed. To calculate the BGB, a literature standard 'root to shoot' expansion factor of 1.25 was used (Murphy, Graham, Vanclay, & Glencross, 2013). This coefficient was multiplied by the previously calculated ACD values to obtain the amount of carbon stored within the ACD and BGB of KI's forests.

Table 2.4.2. KI Forest Carbon Stock. Shows the minimum, representative, and maximum values of metric tons CO_2 within the above ground and below ground biomass per acre of forest and for the entire area of KI's forests.

	Minimum	Average	Maximum
Sequestered Metric Tons CO_2 Per Acre	102	190	278
Sequestered Metric Tons CO_2 For KI's Forested Area	115,084	213,488	311,893

Forest Carbon Sequestration

Because carbon is part of the molecular structure of trees, the rate at which carbon is sequestered depends on the rate at which trees grow (Raich, Russell, & Vitousek, 1997). However, no tree grows at a constant rate over its lifetime; growth rates of trees are rapid at first and tend to decline with age (Raich et al., 1997). For this project, the growth rate of KI's forests was separated into two categories: a growth rate for the first 20yrs of new forest growth, and another for existing forest.

Following the recommendation of Dr. Carla D'Antonio, the growth rates, 59 $g/m^2/yr$, of forests comprised mainly of *Metrosideros polymorpha* located on the windward slopes of Mauna Loa was used as a proxy value for the growth rate of the existing forests found at KI (Raich, Russel, & Vitousek, 1997). To convert from a biomass growth rate to a carbon sequestration rate, the widely used default carbon content value for woody biomass, 50%, was multiplied by our proxy value to obtain a sequestration rate of 29.5g $C/m^2/yr$ (Murphy et al., 2013). The default carbon content value matched well with more in-depth studies, which found that the mean and range of carbon content within tropical angiosperms was 47.1 $\pm$ 0.4% and 41.9-51.6%, respectively (Thomas & Martin, 2012); angiosperms represent the vast majority of trees found within KI's forests (Gerrish, 2003a). Next, this sequestration rate was converted from carbon to carbon dioxide using a conversion coefficient of 3.67 and further converted from g CO_2/m^2 to metric tons CO_2/ac to get a value of 0.44 t CO_2/ac/year.

To estimate the carbon sequestration rate of new forest at KI, the observed rate in comparable secondary forests in Puerto Rico, which averaged 3.1 Mg C/ha/yr during the first 20 years of succession (Chazdon et al., 2006), was adopted. This rate is similar to the 3.05 Mg C/ha/yr (4.5 t CO_2/ac/yr) during the first 20 years of succession in other neotropical secondary forests (Poorter et. al, 2015).

Table 2.4.3. KI Forest Sequestration Rates. The sequestration rates per acre of forest and for all of KI's existing forests in metric tons CO_2 per year.

	Existing Forest	New Forest Growth
Sequestration Rate Per Acre	0.44t CO_2/yr	4.5t CO_2/yr
Sequestration Rate Per Entire Forest Area	492t CO_2/yr	-

Macadamia Orchard Carbon Stock

KI has approximately 400ac of macadamia orchards on their property, with approximately 60 trees per acre. However, only one previous study had been conducted on the carbon stocks of macadamia trees. This analysis used allometric equations to estimate tree biomass, growth rates, density, and carbon conversions to determine the amount of carbon sequestered by macadamia trees (Murphy et al., 2013). This study assessed three different stands of macadamia nut trees, each with different aged trees (10, 17, and 25 years) at the Deenford Macadamia Plantations near Knockrow, Australia (Murphy et al., 2013). Since KI's macadamia nut trees are older than 25 years, some over 100 years old, the carbon stock of the 25yr old macadamia orchards from this report, 0.35 t CO_2/tree, was used as a proxy value for KI's macadamia orchards.

To convert this proxy value from sequestered CO_2 per tree to CO_2 sequestered per acre, an estimated macadamia tree count per acre, 60 trees, was obtained from Island Harvest (J. Trump, personal correspondence, August 24, 2016). This tree count was then multiplied against the chosen proxy value, 0.35 t CO_2, to get a carbon stock of 20.9 t CO_2/ac. This value was then multiplied by the total area of the macadamia orchards at KI to get a total carbon stock of 8,376 t CO_2.

Table 2.4.4. KI Macadamia Carbon Stock. The estimated amount of CO_2 equivalents sequestered per tree, acre, and the entire macadamia orchard on KI's property.

Stock of CO_2 equivalent per tree	0.34t
Stock of CO_2 equivalent per acre	21t
Stock of CO_2 equivalent per entire macadamia orchard	8,376t

Shrub Carbon Stock

The vast majority of carbon within the shrub/scrub land cover is stored within the soil, primarily because of the lack of woody biomass ("Carbon Sequestration Assessment," 2016). Estimates of carbon storage within shrub land cover vary from less than 1% to 5% of the carbon stored within nearby forests that covered the equivalent area (Asner et al., 2016). It was assumed that the carbon stock of the shrub/scrub landscape was 1% per hectare of KI's forests, but to account for uncertainty, a sensitivity analysis was performed to analyze the amount of carbon stored if the shrubs at KI contained 5% of the carbon stock of KI's forests.

Table 2.4.5. KI Shrub Carbon Stock. The amount of carbon stored with KI's forests and shrub land cover, per acre and by total area, under two different carbons storage scenarios for shrubs, 1% and 5% respectively.

	Carbon Dioxide Per Acre	Carbon Per Shrub Land Area
Forest Carbon Stock	190t CO_2	44,485t CO_2
Shrub Carbon Stock As 1% of Forest Carbon Stock	1.9t CO_2	445t CO_2
Shrub Carbon Stock As 5% of Forest Carbon Stock	9.6t CO_2	2,224t CO_2

Coconut Orchard Carbon Stock

KI is planning to expand their agricultural operations in the coming years, which will include a 10ac orchard of coconut trees. To estimate the carbon stock and sequestration rate of this planned 10ac grove of coconuts, a comprehensive analysis of the carbon sequestering capability of coconut orchards in Sri Lanka was reviewed; the specific type of coconut tree studied in this report was the *Cocos nucifera L. var. typica* (Ranasinghe & Thimothias, 2011). This study compared a series of coconut plantations on a variety of soil types and precipitation gradients. The location of KI's proposed coconut grove, as recommended by an agricultural consultant, is sited on the makai (seaward) side of KI's property (Kuhr, Kuhr, & Nugent, 2013). The precipitation and soil type of this area—approximately 1,200 mm of rain annually with deep, well drained, sandy soil (Gerrish, 2003a)—most closely resembles the site studied within the dry low country and mavillu soil series by the Sri Lankan report (Ranasinghe & Thimothias, 2011).

The analysis found that in this specific region, one hectare of coconut trees – with 160 trees per hectare – at 25 years old had an estimated 15 t C/ha (Ranasinghe & Thimothias, 2011). Because of the climatic and soil similarities between KI's proposed coconut site and the area studied within the Sri Lankan analysis, as well as the close age of the two sites – 20yrs at the end of KI's planning horizon and 25yrs in the report – it was decided that the reported value of 15 t C/ha was a good proxy value for KI's planned coconut orchards.

Table 2.4.6. KI Coconut Sequestration Rate. A summary of the values and equations used to calculate the estimated carbon stock of KI's proposed coconut orchard after 20 years.

Carbon stock of coconut trees after 25 years	15 t C/ha
Convert from ha to acres	15 t C/ha ÷ 2.47
Carbon per acre to carbon per total area	6 t C/ac x 10
Convert from carbon to CO_2	60.7 t C x 3.67
Total sequestered CO_2 after 20yrs	222.8t CO_2

Moringa Orchard Carbon Stock

KI is also looking to add a 10ac orchard of moringa trees in the future. Heralded as a superfood, *Moringa olifera* is widely cultivated in both tropical and subtropical regions for its seed pods and leaves, which are high in nutrients, possess anti-bacterial properties, and are rich in anti-oxidants (Leone et al., 2015). There is not much existing literature on the carbon sequestration rate of moringa trees, and what literature does exist is contrasting. Some studies suggest that moringa trees are highly effective in sequestering carbon ("Moringa Tree Fund," 2013) (M N, Patel, Kale, & Patil, 2014) (Gedefaw, 2015), while others suggest that they are poor carbon sinks (Rahman, Kabir, Akon, & Ando, 2015). Since none of the literature reviewed mentioned the age of the trees at the time of the study, nor a growth rate, and because the reports have significantly different results, a sensitivity analysis was performed. The minimum, maximum, and average carbons stock per hectare found within the literature were compared: 4.9t C/ha, 98.7t C/ha, and 51.8t C/ha, respectively (Gedefaw, 2015). The minimum, maximum, and average carbon values were then converted to t CO_2/ac – 7.2 t CO_2/ac, 146.6 t CO_2/ac, and 76.9 t CO_2/ac, respectively – and finally multiplied by the total area of the planned moringa orchard to get a minimum of 72 t CO_2, a maximum of 1,466 t CO_2, and an average of 769 t CO_2.

Table 2.4.7. KI Moringa Sequestration Rate. Shows the minimum, representative, and maximum values of metric tons CO_2 within the above ground biomass per acre and entire area of KI's planned moringa orchard.

	Minimum	Average	Maximum
Sequestered Metric Tons CO_2 Per Acre	7	77	147
Sequestered Metric Tons CO_2 Per Entire Orchard	72	770	1,466

Breadfruit Orchard

KI is also planning to cultivate a 10ac breadfruit orchard. However, no information on the growth rate or carbon content of breadfruit trees was found within the literature. Therefore, an estimate of the carbons stock and sequestration rate of KI's planned breadfruit orchard could not be conducted.

Row Crops and Permaculture

KI currently grows 1 acre of vegetables and edible greens using sustainable farming methods (M. Woo, personal communication, 2016). They also lease an additional 5 acres to the Hawaii Institute of Pacific Agriculture (HIPAg), a permaculture operation (M. Woo, personal communication, 2016). Due to the small size of these operations and a lack of data on the types of plants being grown and their respective carbon contents, a carbon stock and sequestration rate was not calculated.

It is also possible that these agricultural activities represent a source of carbon emissions, as much of the literature lists conventional agriculture as an emission source of carbon, primarily from oxidation and erosion. However, the carbon contained within the volcanic soils of KI's property is not considered labile as it is bound especially tight to the iron and aluminum oxides. Therefore, it is not thought that any carbon emissions would result from the relatively small amounts of soil disturbances caused by these agriculture operations. Permaculture operations generally contain large amounts of stable biomass, and would be assumed to be a carbon sink.

Developed Land

This category includes KI's roads, GRACE Center, Lower Offices, Bond Historic District, Poi Shack, Bond Home, churches, and tilapia aqua culture operation. Since little vegetation exists on these parts of the property, they were assumed to have no carbon storage capability.

KI Emissions

This category includes all emissions from land use change, soil erosion, cattle, and purchased electricity. Under the baseline scenario, emissions include soil erosion, cattle, and purchased electricity. Under the Pasture, Agriculture, Forest, and Riparian scenarios, emissions from land use conversion are also included.

<u>Land Use Conversion</u>

KI has expressed interest in expanding their grazing lands and agricultural activities in the future. Different amounts of forest and shrub land were cleared to allow for these increases under the Pasture, Agriculture, Forest, and Riparian scenarios. 100% of the carbon contained within any vegetation removed as a result of this land use conversion was counted as an emission.

Table 2.4.9. Emissions from Land Use Conversion. The change emissions resulting from land use conversion.

Scenario	Pasture	Agriculture	Forest	Riparian Buffer
Emissions (Tons CO_2)	4,893	4,893	4,060	3,340

Soil Erosion

Emissions from soil erosion were based on the amount of sediment transported from KI's land to the ocean, as determined by the OpenNSPECT model used in the water quality analysis portion of this report. The weight of the sediment, produced by erosion in each scenario, was multiplied by the carbon content per pound of soil to estimate emissions from erosion. It was assumed that the sediment generated from erosion came from the top 10cm of the soil. Therefore, the corresponding carbon content of this portion of the soil, 0.079g C/cm^3/10cm depth, was used.

Table 2.4.10. Calculations of Soil Erosion. A summary of the values used to calculate the annual emissions produced by sediment loading under the baseline scenario.

Sediment Loading	12.75t
Convert to cm^3/10cm depth	12.75t x (1cm^3 ÷ 7.8x10^{-7}t)
Convert to carbon lost	1.63cm^3 x (7.9x10^{-8}g C ÷ 1cm^3)
Convert from carbon to CO_2	1.29t C x 3.67
Total annual CO_2 emissions	4.74t ÷ 20 years = 0.24t

Table 2.4.11. Emissions from Soil Erosion. The sediment loadings and annual emissions resulting from erosion under each of our four land use scenarios.

	Baseline Scenario	Pasture Scenario	Agriculture Scenario	Forest Scenario	Riparian Buffer Scenario
Sediment Loading (Metric Tons)	12.75	12.77	15.19	14.99	12.31
Annual Co_2 Emissions (Metric Tons)	0.24	0.24	0.28	0.28	.23

Cattle Emissions

A model created by the Department of Animal Sciences (DAS) and Department of Agriculture and Resource Economics (DARE) was used to estimate emissions from cattle at KI. This model used information gathered from the most productive cattle operations, defined by the number of beef cows, feedlot cattle, or amount of milk produced annually, in nine states to simulate annual GHG emissions on a per cow and per product basis (Phetteplace, Johnson, & Seidl, 2001).These cattle operations were further broken down into different categories: cow-calf, stocker, feedlot, cow-calf through feedlot, and dairy.

The model then used input data gathered from these cattle operations to determine GHG emissions per product, defined as kg in live weight gain, and per cow. These inputs included nutrient requirements for cattle, land use, fertilizer use, tillage, irrigation, soil carbon sequestration, transportation of cattle/fertilizer, insecticide, and herbicide (Phetteplace et al., 2001). From this data, the DAS and DARE model generated various types of GHG emissions: CH_4, N_2O, and CO_2.

Methane emissions were calculated by taking the gross energy intake per cow and multiplying it by a methane generation coefficient, 6% for pasture raised cattle and 2-3% for feed-lot raised cattle (Phetteplace et al., 2001). The higher methane generation coefficient for the pasture raised cattle is reflective of the quality of the feed; grass and other plants are harder to digest than the high-quality grain that cattle raised in feedlots are given (Harper, Denmead, Freney, & Byers, 1999; Phetteplace et al., 2001).

Nitrous oxide emissions were generated by calculating the nitrogen excretion, which varied depending on the diet of the cow, the synthetic fertilizer application, nitrogen fixation by crops, and nitrogen from crop residues and from the volatiles and leaching of nitrogen from cattle manure and fertilizer (Phetteplace et al., 2001). Finally, carbon dioxide emissions were determined by adding up the fertilizer synthesis and fossil fuel use during the cattle operation, which included transportation (Phetteplace et al., 2001).

KI's cattle operations most closely resemble that of the cow-calf cattle operation, which raise cattle from birth and maintain a year-round herd, selling the cattle to a feedlot or slaughtering facility for final processing into beef when they reach a certain size (M. Woo, personal communication, 2017). Since KI doesn't currently allow for the use of herbicides or insecticides on their property and the majority of their cattle operations don't use fertilizer, only methane emissions per cow, 1175 $\pm$ 36 kg CO_2eq/cow/year, was used as a proxy value to calculate KI's cattle emissions. The reported value matches well with EPA estimates of methane produced per cow per year, 65 kg, which when converted to a CO_2 equivalent is approximately 1,495 kg CO_2eq/cow/year (EPA, 1997). The chosen proxy value was then multiplied by the total number of cattle on KI's property, 321, to achieve total emissions from cattle of 505,745 kg CO_2eq/year or 505.75t CO_2eq/year. Only considering methane emission from enteric fermentation and cattle manure may underestimate the total GHG emissions generated from KI's cattle operations.

Table 2.4.12. Cattle Emissions under the Baseline. The number of cattle per lessee, the emissions rate per cow per year, and the total emissions of all the cattle in kg and metric tons CO_2 equivalent per year.

Lessee	Number Of Cattle	Emissions Rate (Kgco$_2$eq/Head/Year)	Total Emissions (Kgco$_2$eq/Year)
Pu'huluhulu	106	1,175	124,550
H78	32	1,175	37,600
Matt M.	6	1,175	7,050
Ponoholo	100	1,175	117,500
Parker	77	1,175	90,475
Total	321	-	377,175
Total(T Co$_2$eq/Year)	-	-	377.2

Since the area of KI's pastures increased under the four alternative scenarios, it was assumed there would be a corresponding increase in the number of cattle present on the property. To account for this, a stocking coefficient of approximately 1 cow per two acres was calculated by dividing the total cattle on KI's property under the baseline by the amount of pastureland under the baseline scenario. This stocking rate was assumed to be constant between all four alternative scenarios. The stocking coefficient was then multiplied by the new amount of pastureland under each alternative scenario to find the amount of cattle, and the corresponding amount of emissions generated by them.

Table 2.4.13. Cattle Emissions Under all Scenarios. The area of pasture, number of cattle, and emissions generated from cattle for each scenario.

Scenario	Area Of Pasture	Number Of Cattle	Total Emissions (Tco_2eq/Year)
Baseline	580	321	377
Pasture Scenario	1,225	678	797
Agriculture Scenario	1,147	635	746
Forest Scenario	1,053	583	685
Riparian Buffer Scenario	912	505	593

<u>Electricity Emissions</u>

KI currently uses around 15,183 kWh annually. However, as KI's numerous pilot projects begin to mature over the next 20 years, this amount of electricity purchased is expected to increase to approximately 605 MWh (*'Iole Micro-Grid Conceptual Design Report*, n.d.). KI purchases its electricity from Hawaii Electric Light Company (HELCO), but to calculate the emissions from KI's purchased electricity, the types of fuel HELCO used to generate electricity had to be determined. Data from the EIA-923, 2015 report was filtered and sorted by state and power operator. Assuming HELCO didn't purchase electricity from other state power operators, then it generated approximately 68% of its electricity from distillate fuel oil and 32% of its power from residual fuel oil (EIA, 2015). However, finding a report that detailed the emissions associated with the entire life cycle – extraction, production, transport, and consumption - of residual and distillate fuel oil was a challenge. Therefore, these two types of heavy oil were combined into a broader category of 'oil used for electricity generation'. A life cycle assessment (LCA) of oil used for electricity generation in Europe, in 2010 was used to estimate the annual emissions from KI's purchased electricity. The LCA found that 1TWh of electricity produced the following amount of metric tons of CO_2: 30,301 tCO_2 from extraction; 28,399 tCO_2 from transportation; 2,200 tCO_2 from production; and, 858,070 tCO_2 from combustion (Dinca, Badea, & Apostol, 2010). The LCA assumed a transportation distance of 10,000 km to calculate the emissions generated from the transportation stage, but given the lack of data on the origin of the fuel used by HELCO and the relatively small proportion of total emissions contributed by the transportations stage (3%), the transport stage of the LCA was excluded when emissions from KI's purchased electricity were calculated.

To find KI's electricity emissions, the emissions generated from the life cycle of 1 TWh of electricity, minus transport, was scaled down to the emissions generated from KI's electricity consumption. This calculation was completed by dividing KI's annual energy demand by 1TWh and multiplying this conversion factor with the emissions produced from 1TWh to get KI's total annual emissions under the baseline and four alternative scenarios, 13.92 t CO_2 and 554.65 t CO_2, respectively. The increase in electricity consumption under the four alternative scenarios was determined through literature review of a consultation report, which determined that KI would use an estimated 605,000 kWh annually when all of their pilot projects had reached maturity (*'Iole Micro-Grid Conceptual Design Report*, n.d.); it was assumed that all of KI's pilot project reached maturity in year 20 of each alternative scenario.

Table 2.4.14. Emissions from Electricity Use. The present and future energy demand as well as the scope 2 emissions associated with each.

	Energy Demand	**Emissions Generated (Per Year)**
Current	15,183 kWh	13.92t CO_2eq
Future	605,000 kWh	554.65t CO_2eq

Results & Discussion

Baseline Carbon Stocks

The vast majority of the carbon on KI's property, 96%, is stored within the soil, which is quite high when compared to the average amount of carbon stored within the soil of forests in the 48 contiguous US states, 43% ("Carbon Storage in Forests," 2015). However, volcanic soils, such as the soils on KI's property, have high concentrations of aluminum and iron oxides which bind tightly to carbon, allowing these types of soil to hold larger amounts of carbon than soils with lower amounts of iron and aluminum oxides (Chadwick et al., 2003). The forests of the 48 contiguous states of the US have an average of 10kg/m^2/meter depth of carbon (United States Department of Agriculture, 1992), while the soil samples collected by Dr. Chadwick on KI's property contained 180kg/m^2/meter depth of carbon (see figure 2.4.2 in the appendix).

Forests store the second largest amount of carbon on KI's property, 3%, with a higher amount of carbon per acre than the forests of the 48 contiguous US states, 52 versus 22.5 metric tons of carbon respectively (United States Department of Agriculture, 1992). This is representative of tropical forests, which support much larger amounts of above and below ground biomass than temperate forests; above ground carbon densities of forests on the Island of Hawaii have been recorded as high as 217 metric tons of carbon per acre (Asner et al., 2016). KI's macadamia orchards and shrub land combined store only 0.4% of the total carbon stock. This is due to the smaller amounts of woody biomass present per acre.

Table 2.4.15. Baseline Carbon Stocks. The amount of CO_2 stored per acre and by total area of KI's soils, forests, macadamia orchards, and shrubbery, as well as the percentage of total carbon stored within each category.

	Soil	Forest	Macadamia Trees	Shrub
Carbon Sequestered per Acre	2,671 t CO_2	191 t CO_2	22 t CO_2	1.9 t CO_2
Total Carbon Sequestered at KI	5.97×10^6 t CO_2	2.23×10^5 t CO_2	8,375 t CO_2	444 t CO_2
Percentage of Total Carbon	96%	3.6%	0.399%	<0.01%

KI Emissions and Sequestration

Under the baseline scenario, emissions from cattle are the largest source of CO_2, 377 t CO_2eq/year, followed by emissions from electricity consumption, 14 t CO_2/year, and emissions from erosion, 0.24 t CO_2/year. Sequestration from continual forest growth is estimated to sequester 24.7 t CO_2/year, or approximately 6% of overall emissions.

Total emissions increase dramatically under the Pasture, Agriculture, Forest, and Riparian alternative scenarios (see table 2.4.16 below). Land use conversion is by far the largest emitter of CO_2 for each alternative scenario (greater than 75% of total emissions), even with increased numbers of cattle from the availability of more pasture land and the huge rise in electricity usage caused by the assumed maturation of KI's various pilot projects (KI aquaculture, agriculture, GRACE Center, and tours). The CO_2 released by land use conversion results from the clearing of large amounts of forest under the Pasture scenario, Agriculture scenario, Forest scenario, and Riparian scenario (see table 2.4.16 below).

Cattle emissions increase under each of the four alternative scenarios; the availability of more pastureland allows for a higher amount of cattle to be grazed on KI's property. However, cattle are now the second largest contributor to total emissions under each alternative scenario (see table 2.4.16 below). These decreases are caused by the conversion of pastureland to orchards and row crops under the Agriculture scenario, from conversion to forest under the Forest scenario, and to Shrubs under the riparian scenario.

Emissions from electricity also increase, from 13.92 t CO_2/year under the baseline to 555 t CO_2/year for each of the four alternative scenarios. Electricity is now the third largest contributor of emissions.

Despite an increase in erosion caused by land conversion, the addition of row crops, and more cattle, erosion is responsible for less than 1% of total CO_2 emissions. The modeled quantity of soil eroded under each of the alternative scenarios, an average of 13.6 metric tons, is simply not enough to generate a significant amount of emissions.

Sequestration decreases under the Pasture scenario (13.25t CO_2/year) when compared with the baseline (24.7 t CO_2/year) because of reduced forest growth, and increases under the Agriculture scenario (62.9t CO_2/year) due to the addition of coconut and moringa orchards. It further increases in the Forest scenario (65t CO_2/year) with the restoration of 100ac of forest, and even more in the

Riparian scenario (66.6 t CO_2/year) with the addition of a vegetated riparian buffer that prevents land use conversion from occurring. However, sequestration mitigates only a fraction of total annual emissions under the Pasture, Agricultural, Forest, and Riparian scenarios, approximately 1% in each scenario.

Table 2.4.16. The amount of carbon emitted and sequestered by land use conversion, cattle, electricity, erosion, and forest in metric tons of CO_2 equivalent (t CO2eq/year) for each of our four scenarios.

	Land Use Conversion	Cattle	Electricity	Erosion	Sequestration	Net Emissions
Baseline	0	377.18	13.92	0.24	-24.7	367
Pasture Scenario	4,893.00	797	555	0.24	-13.25	6,232
Agriculture Scenario	4,908.70	746	555	0.28	-62.9	6,147
Forest Scenario	4,059.85	685	555	0.28	-65	5,235
Riparian Scenario	3,340.49	593	555	0.23	-66.6	4,422

Because of the lack of site-specific data needed to assess the carbon stocks and sequestration rates of KI's forests, shrub land, pastures, and agricultural activities, this analysis relied heavily on proxy values from similar sites on the Island of Hawaii and Puerto Rico. However, KI's pasture lands and planned breadfruit orchards could not be estimated at all due to lack of available data in the literature. Secondly, the soil samples from KI were taken within the older macadamia orchards on the property. Since a more representative collection of soil samples from KI's property could not be taken, the carbon content of these samples was extrapolated to the entire property. Given that parts of the property have a longer history of intensive sugar cane cultivation and cattle grazing than others, and that parts of the property have lost more soil from erosion than others, we wouldn't expect the soil at KI to have the same carbon content throughout the property. Therefore, while this carbon analysis is a good first order estimate of KI's carbon stocks, it could be an over or underestimate of the true total amount of carbon stored on the property.

For KI's emissions, land use conversion was the largest category of emissions, so an over or underestimate would have the largest effect on KI's total emissions. The amount of CO_2 released from land conversion depends on the carbon stocks of the vegetation being cleared and the amount of carbon from dead vegetation that is lost as atmospheric CO_2. However, even when the lowest reported carbon value for similar forest on the Island of Hawaii was used instead of the average reported carbon value (102 vs 190 t CO_2 respectively), land use conversion remained the highest source of emissions.

The proxy values used to estimate emissions from cattle on KI's property and from KI's electricity consumption matched well with values from the United States Environmental Protection agency and Energy Information Administration. Therefore, the most influential factors for actual emissions from KI's cattle and electricity use are the amount of cattle set out to graze and the amount of electricity used by KI.

In conclusion, while the specific values for KI's carbon emissions, stocks, and sequestration rates may not be precise, they are accurate to their order of magnitude. The order of the sources of emissions from largest to smallest are also thought to be accurate. That is, land use conversion is the largest source of emissions, cattle are the second largest source, electricity consumption the third, and erosion the smallest.

2.5 Wildlife Habitat Availability

Introduction

Due to its highly anthropogenically-modified environment, Kohala Institute (KI) has not historically been prioritized for wildlife species conservation. Even though past surveying efforts revealed that very few native species of concern were present on New Moon Foundation Lands, KI has not been extensively surveyed further for wildlife species in recent years, and no conservation actions were ever recommended (Cowie et al., 1999; Gerrish, 2003c).

As the most geographically isolated archipelago in the world, the Hawaiian Islands support a unique and largely endemic native flora and fauna. Unfortunately, many of these species have now been put at risk of extinction in the face of habitat loss, anthropogenic disturbances, and competition by alien plants and animals. Roughly 25% of the United States' federally listed endangered species reside in Hawaii (Banko, 2004), and over 50% of Hawaii's native birds have already gone extinct (Worthington, 1998). For these reasons, it was meaningful to conduct an assessment of potential impacts to wildlife that may be present at KI.

The approach to the wildlife analysis consisted of a general overview of potential habitat impacts for all species of concern. This approach was selected in order to get a full picture of the possible effects that various management actions might have on the region's various potential wildlife populations. The wildlife analysis incorporated the five scenarios of the project (i.e, the Baseline, Pasture, Agriculture, Forest, and Riparian Buffer Scenarios) into its methodology in order to assess the differences between impacts as land uses changed.

Methods

The first step in performing the general review of habitat impacts on species of concern was to identify the aforementioned animal "species of concern." Initially, all species that might be present in the North Kohala region were considered for habitat review.

These species are presented in Table 2.5.1 on the next page.

Table 2.5.1. Endemic wildlife species that may occur at Kohala Institute. Unlisted species, high elevation forest species, and water-dependent species were omitted from the wildlife analysis.

Species Name	Description	Likelihood	Federal Status
Hawaiian hawk (‘io) *Buteo solitaries*	Raptor	Confirmed	Endangered
Hawaiian hoary bat (‘ōpe‘ape‘a) *Lasius cinereus semotus*	Mammal	Highly likely	Endangered
Hawaiian goose (nēnē) *Branta sandvicensis*	Water bird	Somewhat likely	Endangered
Hawaiian duck (koloa) *Anas wyvilliana*	Water bird	Possible	Endangered
Hawaiian coot (‘alae ke’ oke ‘o) *Fulica alai*	Water bird	Possible	Endangered
Hawaiian stilt (ae’o) *Himantopus mexicanus knudseni*	Water bird	Possible	Endangered
Hawaiian short-eared owl (pueo) *Asio flammeus sandwichensis*	Raptor	Possible	Not listed
Hawaiian honeycreeper (‘amakihi) *Hemignathus virens*	Forest bird	Possible	Not listed
Hawaiian honeycreeper (‘apapane) *Himatione sanguinea*	Forest bird	Possible	Not listed

Next, the species of concern list was pared down based on several criteria. These criteria included:

1. **Risk of extinction**.
   To focus on species with the highest need, only federally listed endangered species were incorporated into the wildlife analysis.

2. **Likelihood of occurrence at KI.**
   Two species of honeycreepers were determined to be likely to occur in the region. However, these species were omitted from the analysis because they typically occur at elevations higher than the extent of KI's property and prefer native vegetation that KI lacks (Gerrish, 2003c).

3. **Terrestrial habitat.**
   Several species of water birds were also determined to be likely to occur in the region. However, these species were omitted from this analysis due to their dependence on aquatic habitats such as ponds and wetlands, which KI's property does not have nor will have over the 20-year planning horizon.

Once all possible species that might be present on KI's property had been reviewed, three species were identified as the "species of concern" for the habitat review. These species are:

1. The Hawaiian hawk (ʻIo);
2. The Hawaiian hoary bat (ʻōpeʻapeʻa); and
3. The Hawaiian goose (Nēnē).

For these three species, a detailed investigation into their general life histories, habitat needs, and current threats was conducted. These species accounts are presented in Appendix 2.5.

Once the requirements for viable habitat for each species were thoroughly understood, a quantitative comparison of the availability of suitable habitat by acreage under each of the five scenarios was performed.

Habitat Requirements

Based on the individual species accounts for the Hawaiian hawk, hoary bat, and goose, general habitat requirements were assigned corresponding to KI's current land cover types: Forest, Shrub, Pasture, Agriculture, and Developed. For each species, these land cover types were classified by suitability as either Highly Suitable, Somewhat Suitable, or Not Suitable.

The habitat suitability by species and land cover type are presented in Table 2.5.2.

Table 2.5.2. Land cover habitat suitability. Suitability classifications of KI's current land cover types as habitat for wildlife species of concern.

	Hawaiian hawk	Hawaiian hoary bat	Hawaiian goose
Highly suitable	Forest	Forest	Shrub
Somewhat suitable	Agriculture, Shrub	Shrub	Pasture, Forest
Not suitable	Pasture, Developed	Agriculture, Pasture, Developed	Agriculture, Developed

Once the habitat suitability had been classified for each species, amounts of suitable habitat were calculated by acreage under each of the five planning scenarios. The total acreages and percentages of habitat suitability for each species under each scenario are presented in Tables A2.5.1 and A2.5.2 in the appendix.

Results & Discussion

The wildlife analysis revealed that suitable habitat for all three species of interest declined under the four alternative scenarios compared to the baseline, though the specific impacts varied by species of concern. The greatest source of this decline in available habitat was simply the fact that in all alternative scenarios, large amounts of land were converted from natural (including alien plant species) to anthropogenic land cover types.

For the two species that depend on forest land for highly suitable habitat, the Hawaiian hawk and the Hawaiian hoary bat, impacts were most severe in the Pasture Scenario where large amounts of land were converted from forest land to pasture land. Adding in 80 acres of agricultural land from the Pasture to Agriculture Scenario slightly benefitted the hawk, which is able to use agricultural trees such as macadamia nut trees for somewhat suitable habitat, but not the hoary bat, which is unable to use such agricultural tree species. Both the hawk and hoary bat further benefitted from the additional 100 acres of forest that was preserved from the Agriculture to the Forest Scenario, and even more so from the additional 170 acres of forest that was preserved from the Forest to the Riparian Buffer Scenario.

For the Hawaiian goose, impacts were less severe. This is because the goose prefers shrub habitats, which KI did not possess very much of to begin with. The goose, however, is able to utilize both forest land and pasture land as somewhat suitable habitat. Therefore, when large amounts of land were converted from forest land to pasture land, the end result for the goose was relatively unchanged. Much like the hawk and the hoary bat, the goose also benefitted from the preservation of natural vegetation (in this case, shrub land) in the Riparian Buffer Scenario, compared to the other three alternatives (Pasture, Agriculture, and Forest).

Refer to Figure 2.5.4 for a visualization of habitat availability for these three species of interest under the five planning scenarios.

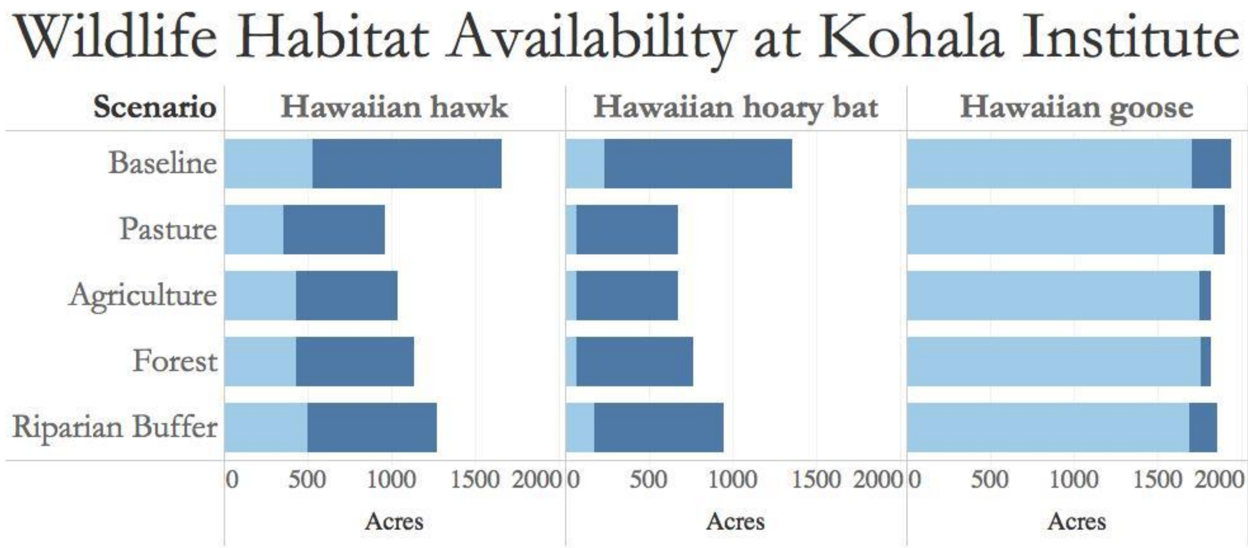

Figure 2.5.4. Availability of suitable habitat for species of concern by acreage under five alternative scenarios. Dark blue indicates highly suitable habitat and light blue indicates somewhat suitable habitat. While habitat availability decreases under all four new scenarios compared to the baseline, the Riparian Buffer scenario has the least negative impacts for the three species of concern.

Part 3. Conclusions

The analyses performed for this study revealed many conclusions for Kohala Institute (KI) related to their current and potential land use impacts on water quality, carbon emissions, and wildlife habitat. In general, this study's findings revealed that:

1. Row crop agriculture had the largest impacts on water quality.

2. Land use conversion from forest to pasture land contributed the most to carbon emissions.

3. Land use conversion from natural to anthropogenic land cover types decreased habitat availability for the three species of concern.

3.1 Water Quality Conclusions

Under the Agriculture and Forest Scenarios, total runoff and pollutant loadings increased the most from the Baseline Scenario due to the addition of 80 acres of row crop agriculture and orchards that are relatively less suitable for soil, water, and nutrient conservation. Under these scenarios, sediment loadings increased the most, by nearly 20%, relative to other water quality pollutant loadings. This is concerning because the Wainaia Gulch on KI's property has been listed as an impaired state water body under the federal Clean Water Act for exceedances in turbidity since 2002. Since turbidity problems are often associated with higher sediment loadings entering a water body, KI could potentially exacerbate an existing water quality problem on their property if they implement future land use activities that do not promote soil conservation (i.e., row crop agriculture and orchards). Fortunately, KI could implement several best management practices (BMPs), such as 50-meter vegetated riparian buffers, cover crops, or tillage management that could mitigate these current and potential water quality impacts in the future.

3.2 Carbon Emission Conclusions

Land use conversion is by far the most significant source of emissions for all alternative scenarios, while cattle is currently the largest source of emissions at KI (see table 2.4.16). There are several strategies to reduce emissions from each of these sources, yet they are expensive and many require further research before they can be implemented.

The simplest method to minimize emissions from land use conversion would be to reduce the amount of trees removed and instead prioritize vegetation that contains low amounts of carbon (i.e. shrubs). There are currently 234 acres of shrubs, which consist primarily of christmass berry (*Schinus terebinthifolius*) and common guava (*Psidium guajava*) (Gerrish, 2003c); both of these tiny trees contain much smaller amounts of carbon on a per acre basis than the densely vegetated forested lands at KI (see table 2.4.5). Removing shrubs instead of forest would still allow for a significant expansion of KI's pasture land, but have a substantially smaller impact on emissions from land use conversion (445 t CO_2/year from removing just shrubs as opposed to over 4,000 t CO_2/year from the removal of shrubs and trees).

Similarly, the easiest way to reduce emissions from cattle would be to remove them from the property altogether. This would have the co-benefit of removing the incentive for large-scale land use conversion. However, cattle ranching has a long history in Hawaii and has become intertwined with Hawaiian culture (Hawaii Tourism Authority, 2017). Through leasing their land to local Hawaiian cattle ranchers KI hoped to maintain good relations with the local community and further incorporate Hawaiian culture into their operations (M. Woo, personal meeting, September 2016). Yet, KI makes a modest income from their annual lease payments and in return gets a minimal amount of land management (M. Woo, personal meeting, September 2016). Because of the short-term lease agreements with the cattle ranchers, generally the land is leased on an annual basis, the ranchers have little incentive to install capital heavy infrastructure on the land (e.g. cattle fencing) or carry out the type of land management that KI originally intended to be performed. If anything, the land has become further overgrown with invasive plants since cattle grazing has occurred on these sections of the property. Therefore, KI needs to critically assess the overall value of maintaining or expanding cattle operations on their property given the large amount of emissions that result from the cattle and from the clearing of vegetation to expand their pastureland, especially in light of their mission to "continue the tradition of sustainability today" (Kohala Institute, 2017).

3.3 Wildlife Conclusions

Suitable habitat for all three wildlife species of concern identified in this analysis declined from the Baseline to Alternative Scenarios due to the conversion of large amounts of land from natural to anthropogenic vegetation. Both of the forest-dependent species, the Hawaiian hawk and Hawaiian hoary bat, witnessed the most significant impacts, since the largest amounts of land conversion occurred from forest to pasture land. For both of these species, "highly suitable" habitat (i.e. forest land) declined sharply from 46% to 25% of the property between the Baseline and Pasture scenarios. However, the Hawaiian hawk maintained more "somewhat suitable" habitat than the Hawaiian hoary bat across the other alternative scenarios when additional agricultural projects were included, since it is adapted to use agricultural habitats whereas the Hawaiian hoary bat is not.

The Hawaiian goose, on the other hand, appeared relatively unaffected across all alternative scenarios because it relies on shrub land as "highly suitable" habitat, which was not prevalent on the property to begin with. This species is adapted to use either forest or pasture land as "somewhat suitable" habitat, so even when large amounts of land were converted from forest to pasture land, its end result changed no more than 5% in either direction in any alternative scenario.

For all three species, however, another trend was evident: amounts of available habitat improved as the alternative scenarios progressed sequentially from Pasture to Riparian Buffer, simply due to the retaining or replacing of more of the woody vegetation that these species prefer. Changes were smallest between the Baseline and Riparian Buffer scenarios, where the most vegetation was preserved. This illustrates that if done with intentionality and avoidance of a few key areas, development can occur with considerably smaller consequences than it otherwise would have.

Part 4. Recommendations

Below are the recommendations for each of the primary impact categories: water quality, carbon emissions, and wildlife habitat.

4.1 Water Quality Recommendations

The water quality assessment offered several recommendations for Kohala Institute (KI) when considering future land use impacts on water quality. The most important water quality recommendation for KI is to implement long-term, autosampler measurement programs that collect comprehensive, real-time water quality data because KI does not have any water quality data on the state water bodies that traverse through their property. The collection of these water quality data is crucial because it will inform KI of their water quality impacts, ensure that they are meeting state water quality standards at every location on their property, and help them meet their mission of sustainable environmental stewardship. The collection of these water quality data will increase operating costs for KI, but KI already has consultants who monitor the quality of their potable water resources (i.e., drinking water resources); therefore, KI has the technical resources to make this water quality monitoring program feasible. When collecting water quality data, KI should analyze both total runoff and nutrient *loadings* and *concentrations* because not only do they have to meet state water quality standards (in units of *concentration*; mg/L) now, but they also might have to abide by state total maximum daily *loads* (TMDLs) if any of their water bodies in the future are listed as 303(d) impaired by the Clean Water Act.

To mitigate potential water quality impacts from anthropogenic land cover types (i.e., agriculture, pasture, and development), KI should look into implementing best management practices (BMPs), especially in water-quality-degradation-prone areas on their property (e.g., gulches). Not only can BMPs help KI in reducing water, soil, and nutrient loss from their anthropogenic land use activities, they can also help KI meet their goal of sustainable land use by maintaining good water quality (Esgate, Ilano, & El-Swaify, 2015). Examples of NRCS-recommended BMPs that KI could expand upon or implement in the future include:

- Cover crops (ground cover on exposed soils);
- Mulching (organic/inorganic materials protecting exposed soils and providing nutrients);
- Residue and tillage management (using fallen plant residue instead of mulch for soil protection and nutrients);
- Tree/shrub establishment (increasing forest and shrub cover for erosion control); and
- Vegetated riparian buffers (permanent, vegetated strips protecting water bodies and their steep slopes from erosion) (Esgate et al., 2015).

Cover crops would be an ideal BMP for KI to implement for their farming projects because not only would cover crops reduce sediment loss from these areas, but they would also allow KI to cultivate other types of crops that are commonly grown in Hawaii. A common cover crop that is used as a BMP for sediment control and grown in Hawaii for cultivation is the onion. Other BMPs KI can use for their farming projects include mulching, residue management, and tillage management. Not only are these BMPs ideal for raindrop erosion control, but they are also ideal for providing appropriate levels of nutrients, soil moisture, and weed protection by utilizing both organic (e.g., plant residue) and inorganic (e.g., plastic sheets) materials that KI already has available to them. Lastly, tree/shrub establishment and 50-meter vegetated riparian buffers along KI's gulch systems would be recommended for KI to implement because they need to protect their gulch systems from water quality degradation, as state and federal regulations mandate. Since KI's gulch systems have very steep slopes with highly erodible soils, the establishment *or* preservation of existing trees, shrubs, and grasses in these areas will help increase soil stability and buffer against sediment loss (Esgate et al., 2015). Fortunately, KI already performs organic farming so water quality issues related to chemical fertilizers and pesticides are not of concern.

Lastly, KI should discuss with its upstream neighbors about each other's future land use activities. Since KI's upstream neighbor is Parker Ranch, a major cattle ranching operation in the U.S., KI should monitor and evaluate how Parker Ranch will impact the quality of water entering their property. A communicative relationship will not only help KI from receiving degraded water quality from its upstream neighbors, it will also further protect water quality in the ʻIole Ahupuaʻa from degradation as a whole.

4.2 Carbon Emission Recommendations

Of the four emission categories identified in this report (land use conversion, cattle, electricity consumption, and erosion), land use conversion of forest to pastureland emits the most CO_2 in each of the four alternative scenarios. It's important to note that the removal of any trees on the property will result in carbon emissions, whether it's to expand KI's pastures, or their roads and new buildings. Unfortunately, mitigation is currently limited; options to reduce emissions from land-use conversion include transforming cleared vegetation into biochar, avoidance (deciding not to remove trees), or afforestation elsewhere, as a way to offset emissions.

Biochar—a charcoal like material—has the potential to sequester carbon for hundreds to thousands of years, increase the quality of soil, and reduce nitrogen emissions from soil, but it is still not well understood (Spokas, 2010). Biochar is produced when carbon containing material, such as plants, undergoes pyrolysis in anaerobic conditions; biochar is resistant to decomposition and oxidation, making it a potentially stable source of sequestered carbon. For KI, biochar could be used as a means to mitigate emissions from land use conversion, for example, when woody plants such as trees are cleared for alternative land uses they could be converted into biochar instead of being left to rot (Spokas, 2010). This biochar could also be applied as a soil amendment; studies have shown that biochar increases the soil's organic content and its ability to retain moisture, both of which improve the quality of the soil for cultivation and afforestation (Spokas, 2010).

Biochar has also been shown to reduce nitrous oxide emissions from over fertilization of soil and to reduce nitrogen leaching, which would have the co-benefit of reducing the nitrogen loads to nearby water sources (Singh, Hatton, Singh, Cowie, & Kathuria, 2009). However, the mechanisms that make biochar a stable form of sequestered carbon, and allow it to reduce nitrogen emissions and leaching are not well understood (Spokas, 2010; Singh et al., 2009). In addition, the amount of carbon contained within the biochar, its stability, and its benefits as a soil amendment all depend on the parent material. Considering the heterogeneous mix of vegetation within KI's forests and the limited understanding of biochar, this mitigation method would need extensive research before it could be fully implemented.

However, KI's desire to be a "living laboratory" could make biochar an interesting opportunity as a pilot project, especially in a partnership with one or more of the several universities that KI is involved with (Kohala Institute, 2014). Moreover, Hawaii's renewable portfolio standard indicates that biomass generation does qualify as a renewable energy source ("Renewable Portfolio Standard," 2015). A biomass generator that uses anaerobic pyrolysis could be both a source of renewable energy for KI, generate sellable renewable energy credits, and produce biochar (Spokas, 2010). If further research demonstrates that biochar is a feasible way to sequester carbon for long periods of time, it could be a promising mitigation method.

Since biochar requires further investigation, avoidance and afforestation were also considered; avoidance refers to the act of not removing forest, while afforestation is the process of reforestation. Avoidance is the simplest and cheapest option for mitigation, however it may not be realistic given the economic and cultural interests of KI. It's also important to consider that almost all of the plant species within the forests are alien, some of which are highly invasive (*Psidium cattleyanum, Psidium guajava, Falcataria moluccana*, and *Rauvolfia vomitoria*). Clearing these alien forests and replacing them with native or endemic plant communities could be beneficial to both native biodiversity (Cordell, Ostertag, Vitousek, & Warman, 2015). In particular, koa trees could be a good option for afforestation as they are a pioneer species for reestablishing native plant communities, grow quickly, and are valuable as timber (Daily et al., 2009). One sustainable timber provider, Hawaiian Legacy Hardwoods, took advantage of these attributes to gain renewable energy credits from The Gold Standard Foundation, a Swiss-based non-profit, for planting hundreds of thousands of koa trees on the Hawaii Islands (Gomes, 2015). Thus, a combination of afforestation and avoidance could be used to reduce KI's emissions and provide monetary benefits in the form of timber sales and renewable energy credits.

Cattle are the largest contributor to KI's emissions under the baseline scenario, and the second largest under all four alternative land use scenarios. Opportunities for minimizing emissions from grazing cattle are also limited and include vaccinations, dietary change, and animal selection (Buddle et al., 2011). However, the simplest and most economical option for KI is to reduce the amount of cattle on the property.

Methane is produced in the rumen, or fore-stomach, of cattle by a group of microbes called methanogens. Vaccinating against methanogens could one day be a cost-effective way at reducing methane production from cattle, however more research needs to first be done (Buddle et al., 2011). This process is complicated by potential negative health effects to the cows from the vaccination (Buddle et al., 2011). Furthermore, reducing the methanogens in the rumen of cattle could affect the amount of energy they obtain from their diet and cause them to eat more, producing more methane (Buddle et al., 2011). Methanogens help break down the cellulose and lignin of plants into chemicals that cattle can utilize, such as glucose (Buddle et al., 2011). Therefore, a diet that incorporates feeds or plants with less cellulose and lignin can reduce the amount of methane produced by cattle. Plant species high in sugar, tannins, and saponins have also been shown to reduce methane produced by cattle, however the results are varied (Buddle et al., 2011).
However, methane mitigations strategies that require daily supplementation of pasture grazing cattle's diet are generally unfeasible due to their high cost(Buddle et al., 2011). Thus, changing the composition of the edible plant species within the pasture is currently the only effective way to reduce emissions from grazing cattle.

Selective breed of animals with highly efficient digestive systems has also been shown to reduce methane emissions (Buddle et al., 2011). However, this strategy is labor intensive and requires expensive equipment. Additionally, cattle with highly efficient digestive systems might not possess the traits desired for beef cattle (Buddle et al., 2011).

Vaccination, dietary change, and animal selection have all been identified as potential methods to reduce methane emissions from cattle. However, each of these three identified mitigation strategies has issues that make it less than desirable to employ: vaccinations have yet to be proven, dietary change involves replanting desirable plants over hundreds of acres of pasture, and animal selection requires expensive equipment. Given that KI simply leases land for these cattle operations and gets only a modest lease payment for each operation (KI makes less than $10,000 annually from all of their cattle operations – (M. Woo, personal communication, August 2016), removing the cattle operations from their property would be the cheapest and simplest method to reduce emissions from cattle.

4.3 Wildlife Habitat Recommendations

The wildlife analysis offered several lessons for KI when considering future land use impacts on wildlife species of concern. The first and most significant of these is that in order to effectively plan for conservation, clear goals need to be set in place. For KI, this would mean first being certain of which wildlife species (if any) are located on the property before any plans to protect them could commence. For this reason, it is recommended that KI pursue a more recent, thorough biological survey of the property and implement a plan for long-term monitoring to detect evidence of possible wildlife species. Such evidence could include actual sightings, nests, eggs, signs of foraging, etc. Until KI is certain of where these species are located on their property, conservation management actions may be futile.

Additionally, if wildlife species are found to be present on the property or if KI establishes a goal of bringing them to the property in the future, KI would need to determine which species it was most interested in protecting, as the three species of interest have unique habitat needs. If the goal was to conserve the Hawaiian hawk or Hawaiian hoary bat, preserving and promoting forest habitats would be the priority; whereas if the goal was to conserve the Hawaiian goose, it would be shrub habitat. While all three of these species have inherent value as endemic, endangered species, conserving them might yield very different benefits for land managers.

When approaching the complicated issue of wildlife conservation, KI does not need to go it alone, given that there are several opportunities for partnerships and potential habitat connectivity nearby on the island. For example, the Hawaii Wildlife Center is a neighbor to KI located right across the 270 highway in Kapaʻau, and would undoubtedly be able to offer expert assistance when beginning such an endeavor. Additionally, the US Forest Service manages many areas in Hawaii such as the nearby Kohala Forest Reserve, and may be able to offer additional resources when developing species conservation plans.

Lastly, the greatest recommendation to benefit wildlife throughout any of the KI's future activities is to simply be on the lookout for signs of wildlife species and take care to avoid disturbing them. In particular, if any land conversion does occur, especially from Forest land to another land type, great caution should be taken to look out for nests in the trees that are to be removed. All three of the species of interest, the Hawaiian hawk, Hawaiian hoary bat, and Hawaiian goose, are currently endangered, due in large part to their inability to establish successful nests, which is often due to anthropogenic disturbances. Even if no other actions are taken, this is a good way to minimize impacts to wildlife species across the property and promote the viability of these sensitive species in the future.

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Appendices

Appendix 2.2: Accessibility Analysis

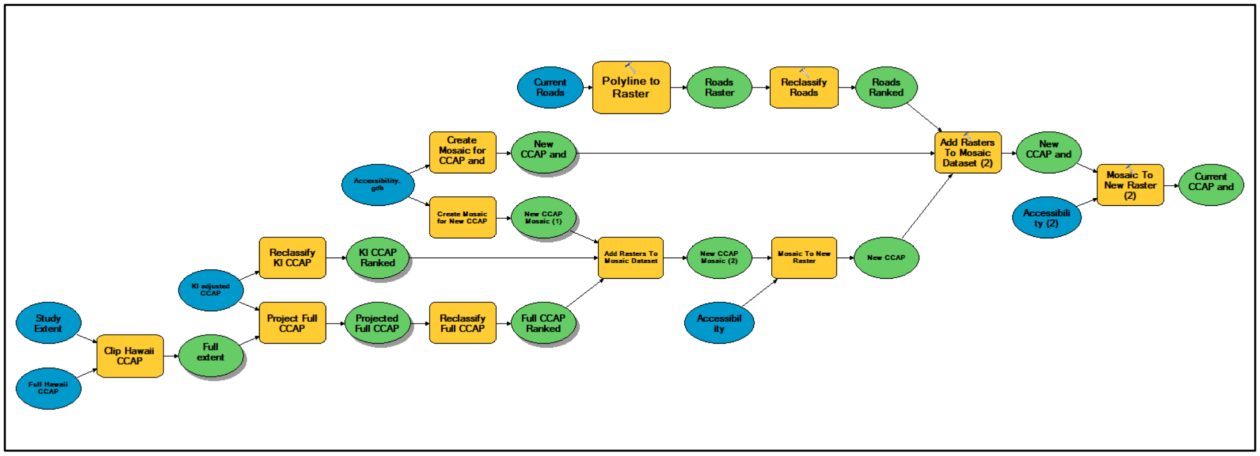

Figure A2.2.1. ArcGIS Model for obtaining a land cover raster with current CCAP and road conditions, to be combined with slope to create a cost surface raster.

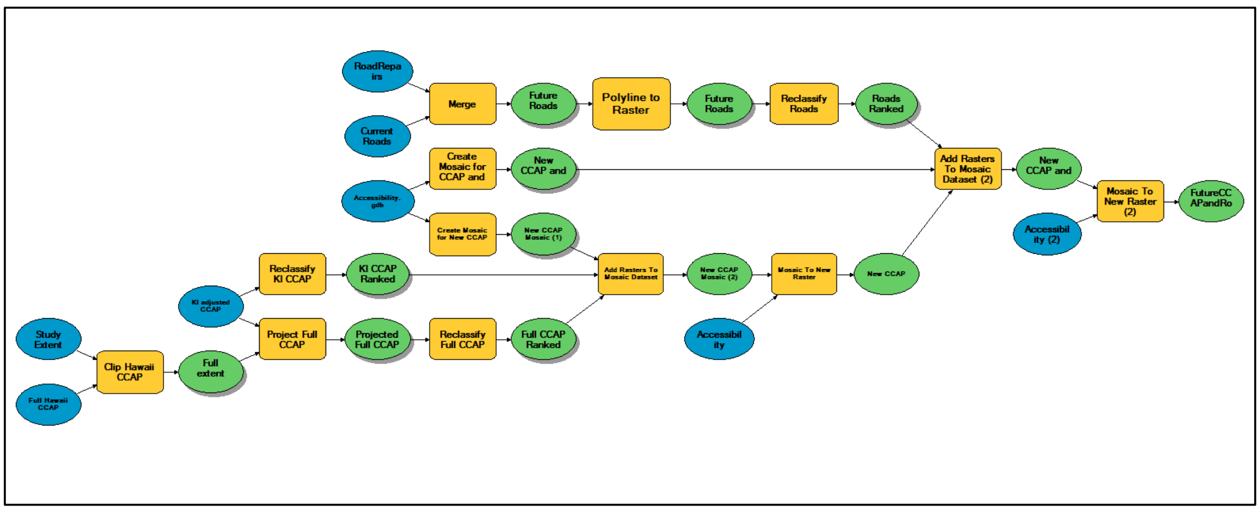

Figure A2.2.2. ArcGIS Model for obtaining a land cover raster with potential future CCAP and road conditions, to be combined with slope to create a cost surface raster.

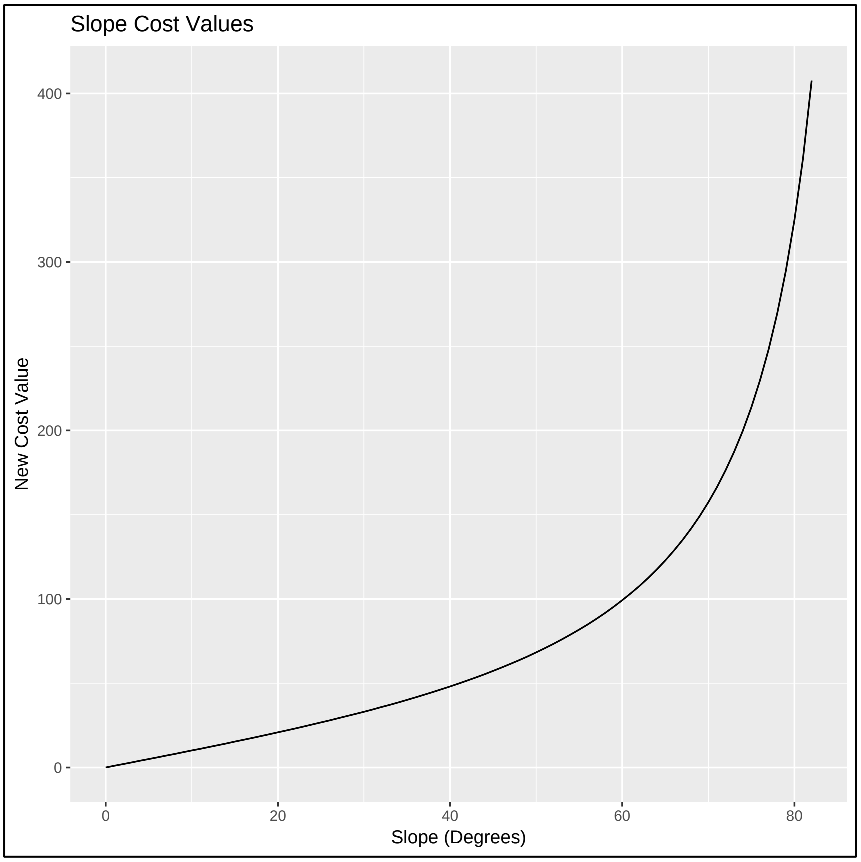

Figure A2.2.3. Relative costs of traveling over slopes. The difficulty of travel, or relative travel cost, does not increase with a linear fashion when traveling up or down slopes. Difficulty increases exponentially as slopes increase.

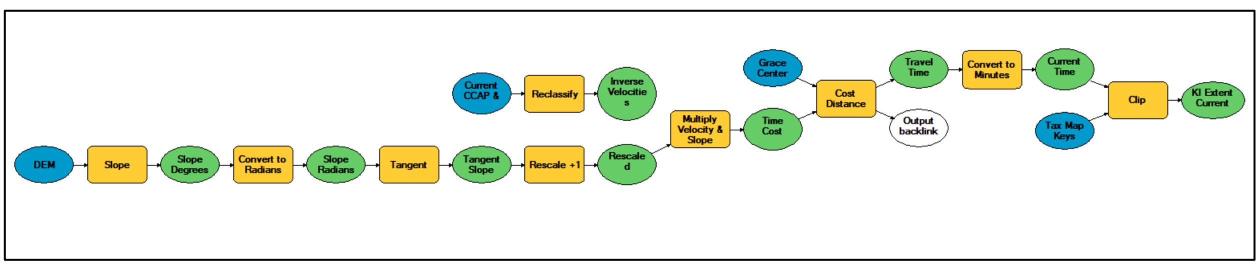

Figure A2.2.4. ArcGIS Model for obtaining the travel cost raster with KI's existing road network.

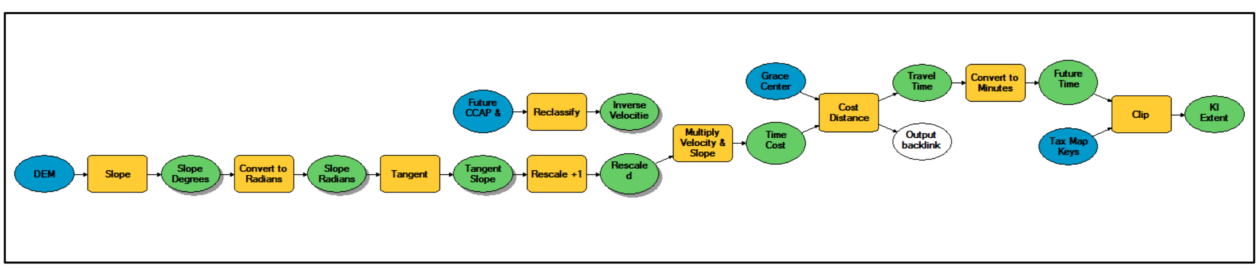

Figure A2.2.5. ArcGIS Model for obtaining the travel time cost raster with potential future roads.

Appendix 2.3: Water Quality Analysis

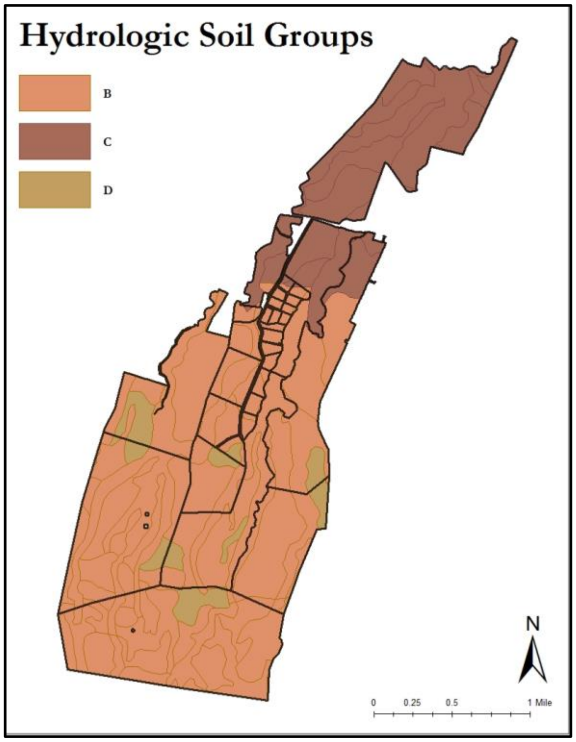

Figure A2.3.1. Hydrologic soil groups on Kohala Institute's (KI) property. Sources: Hawaii Statewide GIS Program, Kohala Institute, and Esri SSURGO 2014.

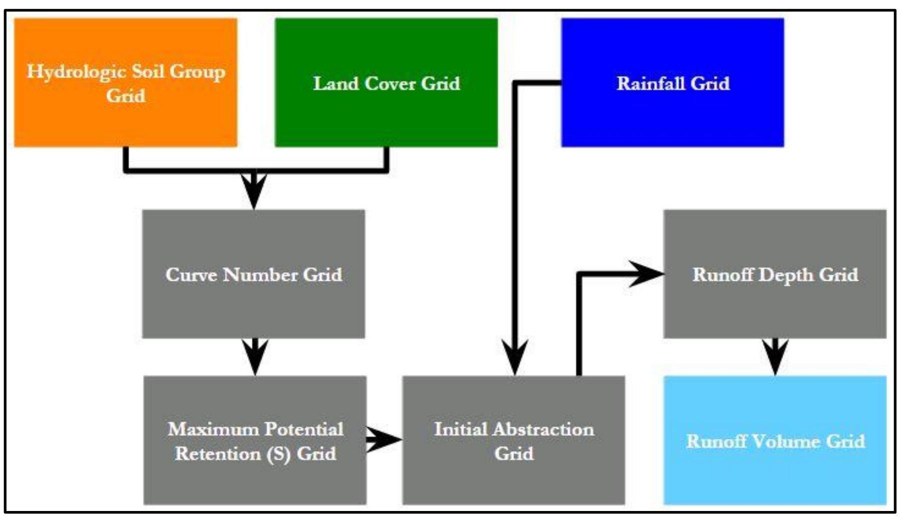

Figure A2.3.2. OpenNSPECT total runoff calculation workflow.

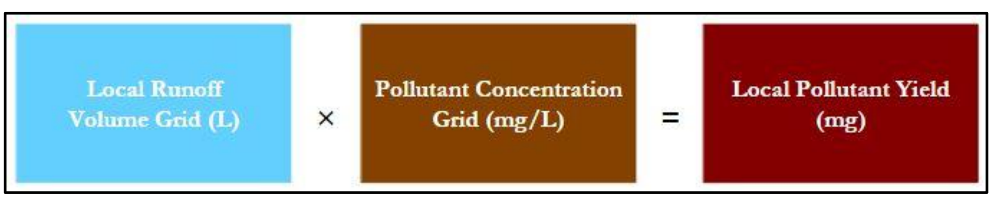

Figure A.2.3.3. OpenNSPECT pollutant loading calculation workflow.

Table A2.3.1. Revised universal soil loss equation (RUSLE) c-factors. Source: NOAA

C-CAP Value	C-CAP Class	C Factor
2	High-Intensity Developed	0.000
3	Medium-Intensity Developed	0.010
4	Low-Intensity Developed	0.030
5	Developed, Open Space	0.005
6	Cultivated Land	0.240
7	Pasture/Hay	0.005
8	Grassland	0.120
9	Deciduous Forest	0.009
10	Evergreen Forest	0.004
11	Mixed Forest	0.007
12	Scrub/Shrub	0.014
13	Palustrine Forested Wetland	0.003
14	Palustrine Scrub/Shrub Wetland	0.000
15	Palustrine Emergent Wetland	0.000
16	Estuarine Forested Wetland	0.003
17	Estuarine Scrub/Shrub Wetland	0.003
18	Estuarine Emergent Wetland	0.003
19	Unconsolidated Shore	0.500
20	Bare Land	0.700
21	Water	0.000
22	Palustrine Aquatic Bed	0.000
23	Estuarine Aquatic Bed	0.000

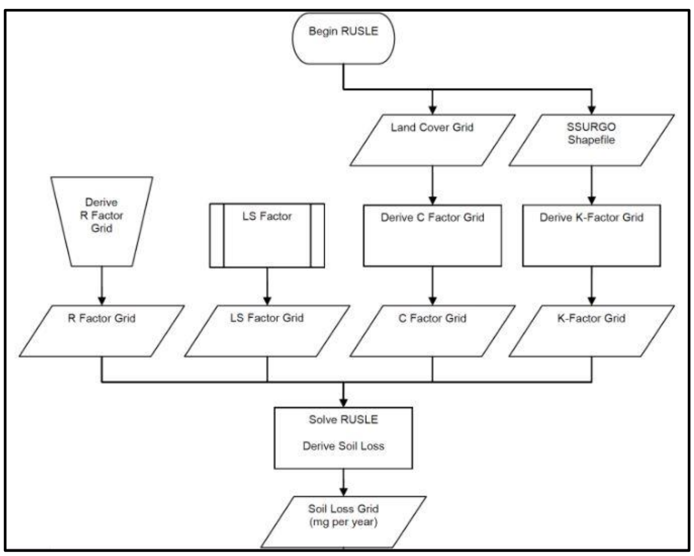

Figure A.2.4.4. OpenNSPECT sediment yield calculation workflow.

Table A2.3.2. C-CAP Land Cover Classes and their pollutant coefficients. *Source: Technical Guide for OpenNSPECT, Version 1.2., 2014.*

C-CAP Value	C-CAP Land Cover Class	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Total Zinc (mg/L)	Total Lead (mg/L)
2	High-Intensity Developed	0.47	2.22	71.00	0.06	0.09
3	Medium-Intensity Developed	0.30	2.29	27.00	0.06	0.06
4	Low-Intensity Developed	0.18	1.77	19.10	0.03	0.04
5	Developed Open Space	0.05	1.25	11.10	0.03	0.03
6	Cultivated Land	0.42	2.68	107.00	0.03	0.03
7	Pasture/Hay	0.48	2.48	55.30	0.03	0.02
8	Grassland	0.05	1.25	55.30	0.03	0.03
9	Deciduous Forest	0.05	1.25	11.10	0.01	0.00
10	Evergreen Forest	0.05	1.25	11.10	0.01	0.00
11	Mixed Forest	0.05	1.25	11.10	0.01	0.00
12	Scrub/Shrub	0.05	1.25	11.10	0.01	0.00
13	Palustrine Forested Wetland	0.20	1.10	19.00	0.02	0.00
14	Palustrine Scrub/Shrub Wetland	0.20	1.10	19.00	0.02	0.00
15	Palustrine Emergent Wetland	0.20	1.10	19.00	0.02	0.00
16	Estuarine Forested Wetland	0.20	1.10	19.00	0.02	0.00
17	Estuarine Scrub/Shrub Wetland	0.20	1.10	19.00	0.02	0.00

Running OpenNSPECT

The first step in running OpenNSPECT is calculating runoff (i.e., water that runs off the surface of the land during a rain event). OpenNSPECT uses the Natural Resources Conservation Service (NRCS) Curve-Number Method from the NRCS *Urban Hydrology for Small Watersheds: Technical Release 55* (TR-55) to calculate runoff estimations. The equations that are used to calculate retention (S), initial abstraction (I_a), and runoff depth (Q) are:

1. $Q = (P-I_a)^2 / [(P-I_a)+S]$
2. $I_a = 0.2*S$
3. $S = (1000/CN) - 10$

Where Q = runoff (in), P = rainfall (in), S = potential maximum retention after runoff commences (in), I_a = initial abstraction (in), and CN = runoff curve number; Note: if $(P-I_a) \leq 0$, then Q = 0, which prevents artificial sinks from being reintroduced into the runoff analysis (*Technical Guide for OpenNSPECT, Version 1.2*, 2014).

Curve-Number Grid

The curve-number grid illustrates the general permeability of an area based on its land cover types and soil characteristics (i.e., hydrologic soil group; a method to categorize soils with similar characteristics). Curve numbers range from zero (i.e., 100% precipitation infiltration into the soil) to 100 (i.e., 0% precipitation infiltration into the soil), which are used to approximate the depth of runoff (Q) (Table 2.3.3) (*Technical Guide for OpenNSPECT, Version 1.2*, 2014).

Table 2.3.3. C-CAP Land Cover Classes and their Curve Numbers. *Source: Technical Guide for OpenNSPECT, Version 1.2., 2014.*

C-CAP Value	C-CAP Class	TR-55 Cover Type	TR-55 Treatment	TR-55 Condition	Group A	Group B	Group C	Group D
2	High-Intensity Developed	Commercial and Business			89	92	94	95
3	Medium-Intensity Developed				77	85	90	92
4	Low-Intensity Developed	1/4 Acre Residential			61	75	83	87
5	Developed Open Space				49	69	79	84
6	Cultivated Land	Row Crops	Straight Row	Good	67	78	85	89
7	Pasture/Hay				39	61	74	80
8	Grassland	Pasture, Grassland, or Range		Good	30	58	71	78
9	Deciduous Forest	Woods		Good	30	55	70	77
10	Evergreen Forest	Woods		Good	30	55	70	77
11	Mixed Forest	Woods		Good	30	55	70	77
12	Scrub/Shrub	Brush		Good	30	48	65	73
13	Palustrine Forested Wetland				0	0	0	0
14	Palustrine Scrub/Shrub Wetland				0	0	0	0
15	Palustrine Emergent Wetland				0	0	0	0
16	Estuarine Forested Wetland				0	0	0	0
17	Estuarine Scrub/Shrub Wetland				0	0	0	0
18	Estuarine Emergent Wetland				0	0	0	0
19	Unconsolidated Shore				0	0	0	0
20	Bare Land	Fallow	Bare soil		77	86	91	94
21	Water				0	0	0	0
22	Palustrine Aquatic Bed				0	0	0	0
23	Estuarine Aquatic Bed				0	0	0	0

Maximum Potential Retention

Next, the maximum potential retention (S) is calculated, which represents the ability of soils to retain or absorb liquids. OpenNSPECT calculates retention for each grid cell in an area of interest with the following equation:

$$Retention\ (S) = (1000/Curve\ Number) - 10$$

This calculation is important because any precipitation that is retained or absorbed by soils will not be included in the runoff depth (Q) (*Technical Guide for OpenNSPECT, Version 1.2*, 2014).

Initial Abstraction

After calculating the maximum potential retention (S), the initial abstraction (I_a) is calculated, which determines water losses (e.g., water intercepted by surface depressions, vegetation, evaporation, infiltration) before runoff develops. OpenNSPECT calculates the initial abstraction for each grid cell in an area of interest using the following equation (*Technical Guide for OpenNSPECT, Version 1.2*, 2014):

$$Abstraction\ (Ia) = 0.2\ x\ Retention = 0.2\ x\ S$$

Calculating Annual Runoff

Once the curve-number (CN), maximum potential retention (S), and the initial abstraction (I_a) grids have been created, these grids and the input average annual rainfall grid can be used to calculate an event-based runoff scenario with the following equation from the NRCS TR-55 (*Technical Guide for OpenNSPECT, Version 1.2*, 2014):

$$Runoff\ Depth = (Rainfall - Abstraction)2 \,/\, (Rainfall - Abstraction) + Retention$$

OpenNSPECT can also calculate annual-based runoff scenarios, which were used in this water quality assessment, based on the event-based runoff equation. However, the annual runoff equation takes into account the average number of rain days seen in a given year for the area of interest (*Technical Guide for OpenNSPECT, Version 1.2*, 2014):

$$Runoff\ Depth\ (Q) = \frac{[Rainfall\ x\ (Abstraction\ x\ Rain\ Days)]^2}{[(Rainfall\ x\ (Abstraction\ x\ Rain\ Days)) + (Retention\ x\ Rain\ Days)]}$$

Once the annual runoff depth grid has been calculated, OpenNSPECT will create a "true" annual runoff volume grid by taking the annual runoff depth grid and multiplying it by the cell area (e.g., 30m x 30m cell = 900 m^2) (*Technical Guide for OpenNSPECT, Version 1.2*, 2014).

As stated above, the annual precipitation scenario in OpenNSPECT calculates annual pollutant loadings of total runoff, phosphorus (TP) and nitrogen (TN) based on the number of "rain days" in a given year (i.e., the number of rain days that experienced enough rainfall to produce surface runoff in a given year), which must be estimated and inputted into the model (Eslinger, 2014; Michaud & Stewart, 2012). This value is important because it can create notable changes to total runoff and pollutant loading estimations as it determines how total annual precipitation is delivered to an area of interest over the course of a year (Michaud & Stewart, 2012). Land cover type data, specifically their respective areas and curve numbers, were used to determine the minimum amount of rainfall needed to produce surface runoff, I_a, at KI; the initial abstraction turned out to be a threshold of greater than 1.03 inches of rain, meaning that more than 1.03 inches of rain would be needed to produce surface runoff at KI (Eslinger, 2014).

Using this minimum rainfall threshold and normally-distributed daily precipitation data – taken from the Kohala Mission rain gauge station, which was acquired from the NOAA Regional Climate Centers: ACIS Drought Portal from 1986 to 2015 – it was determined that the average number of rain days at KI is 15 rain days per year with a standard deviation of $\pm$ 6 rain days (Eggleston, 2017). These daily precipitation data, recorded at the Kohala Mission rain gauge station from 1986 to 2015, are 76% complete; therefore, a conservative estimate of the average number of rain days per year at KI has been used for this water quality assessment.

With this average and standard deviation (i.e., 15 ± 6 rain days per year), 100 samples of 20-year time periods (i.e., planning horizons) were generated using a random number generator in RStudio. Of these 100 samples, three 20-year time periods were selected – which contained the minimum (i.e., 227 total rain days), median (i.e., 301 total rain days), and maximum number (i.e., 363 total rain days) of rain days – to see how total runoff, TP, and TN loadings would vary not only by land use scenario, but also by precipitation scenario; annual sediment loadings were calculated using a different, more credible method in OpenNPSECT (see the "Calculating Annual Erosion with the Revised Universal Soil Loss Equation (RUSLE)" section below). It is important to note that the average annual rainfall is constant in these water quality analyses; therefore, as the total number of rain days increases, total runoff and pollutant loadings decrease because more runoff is being lost to processes such as evapotranspiration and soil absorption with each additional, discrete rain day (Eslinger, 2017).

Calculating Annual Sediment Loadings with RUSLE

To calculate annual sediment loadings, OpenNPSECT uses the revised universal soil loss equation (RUSLE), which is as follows:

$$A = R * K * L * S * C * P$$

Where A = average annual soil loss (mg), R = rainfall/runoff erosivity factor (feet * tonfeet * inch / acre * hour * year), K = soil erodibility factor (ton * acre * hour / acres * tonfeet * feet * inch), L = length-slope factor (feet), S = slope steepness factor (%), C = cover management factor (unitless), and P = supporting practices factor (not included in this version of OpenNSPECT) (Michaud & Stewart, 2012; *Technical Guide for OpenNSPECT, Version 1.2*, 2014).

These sediment delivery results were used instead of those calculated using total suspended solids (TSS), because a previous 2012 study found that sediment loadings calculated by the RUSLE equation were more credible (Michaud & Stewart, 2012). This is because the RUSLE equation assumes that erosion is not related to the average annual rainfall, but rather to soil erodibility, land cover type and management, kinetic energy of raindrops, and topography, as opposed to treating erosion as a nutrient (i.e., multiplying the pollutant concentration (mg/L) by the total runoff (L)) where sediment loadings are virtually proportional to runoff (Michaud & Stewart, 2012). Consequently, the RUSLE equation only allowed sediment loading comparisons between the five land use scenarios and not across the three precipitation scenarios (Eslinger, 2017).

Differences in Total Runoff and Pollutant Loadings by Land Cover Type

While NOAA does not recommend comparing the specific runoff and pollutant loading estimates generated by OpenNSPECT, it is still valid to compare the relative differences between estimates when evaluating water quality impacts (Eslinger, 2017; Mausio, 2017). From this water quality assessment, it was found that anthropogenic land cover types (i.e., agriculture, pasture, and development) contributed the most to total runoff and pollutant loadings per acre across all five land use scenarios (Fig. 2.3.1-2.3.4). The agriculture land cover type contributed the most to total runoff and pollutant loadings per acre because it represents row crops, which are highly susceptible to water, nutrient, and sediment loss due to lack of ground cover (i.e., vegetation that reduces water, nutrient, and sediment loss) (Blanco-Canqui & Rattan, 2008; Esgate et al., 2015; Estler, 1991).

After agriculture, developed and pasture areas contributed the second- and third-most to total runoff and pollutant loadings per acre, respectively. While pasture land comprised a larger portion of the total area than developed land in each land use scenario, developed land contributed more to total runoff and pollutant loadings per acre than pasture land because its imperviousness (i.e., ability to generate surface runoff; curve number (CN)) was as much as 23% greater than the imperviousness of pasture land (Table 2.3.3). Moreover, while forest and shrub lands comprised the majority of the area in the Baseline Scenario, they are land cover types with the lowest pollutant coefficients and curve numbers (CN), making them the least-contributing land cover types to total runoff and pollutant loadings per acre (Table 2.3.2-2.3.3; Fig. 2.3.1-2.3.4).

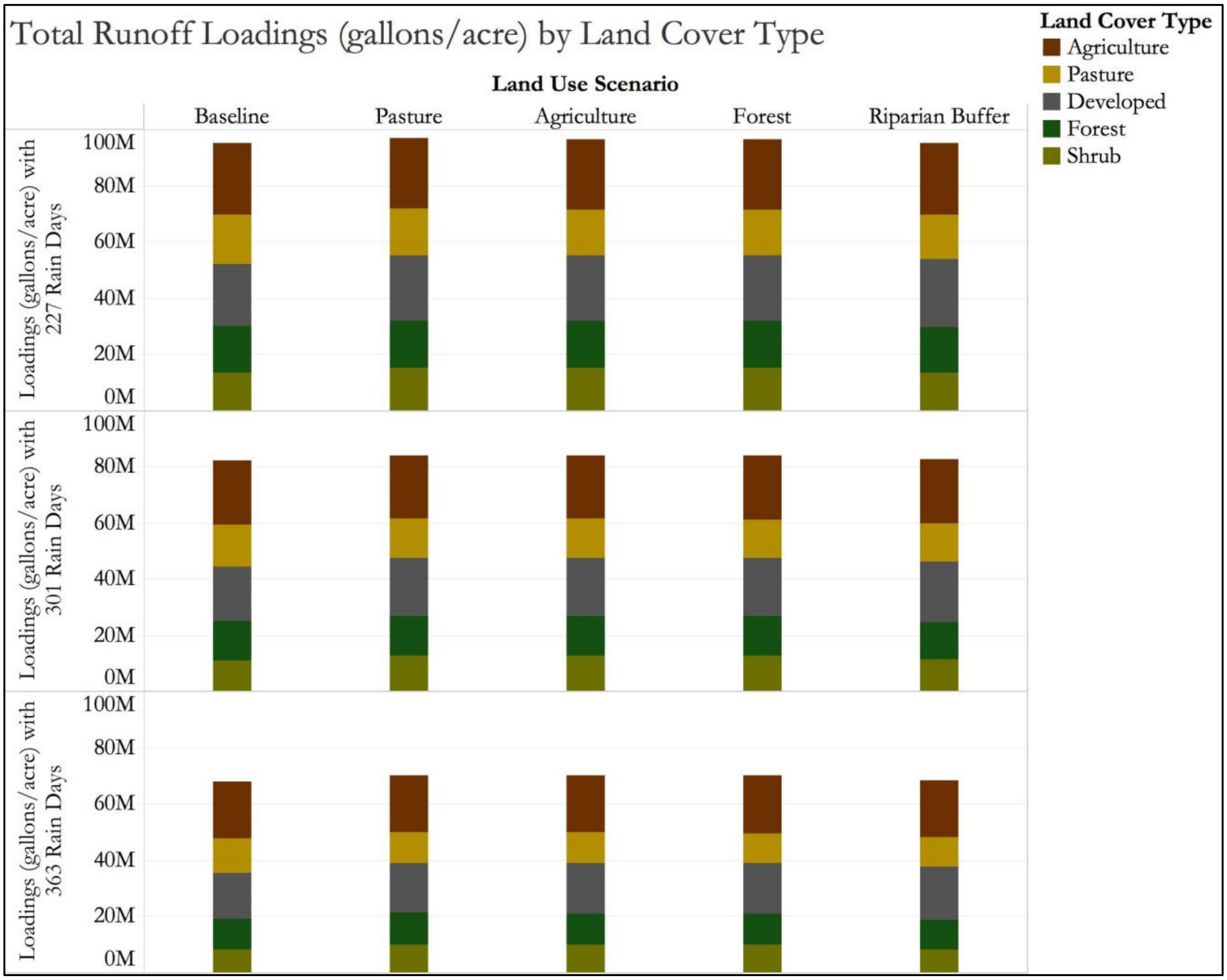

Figure A.2.4.5. Total runoff loadings (gallons/acre) by land cover type under each land use scenario and precipitation scenario. The first precipitation scenario (i.e., row) has the minimum number of rain days (i.e., 227 rain days) over the 20-year planning horizon. The second precipitation scenario (i.e., row) has the median number of rain days (i.e., 301 rain days) over the 20-year planning horizon. The third precipitation scenario (i.e., row) has the maximum number of rain days (i.e., 363 rain days) over the 20-year planning horizon.

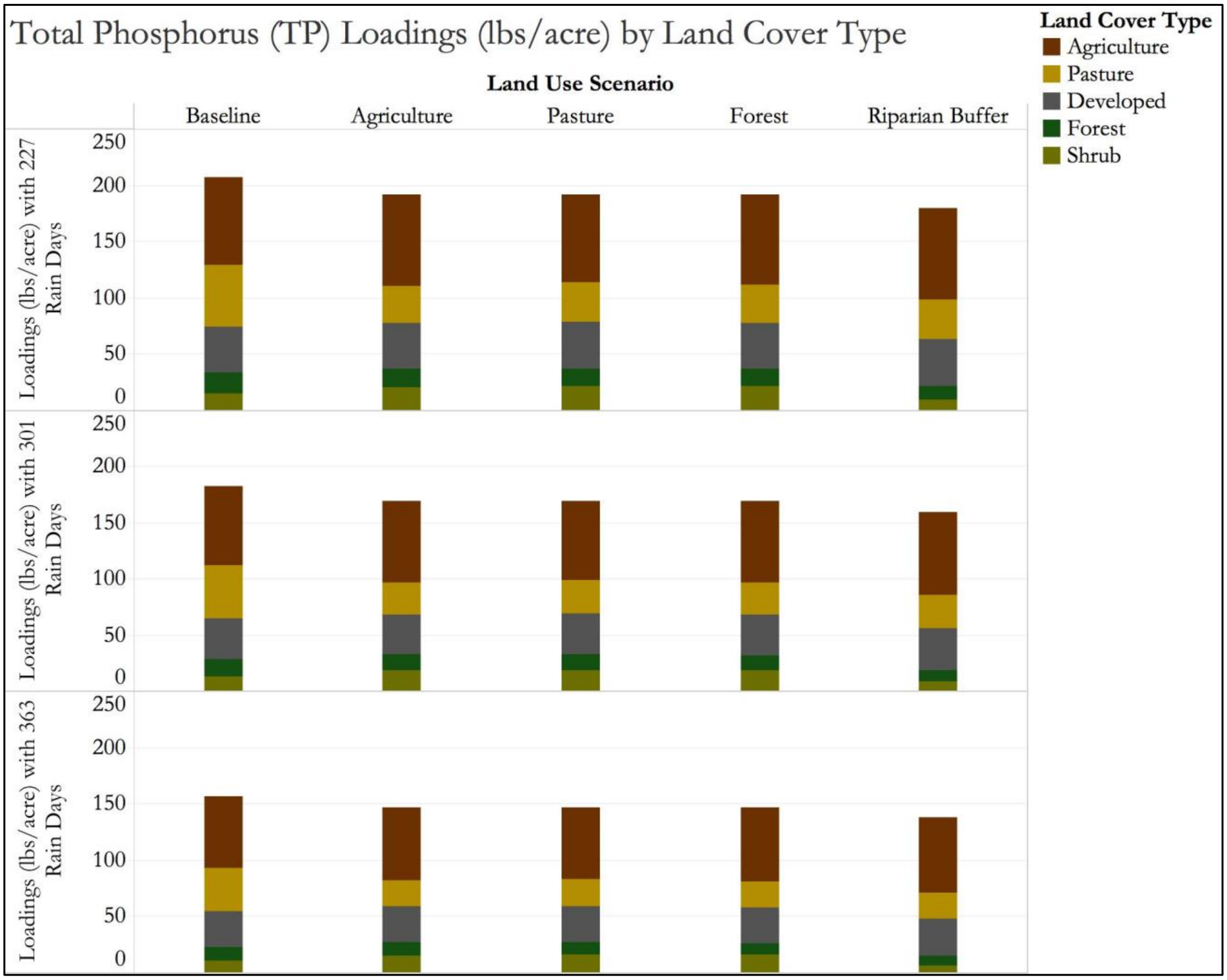

Figure A.2.4.6. Total phosphorus (TP) loadings (lbs/acre) by land use type under each land use scenario and precipitation scenario. The first precipitation scenario (i.e., row) has the minimum number of rain days (i.e., 227 rain days) over the 20-year planning horizon. The second precipitation scenario (i.e., row) has the median number of rain days (i.e., 301 rain days) over the 20-year planning horizon. The third precipitation scenario (i.e., row) has the maximum number of rain days (i.e., 363 rain days) over the 20-year planning horizon.

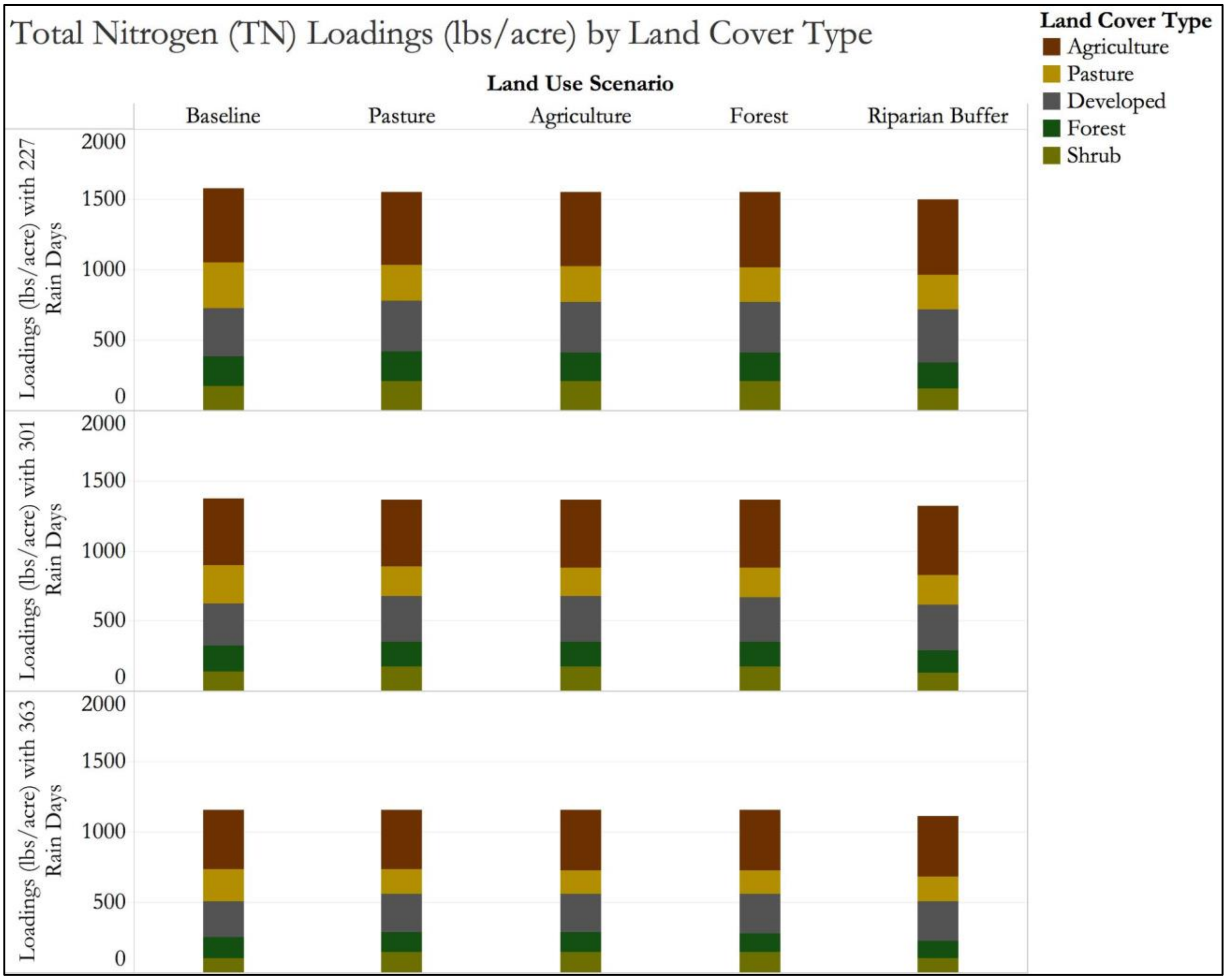

Figure A.2.4.7. Total nitrogen (TN) loadings (lbs/acre) by land cover type under each land use scenario and precipitation scenario. The first precipitation scenario (i.e., row) has the minimum number of rain days (i.e., 227 rain days) over the 20-year planning horizon. The second precipitation scenario (i.e., row) has the median number of rain days (i.e., 301 rain days) over the 20-year planning horizon. The third precipitation scenario (i.e., row) has the maximum number of rain days (i.e., 363 rain days) over the 20-year planning horizon.

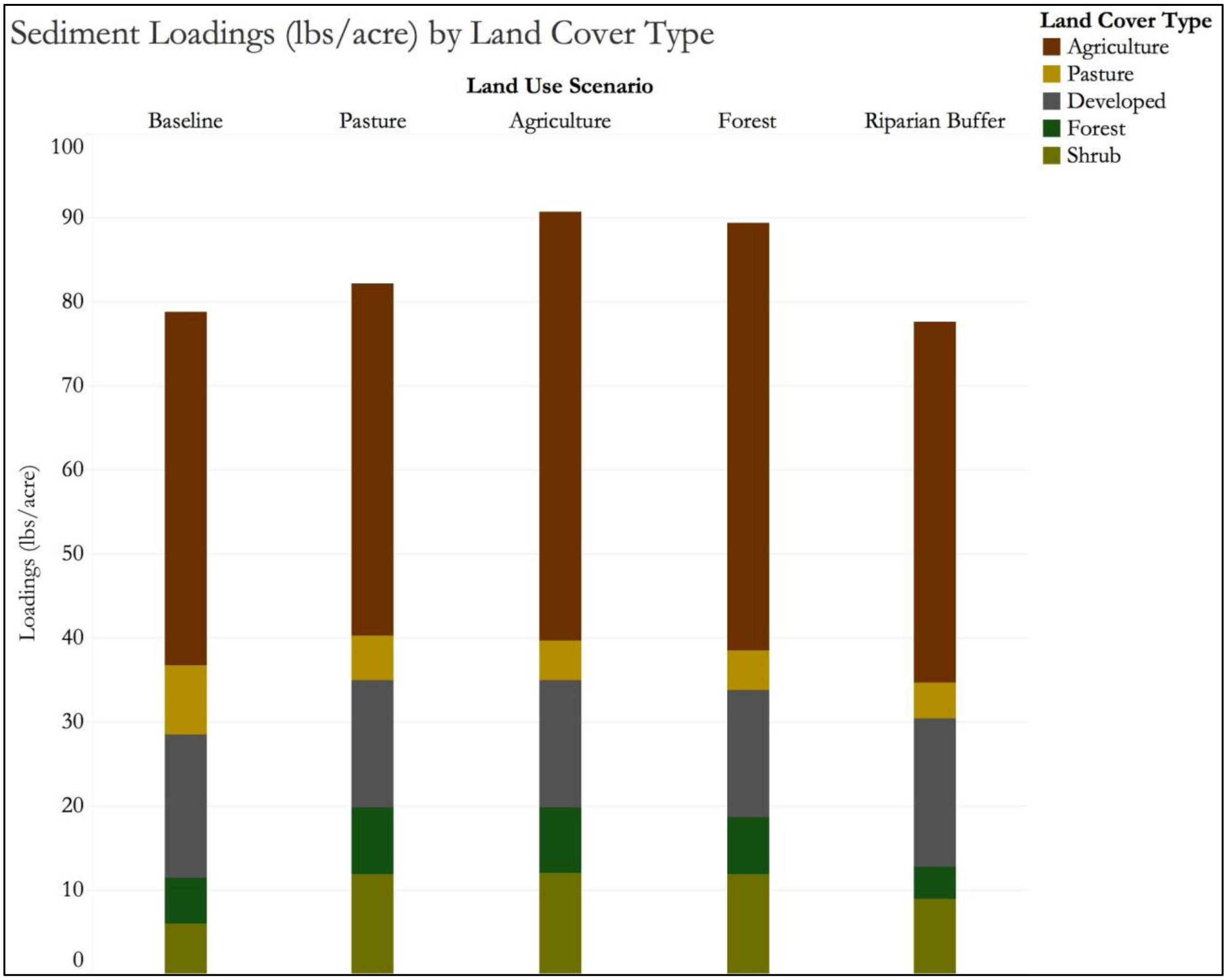

Figure A.2.4.8. Total sediment loadings (lbs/acre) by land cover type under each land use scenario. Since RUSLE uses the R-factor (i.e., a coefficient for rainfall erosivity) instead of the number of rain days to calculate sediment loadings, sediment loadings did not change between the three precipitation scenarios (i.e., all percent differences will be 0%).

Appendix 2.4: Carbon Emissions Analysis

Table A2.4.1. Soil Carbon Stock Equations. A summary of the values and equations used to convert from the carbon content of 100 cm^3 of soil, 0.18g C/100cm^3, to the amount of carbon within the top meter of soil throughout KI's property.

Carbon content of one cm^3 to a depth of 100cm	0.18g
Convert from cm^3 to m^3	(100 x 100 x 100) x 0.18g
Convert from g to kg	180,000 g/m^3 ÷ 1,000
Convert from m^3 to ac/meter depth	4,047 x 180 kg/m^3
Convert from kg to metric tons	1,768,639,694 kg/ac/meter depth ÷ 1,000
Find carbon stock of entire property	2,428 x 1,800 t/ac/meter depth
Remove developed land area	1,768,640t C/meter depth of KI – 140,588t C/meter depth of developed area
Convert from sequestered carbon to sequestered CO_2	3.67 x 1,628,052t C/meter depth of KI's property

Table A2.4.2. Forest Carbon Stock Equations. A summary of values and conversion factors used to convert the proxy value to metric tons of carbon dioxide per forested area of KI's property.

Average ACD proxy value for lowland wet forests near Hilo	128 $\pm$59t C/ha
Conversion from carbon to CO_2	128 x 3.67
Conversion from hectares to acres	470t CO_2/ha ÷ 2.47
Conversion from acres to entire forested area	190t CO_2/ac x 1,123ac
Including carbon with BGB	213,488t CO_2/ac x 1.25

Table A2.4.3. Forest Sequestration Equations. A table summarizing the equations and values used to convert from a biomass growth rate ($g/m^2/yr$) to a sequestration rate of carbon dioxide (t/ac/yr) for KI's existing forest.

Biomass growth rate	59 $g/m^2/yr$
Conversion to from meters to acres	59 $g/m^2/yr$ x 4,047
Conversion from grams to metric tons	238,765 g/ac/yr ÷ (1 x 10^6)
Conversion from biomass to carbon	0.24 t/ac/yr ÷2
Conversion from carbon to CO_2	0.12 t C/ac/yr x 3.67

$$Stem\ volume(m^3) = \frac{\pi \times \left(\frac{\text{Diameter}(\text{cm}(\text{underbark}))}{200}\right) 2 \times \text{Height(m)}}{3}$$

Figure A2.4.1. Stem Volume Equation. The equation used to calculate the stem volume, m^3, of macadamia trees.

Table A2.4.4. Macadamia Carbon Stock Equations. A summary of values and equations used to convert the proxy value of sequestered CO_2 per tree to the total sequestered CO_2 within the macadamia orchards on KI's property.

Sequestered metric tons CO_2 per tree	0.34t CO_2
Convert from metric tons CO_2 sequestered per tree to CO_2 sequestered per acre	0.34t CO_2 x 60
Convert from metric tons CO_2 sequestered per acre to metric tons CO_2 for the entire macadamia orchard	21t CO_2/ac x 400

Table A2.4.5. Coconut Sequestration Equations. A summary of values and equations used to calculate the amount of carbon sequestered by KI's proposed coconut orchard after 20 years.

Carbon stock of coconut trees after 25 years	15 t C/ha
Convert from ha to acres	15 t C/ha ÷ 2.47
Carbon per acre to carbon per total area	6 t C/ac x 10
Convert from carbon to CO_2	60.7 t C x 3.67
Total sequestered CO_2 after 20yrs	222.8t CO_2

Table A2.4.6. Moringa Sequestration Equations. A summary of values and equations used to calculate the amount of carbon sequestered by KI's proposed moringa orchard after 20 years.

Average carbon stock of moringa trees per hectare	51.8t C/ha
Convert from ha to acres	51.8t C/ha ÷ 2.47
Carbon per acre to carbon per total area	51.8t C/ac x 10
Convert from carbon to CO_2	518t C x 3.67
Total sequestered CO_2 after 20yrs	769t CO_2

Table A2.4.7. Electricity Emissions Equations. A summary of values and equations used to calculate the current and future scope 2 emissions of KI.

Emissions from 1 TWh of electricity produced with oil	918,970 t CO_2
Current KI emissions conversion value	15,183 kWh ÷ 1,000,000,000 kWh = 1.52×10^{-5}
Current KI scope 2 emissions	(1.52×10^{-5}) x 918,970 t CO_2
Future KI emission conversion value	605,000 kWh ÷ 1,000,000,000 kWh = 6.05×10^{-4}
Future KI scope 2 emissions	(6.05×10^{-4}) x 918,970 t CO_2

Bulk Density & Moisture				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
				(Bulk Density) 33 kPa	Oven Dry	Cole Whole Soil	(- - - Water Content - - -) 6 kPa	10 kPa	33 kPa	1500 kPa	1500 kPa Moist	Ratio AD/OD	WRD Whole Soil	Aggst Stabl 2-0.5mm	(- - Ratio/Clay - -) CEC7	1500 kPa
Layer	Depth (cm)	Horz	Prep	(- - - g cm^{-3} - - -)			(- - - % of < 2mm - - -)						cm^3 cm^{-3}	%		
				4A1d	4A1h				4B1c	3C2a1a	4B2b	3D1	4C1b		8D1b	8D1b
98P01535	0-10	A	S	0.78	1.24	0.166			79.1	31.0		1.070				
98P01535	0-10	A	M								43.7	1.746	0.27		1.65	0.77
98P01536	10-27	Bw1	S	1.12	1.26	0.040			36.4	26.2		1.058				
98P01536	10-27	Bw1	M								27.1	1.290	0.10		0.46	0.52
98P01537	27-40	Bw2	S	1.13	1.32	0.053			39.9	25.8		1.063				
98P01537	27-40	Bw2	M								32.6	1.335	0.08		0.47	0.69
98P01538	40-52	2A	S	1.03	1.17	0.043			38.0	24.9		1.062				
98P01538	40-52	2A	M								31.8	1.334	0.06		0.51	0.73
98P01539	52-72	2Bw	S	1.09	1.28	0.055			41.6	24.6		1.047				
98P01539	52-72	2Bw	M								34.0	1.381	0.08		0.27	0.73
98P01540	72-84	3A	S	1.48	1.62	0.031			28.8	20.5		1.027				
98P01540	72-84	3A	M								24.5	1.281	0.06		0.17	0.48
98P01541	84-109	4Bw1	S	1.20	1.36	0.043			39.1	25.8		1.048				
98P01541	84-109	4Bw1	M								35.7	1.391	0.04		0.22	0.64
98P01542	109-145	4Bw2	S	1.14	1.32	0.050			43.9	28.4		1.050				
98P01542	109-145	4Bw2	M								37.9	1.418	0.07		0.24	0.66
98P01543	145-172	4Bw3	S	1.01	1.19	0.056			49.1	29.3		1.054				
98P01543	145-172	4Bw3	M								37.5	1.428	0.12		0.29	0.71
98P01544	172-212	4C	S	0.95	1.10	0.049			60.5	32.6		1.046				
98P01544	172-212	4C	M								43.3	1.507	0.16		0.29	0.89
98P01545	212-248	4Cr1	S							34.4		1.041				
98P01545	212-248	4Cr1	M								44.1	1.535			0.28	0.94
98P01546	248-270	4Cr2	S							25.8		1.038				
98P01546	248-270	4Cr2	M								32.9	1.485			0.41	1.08
98P01547	270-325	4Cr3	S							20.1		1.037				
98P01547	270-325	4Cr3	M								25.5	1.444			0.45	1.26
98P01548	325-350	4Cr4	S	1.16	1.22	0.016			42.8	15.0		1.049				
98P01548	325-350	4Cr4	M								19.9	1.395	0.25		1.47	1.78

*** Primary Characterization Data ***

Pedon ID: 98HI001001 (Hawaii, Hawaii) Print Date: Jan 16 2017 3:19PM

Sampled As : KOHALA Very-fine, mixed Ustic Humitropepts

USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 98P0265

Carbon & Extractions				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-
				(- - - - - Total - - - - -) C	N	S	Est OC	OC (WB)	C/N Ratio	(- - - Dith-Cit Ext - - -) Fe	Al	Mn	(- - - - - - Ammonium Oxalate Extraction - - - - - -) Al+½Fe	ODOE	Fe	Al	Si	Mn	(- - - Na Pyro-Phosphate - - -) C	Fe	Al	Mn
Layer	Depth (cm)	Horz	Prep	(- - - - - - - - - - % of <2 mm - - - - - - - - - -)						(- - - - - - - - - - - - % of < 2mm - - - - - - - - - - - -)								mg kg^{-1}	(- - - - - - % of < 2mm - - - - - -)			
				6A2e	6B4a					6C2g	6G7f	6D2f		4G2	6C9c	6G12b	6V2c	6D5b				
98P01535	0-10	A	S	10.18	0.617		10.2		16													
98P01535	0-10	A	M							11.7	--	--	2.13	0.35	2.48	0.89	0.12	3774.0				
98P01536	10-27	Bw1	S	2.77	0.310		2.8		9													
98P01536	10-27	Bw1	M							11.9	--	--	2.06	0.36	2.25	0.94	0.17	3646.0				
98P01537	27-40	Bw2	S	2.22	0.299		2.2		7													
98P01537	27-40	Bw2	M							12.2	--	--	2.25	0.36	2.54	0.98	0.19	4490.0				
98P01538	40-52	2A	S	2.07	0.293		2.1		7													
98P01538	40-52	2A	M							12.6	--	--	2.61	0.36	2.95	1.14	0.23	4577.0				
98P01539	52-72	2Bw	S	1.06	0.179		1.1		6													
98P01539	52-72	2Bw	M							14.1	--	--	2.03	0.37	2.06	1.00	0.19	2013.0				
98P01540	72-84	3A	S	0.79			0.8															
98P01540	72-84	3A	M							15.1	--	--	0.67	0.12	0.61	0.36	0.10	621.0				
98P01541	84-109	4Bw1	S	1.06			1.1															
98P01541	84-109	4Bw1	M							20.7	--	--	0.89	0.18	0.85	0.47	0.13	43.0				
98P01542	109-145	4Bw2	S	0.99			1.0															
98P01542	109-145	4Bw2	M							20.1	--	--	1.03	0.23	0.98	0.54	0.14	--				
98P01543	145-172	4Bw3	S	1.03			1.0															
98P01543	145-172	4Bw3	M							17.5	--	--	1.19	0.27	1.02	0.68	0.13	--				
98P01544	172-212	4C	S	0.73			0.7															
98P01544	172-212	4C	M							15.8	--	--	1.10	0.17	0.93	0.63	0.12	137.0				
98P01545	212-248	4Cr1	S	0.60			0.6															
98P01545	212-248	4Cr1	M							15.1	--	--	1.07	0.16	0.89	0.63	0.12	94.0				
98P01546	248-270	4Cr2	S	0.38			0.4															
98P01546	248-270	4Cr2	M							14.2	2.0	0.2	0.91	0.13	0.79	0.51	0.10	214.0				
98P01547	270-325	4Cr3	S	0.28			0.3															
98P01547	270-325	4Cr3	M							14.2	2.1	0.3	0.87	0.12	0.85	0.45	0.10	295.0				
98P01548	325-350	4Cr4	S	0.06			0.1															
98P01548	325-350	4Cr4	M							12.0	1.9	0.3	1.56	0.25	1.12	1.00	0.35	878.0				

[1,1,2,3,4,5,6,7,8,9,10,11,12,13] Analyzed size fraction = <2 mm

Figure A2.4.2. O. Chadwick's Soil Sample Data.

Appendix 2.5: Wildlife Habitat Analysis

Species Accounts

Hawaiian hawk (‘Io)
Buteo solitarius

The Hawaiian hawk or ‘io, *Buteo solitaries*, is the only native species that was confirmed as present on KI’s property during the 1999 biological survey (Cowie et al., 1999). This bird of prey is of particular importance in Hawaiian culture as it is said to be an “‘aumakua” or god in the form of an animal (“Recovery of the Hawaiian hawk or ‘Io,” 2009). ‘Io have been protected under the ESA since 1967, though critical habitat has not been designated, and were recently proposed for delisting in both 2009 and 2014, though they have not been formally delisted yet.

Historically, the ‘io has been observed in all districts of Hawaii Island ranging from sea level to high mountainous elevations (Griffin, 1984). They have been observed in rainforests, dry forests, and even lowland agricultural areas such as macadamia nut orchards. They are an opportunistic predator with a widely varied diet, including both native and nonnative rats, mice, birds, mongoose, and insects. Although they have been observed on several Hawaiian Islands, they only breed on the Island of Hawaii (“Recovery of the Hawaiian hawk or ‘Io,” 2009).

Compared with other forest raptors, ‘io have longer nestling, incubation, and post-fledgling dependency phases (Griffin, 1984). ‘Io nest from September through March, lay eggs in April or May, and hatch in June; human disturbances at any stage of this process can lead to serious problems for this species. ‘Io are unique in that a typical clutch consists of only one egg. In recent years, the greatest threat to this native Hawaiian bird was thought to be illegal hunting, shooting, or “harassment” of the birds, resulting in nest abandonment by parents prior to breeding, abandonment of young by parents, nest abandonment by young prior to fledging, or taking of young by predators (Griffin, 1984).

Another prevalent threat to the ‘io comes from habitat loss and degradation. ‘Io are non-migratory and will remain in one territory year-round in which they will hunt, nest, and attack intruders, making their habitat ranges especially important (Griffin, 1984). As forest birds, the ‘io relies on tree cover for nesting, but forests have been disappearing from Hawaii at an alarming rate. In fact, most lowland forests on Hawaii were modified by humans even before European contact (Kirch, 1982), and since then, they have continued to be cleared for timber harvesting, agriculture, or pasture land (Berger, 1981).

Figure 2.5.1. The Hawaiian Hawk. Image: OSSweb via Pinterest.

The persistent deforestation of native trees such as koa and ʻōhiʻa (and even the nonnative trees that replace them) has dramatically reduced the amount of habitat available to all species that rely on forest areas, including the ʻio. Much like the hoary bat, ʻio do not show a preference for native vs. nonnative tree cover, and studies have shown equal nesting success in forests dominated by ʻōhiʻa, koa, or exotic trees (Griffin, 1984). In fact, ʻio had equally successful nests in areas dominated by pasture or agriculture land as long as there were still trees present for nesting, which indicates the importance of preserving as much tree cover as possible throughout various types of land uses.

Additional threats to the ʻio include predation of eggs by nonnative cat and rat species, avian diseases such as pox and malaria, and poisoning by pesticides and rodenticides (Griffin, 1984); the latter of these threats is less relevant to KI since pesticides are not used on the property. The greatest actions KI can take to promote the ʻio would be to preserve its forest habitats and prevent hunters from illegally entering their land.

Hawaiian hoary bat (ʻōpeʻapeʻa)
Lasius cinereus semotus

The Hawaiian hoary bat, *Lasius cinereus semotus*, is a nocturnal, insect-feeding, solitary-roosting bat. It is one of three subspecies of North American hoary bats. The Hawaiian hoary bat has been protected by the Endangered Species Act since 1970, but critical habitat has not been designated (Worthington, 1998). In addition to being Hawaii's only bat, this subspecies is particularly special because it is the only known native terrestrial mammal still present on the Hawaiian Islands ("ʻŌpeʻapeʻa or Hawaiian Hoary Bat, Lasiurus cinereus semotus," 2005). Although it was not observed in the biological survey of the Bond Historic District on KI's property, local experts noted that it is "highly probable" to be found in the region (Cowie et al., 1999), and may not have been observed due to its nocturnal behavior.

The Hawaiian hoary bat has been observed on all of the major Hawaiian Islands and may migrate between them in its life, but the largest populations have been observed on Hawaii Island . It has been observed in a wide variety of habitats from 0-2,000 m, including coastal areas, wetlands and streams, rainforests, and dry forests, and it has highly variable home ranges that are thought to have resulted from the patchy and fragmented habitat available to them on the islands (D'Elia, 2011b). Its habitat requirements were not well understood at the time of its listing and are still undergoing research on Hawaii Island to obtain more accurate information (D'Elia, 2011b).

Figure 2.5.2. The Hawaiian hoary bat. Image: Go Green Travel Green via Pinterest.

However, some clear trends have emerged from the existing literature available regarding this bat: namely, it roosts in trees and does not show a preference for any particular species of tree (Worthington, 1998). The bat can roost in trees ranging from 3-29 feet in height, and also tends to prefer roosting at pasture-forest edge boundaries ("ʻŌpeʻapeʻa or Hawaiian Hoary Bat, Lasiurus cinereus semotus," 2005). While some studies have shown the bat to be strongly associated with native vegetation such as ʻōhiʻa trees (Jacobs, 1994), others have shown the bat to be more frequently observed in nonnative vegetation (Kepler & Scott, 1990); additional studies have confirmed that there is no significant difference in the amounts of bats observed in native, nonnative, or mixed forest types (Reynolds, Nielson, & Jacobi, 1998), and that the replacement of native trees with nonnative species should not negatively impact the bat (Tomich, 1986).

The Hawaiian hoary bat is thought to have declined due to the reduction in tree cover on the Hawaiian Islands since early historic times, and currently, the greatest threat to the bat is still habitat loss (D'Elia, 2011b). Therefore, management actions to help promote this bat should focus on ensuring that its critical roosting and foraging habitats are protected. For KI, this directly translates to promoting forested areas on the land whenever possible, which may be either native, nonnative, or mixed. Additional threats include pesticide use, barbed wire fences and wind farms; fortunately, KI does not use pesticides on its land, nor has barbed wire fences or windmills present on the property, so it is currently not contributing to the decline of the subspecies in those ways.

Hawaiian goose (Nēnē)
Branta sandvicensis

The Hawaiian goose or Nēnē, *Branta sandvicensis,* is an endemic water fowl, a relative of the Canadian goose, and Hawaii's only surviving native goose. The Nēnē was identified during the 1999 biological survey as an occasional visitor to KI's property (Cowie et al., 1999). Despite being Hawaii's official state bird, the Nēnē is endangered at both the state and federal level and is considered the 8th most endangered water fowl in the world (Banko, 2004). The Nēnē has been listed since 1967 with a priority ranking of 2, but critical habitat has not been designated. Currently, there are wild populations of Nēnē found on the islands of Hawaii, Kauai, and Maui, with a small captive-bred population on Molokai. This goose is highly adaptable and has been observed at elevations ranging from sea level to 2,500 m in grassland, shrubland, dry forest, lava flows, cinder fall, and even anthropogenic habitats such as pasture and golf courses (Banko, 2004). It is also a highly terrestrial species, meaning it relies on small bodies of fresh water on land. Nēnēs are distinct from other geese in this way, as well as the fact that they are non-migratory (Olson & James, 1991).

Like many species, the Nēnē's historical distribution is not well known, but fossil evidence suggests that it used to be much more widely distributed compared to today. Its populations declined sharply in the 1800s, likely due to lowland habitat loss from land conversion for agriculture and grazing, and hunting during the Nēnē's breeding season in the fall and winter. Furthermore, genetic evidence indicates that Nēnēs also underwent a severe drop in genetic diversity at this time, likely due to the low numbers of birds remaining (Banko, 2004).

Figure 2.5.3. The Hawaiian goose. Image: ABC Birds via Pinterest.

Like many Hawaiian bird species, it is believed that the Nēnē formerly preferred lowland habitats due to the greater availability of food and chance of gosling survival in the warm, wet regions; however, the Nēnēs have been pushed upwards to higher elevations because the lowland habitats have been so anthropogenically modified that they are now unsuitable (Banko, 2004).

Unlike Hawaii's vast collection of forest birds, who prefer to nest in trees, the Nēnē builds its nests on the ground in dense, shrubby grasslands, and have been shown to prefer native over nonnative vegetation (Banko, 2004). They also tend to remain close to water sources when available, but these may be artificial water sources. Nēnē are generalists when it comes to their diets and have been shown to have more nonnative than native foods in their diet – likely due to the higher proportion of nonnative forage available to them – which includes leaves, seeds, and grasses (Banko, Black, & Banko, 1999). Breeding can occur almost year-round, with the exception of summer, and an average clutch size for the Nēnē is 3-5 eggs.

Currently, the Nēnē is still a highly threatened species, and even the "established" populations in the wild need to be supported with the release of additional captive-bred geese (Banko, 2004). The Nene's greatest threats continue to be direct pressures from hunting and habitat loss or degradation. Additionally, Nēnē continue to be highly threatened by introduced species that prey on it such as dogs, cats, rats, and mongoose, dating back to both European and Polynesian colonization of the island. At one time, the population of Nēnēs was estimated to be as low as 30 birds; thus, formal efforts to recover the species have been underway since 1927 with varying degrees of success.
The greatest actions that KI could take to preserve the Nēnē include preventing predation of eggs by nonnative species, and providing habitat with enough nutritional forage for the breeding mothers and fledglings (Banko, 2004). Feral pigs, which are found on KI's property, are also a major concern, so future efforts to assist the Nēnē could focus on restricting pigs from the land.

Additionally, adding more terrestrial water bodies to the property such as the artificial lowland taro patches, especially in lowland regions, would benefit this bird. The Nēnē has a Safe-Harbor Agreement and various private landowners have had success in providing appropriate, if artificial, habitat for this goose in recent years (D'Elia, 2011a).

Table A2.5.1 Habitat availability by wildlife species, suitability, and scenario, in total acres.

Species	Suitability	Baseline	Pasture	Agriculture	Forest	Riparian
Hawaiian Hoary Bat	High	1,123	603	603	698	772
	Somewhat	234	67	67	67	171
	Not	1073	1774	1774	1680	1502
Hawaiian Hawk	High	1,123	603	603	698	772
	Somewhat	532	355	433	433	500
	Not	775	1486	1408	1314	1173
Hawaiian Goose	High	234	67	67	67	171
	Somewhat	1,704	1,829	1,751	1,752	1,684
	Not	492	548	626	626	590

Table A2.5.2. Habitat availability by wildlife species, suitability, and scenario, in percentages.

Species	Suitability	Baseline	Pasture	Agriculture	Forest	Riparian
Hawaiian Hoary Bat	High	46%	25%	25%	29%	32%
	Somewhat	10%	3%	3%	3%	7%
	Not	44%	73%	73%	69%	61%
Hawaiian Hawk	High	46%	25%	25%	29%	32%
	Somewhat	22%	15%	18%	18%	20%
	Not	32%	61%	58%	54%	48%
Hawaiian Goose	High	10%	3%	3%	3%	7%
	Somewhat	70%	75%	72%	72%	69%
	Not	20%	22%	26%	26%	24%