TRACING SOCIAL-ECOLOGIAL RELATIONSHIPS:

HĀʻENA, *KAUAʻI, HAWAIʻI*

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Abstract

Natural resources are shared by heterogeneous populations. Each subgroup of resource users within a population has a different perspective of the resource's health, and their responsibility to steward that natural resource. This research was conducted under a premise that heterogeneous populations of resource users can arrive at a shared understanding of a social-ecological system's current state if they have a shared understanding of its history. Two established frameworks were operationalized to methodically examine the history of any social-ecological system. This is a case study about historical events that occurred in *Hāʻena, Kauaʻi* between 1975 and 2015. One framework exposed the introduction of actors and their relationships to the resource system over time. The benefits each resource user group receives from the ecosystem were also identified. The second framework linked related events in a way that revealed the historical management transitions for each of the major fresh water management areas in the social-ecological system. This broad historical understanding was used to create social time series variables from qualitative data that were tested for statistical correlation to existing ecological time series data. Correlations identified through multiple regression analysis showed Hurricane *ʻIniki* may have had a negative influence on coastal salinity in *Hāʻena*, and positive influence on groundwater levels. Groundwater level is negatively related to well chlorides, which points to impending saltwater intrusion of the well. This research introduces a mixed method approach for understanding the social-ecological relationships within a system. These methods may be useful for disparate groups of people coming together to perpetuate a shared natural resource. Decision makers and concerned citizens can use research outputs to better understand how historical events shaped current issues and the perspective of different actors. The results of the correlational analysis of qualitative and quantitative data can be useful to guide environmental management based on scientific inquiry.

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List of Abbreviations

CBSFA	Community Based Subsistence Fishing Area
DAR	Department of Aquatic Resources
DLNR	Department of Land and Natural Resources
FWS	Fish and Wildlife Service
IAD	Institutional Analysis and Development
MTF	Management Transition Framework
SES	Social Ecological System
SHDOH	State of Hawaii Department of Health
TMK	Tax Map Key

CHAPTER 1

POINT OF REFERENCE

1.1 Problem

The people who dwell in *Hāʻena* on the north shore of *Kauaʻi* have become more heterogeneous in culture and preferences over time. Constantly changing human activities affect the surrounding environment, including common pool natural resources that all can use and no one owns, such as freshwater and coastal habitat (Ostrom et al. 1994; Dietz et al. 2003). Conflicting views of an acceptable state of these resources became an issue when the people who have the most experience and historical knowledge of the ecosystem wanted to revive previous biophysical features within *Hāʻena* State park (State of Hawaii 2017). Meanwhile, newer actors, who had less historical perspective of the ecosystem's previous state and function, interacted with the environment in a different way. These conflicting viewpoints obstructed managing the shared common pool resources via co-management, an arrangement between the government and different stakeholder groups (Tipa and Welch 2006), which would assign rights and limitations of access across different actors (Bromley 1991, Rose 1994, Agrawal 2001). Hawaiʻi is moving towards co-management (Ayers and Kittinger 2014), although this is hard to achieve without social adaptation and compromise toward common desired outcomes (Diane et al. 2004). Social-ecological systems are defined by the human-environmental relationships over time. A shared understanding of the history of these relationships can help clarify possible outcomes and how they should be prioritized. This research operationalizes established frameworks for understanding social-ecological systems to bring resolution to important historical and spatial aspects. This understanding can provide a common ground for stakeholders to understand each other's motivations, prioritize future caretaking efforts, and establish monitoring protocol to measure progress toward shared desired outcomes.

1.2 Importance

Hāʻena is the first community in *Hawaiʻi* to legislatively designate a Community Based Subsistence Fishing Area (CBSFA) and to pass an administrative rules package to manage coastal resources (State of Hawaii 2015). On October 24, 2014, these rules were approved by the State of Hawaii, over twenty other Hawaiian communities were positioning themselves to model their coastal rule making process after *Hāʻena*. The entire process to develop the first set of rules lasted over a decade (Ayers and Kittinger 2014). It is important to document the persistence and re-occurring self-organization of families who dwell in *Hāʻena*. This social-ecological system is a resilient example of intergenerational knowledge sharing that teaches how to care for an abundance of natural resources while preserving social connections and habitat quality (Berkes 2009, Agrawal 2001, Berkes et al. 2008).

This research is one of the first to operationalize key frameworks in the common pool resources literature. Three different methodologies are employed to arrive at a common historical understanding of the social-ecological system examined in this case study. The first methodology operationalizes the specific concept of 'nested focal action situations' (McGinnis and Ostrom 2011). This concept is embedded in the evolution of the Social Ecological System Framework (Ostrom 2009). The second methodology operationalizes the Management Transition Framework (Pahl-Wostl et al. 2010). The third methodology is a novel approach that combines what was learned from the first two methodologies to create time series from qualitative information that can be correlated to existing quantitative time series. This overall research introduces a mixed method approach for understanding the social-ecological relationships within a system.

These methods may be useful for disparate groups of people coming together to perpetuate a shared natural resource. Decision makers and concerned citizen can use research outputs to better understand how historical events shaped current issues and the perspective of different actors. The results of the correlational analysis of qualitative and quantitative data can be useful to guide environmental management based on scientific inquiry.

1.3 Literature Review

The concept of 'nested focal action situations' (McGinnis 2011a, McGinnis 2011b, McGinnis and Ostrom 2014) is operationalized in this research. 'Nested focal action situations' or interrelated historical events combine the Social Ecological System (SES) Framework (Ostrom 2009) and the Institutional Analysis and Development (IAD) Framework (Ostrom 2011). These frameworks were built on the theory that predictive models cannot be generalized to solve overuse and destruction of shared natural resources (Ostrom 2007). There is no panacea; a diagnostic framework should be applied on a case-by-case basis. The fundamental components of these frameworks will be described through this case study of *Hāʻena* in Chapter 2. Implications for future caretaking of the land will include the diagnostic analysis that operationalizes the most recent updates of the SES Framework language (McGinnis and Ostrom 2014).

Like the concept of ‘nested focal action situations’, the Management Transition Framework (MTF) (Pahl-Wostl et al. 2010) is heavily based on the IAD Framework (Ostrom 2011). The SES Framework (Ostrom 2009) describes a static system using variables while the MTF dynamically describes the social-ecological system by tracing policy outcomes through changes in governance systems. The fundamental components of this framework and how it was used to diagnostically analyze the social-ecological system of *Hāʻena* will also be described in Chapter 2. The analysis provides different aspects for addressing future management and policy creation.

This case study of *Hāʻena* is built upon publically archived English language documentation about this social-ecological system. The research of documented information was shared with people who regularly interact with the system in order to verify and expand the knowledge. Andrade (2008) wrote a thorough documentation of this social-ecological system’s history until it was partitioned for smaller parcels of private ownership in 1967. Prior to Andrade’s historical account Earle (1978) and Earle & Ericson (1977) provided a comprehensive English-language archeological and anthropological study of the area that gave insight to how common pool resources were cared for in *Hāʻena* and surrounding *ahupuaʻa*. Hawaiian language resources would provide even more dimension to this understanding. Many papers have been published about the creation and planning of the *Hāʻena* Community Based Subsistence Fishing Area (CBFSA) which defines the coastal boundaries co-managed by community stakeholders and the Hawaii State Department of Land and Natural Resources (Vaughan and Vitousek 2013, Vaughan and Ardoin 2014, Ayers and Kittinger 2014, Vaughan and Caldwell 2015, Vaughan and Ayers 2016, Vaughan, Thompson, and Ayers 2017). The analysis in Chapter 3 quantitatively examines the historical events that occurred between Andrade (2008) and the current co-management of shared natural resources in this social-ecological system.

The people of Hawaii became almost 98% literate after being introduced to the written language. Hawaiians used newspapers to convey current news and opinions in addition to stories and legends that were passed on from generation to generation. These legends commemorate the land and what it has done for the Hawaiian people. In the modern day, we have yet to completely unlock the knowledge that was deposited in these newspapers, which ran from 1838 to 1944

(Chinn et al. 2014). Additional knowledge is held with families that needs to be shared privately or publically in order to live on.

1.4 Motivation & Research Questions

This research operationalizes the Social Ecological Systems (SES) Framework (Ostrom 2009) as well as the Management Transition Framework (MTF) (Pahl-Wostl et al. 2010) to create time series social and ecological variables. These established theoretical frameworks are built off the assumption that previous states of the system should be traced in order to define the current state. This research quantified historical social and ecological concepts to create a substantiated understanding of the system limited by data availability and experience. This inquiry built upon and applied methodologies designed to establish a shared understanding of social-ecological system transitions and changes, which are critical to defining the current state. It is hoped that discordant groups can replicate these methodologies to arrive at a shared understanding of their systems and how to move forward together.

The *ahupua'a* boundary of *Hā'ena* on the island of *Kaua'i* is the unit of analysis for this case study. Chapter Two of this dissertation answers the first research question: How has the social-ecological system of *Hā'ena* changed over time? The results provide an understanding of how the system arrived at its current state. This historical conceptualization allowed for creation of variables that can be correlated over time. Chapter Three uses quantitative statistics to answer the second question: What social and ecological statistical relationships have occurred over time? Chapter Four takes all results from Chapters Two and Three to answer the third and final research question: How can this research improve social and ecological outcomes?

This research advances the field of diagnostic social-ecological system studies by providing a case study example that methodically examines the history of a geographic unit of analysis. These methods provide a systematic way of examining and recording historical data to statistically analyze the relationship of qualitative and quantitative data as well as social and ecological data over time. The methods can be used to inform current management and policymaking in this place, and serve as a potential framework for others. The results are then synthesized to provide direction for research and management investigations that improve caretaking through scientific inquiry.

CHAPTER 2

EXAMINING THE TIME BEFORE

This chapter answers the research question, how has the social-ecological system of *Hāʻena* changed over time? This was accomplished through the operationalization of two established social-ecological system frameworks. *Hāʻena* is examined by unpacking the basic social-ecological system components provided by these frameworks. The theories and concepts upon which this research was founded will be delineated to understand how it adds to the field of social-ecological system analysis. First the working definition of a social-ecological system will be established, as well as the geographic unit of analysis, the *ahupuaʻa* of *Hāʻena*. Different perspectives of the system are revealed using concepts derived from the Social Ecological System (SES) Framework (Ostrom 2009), the Institutional Analysis and Development (IAD) Framework (Ostrom 2011), and the Management Transition Framework (MTF) (Pahl-Wostl et al. 2010). The relevant components, operationalization methodology, and results of operationalization for the SES Framework and MTF will be discussed in their own sections. Together, the frameworks create systematic ways to holistically answer the research question for this chapter.

2.1 Introductory Definitions

2.1.1 Social-Ecological Systems

Social-ecological systems are defined by Anderies et al. (2014, p. 3) as "social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units." An *ahupuaʻa* is a Hawaiian community-level land division unit that has been implemented in various ways as part of a larger social-ecological system.

2.1.2 *Ahupuaʻa*

The underlying goal of an *ahupuaʻa* is to maximize resource availability and abundance (Winter 2015). It is both physical and social. Physical boundaries were formed to delineate these units for privatization of the land in the 1848. Prior to this there was an informal social understanding of societal structure and insularity of capital exchange that defined these systems (Beamer 2001, Earle and Ericson, 1977). Andrade (2001) discusses a Hawaiian geography not being built upon visual cartographic maps, but chants (*oli*), song (*mele*), and stories (*mo`olelo*) about the people and their legendary feats on the land that are passed on from generation to generation.

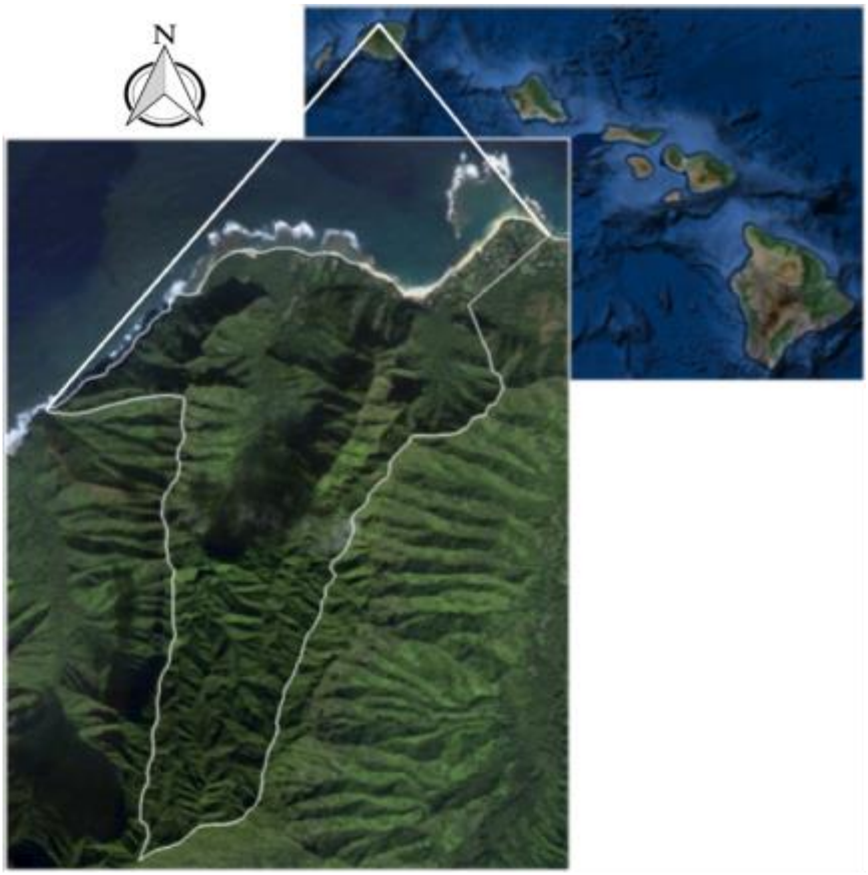
The *konohiki* or resource manager played an instrumental role in this type of system. He or she summoned social capital to complete large infrastructure projects to benefit those who contribute to this social-ecological system (Handy, 1989). This person had a keen understanding of the seasonal patterns of the place that guided farming and fishing activities. Participation in the system was completely at will. Families were not bound to the *ahupuaʻa* contractually, but participated for the social and material benefits that kept them well fed and resilient in times of conflict and extreme climatic events (Andrade 2008). Experiential knowledge was passed on for generations between people who loved a place. After the *Māhele* in 1848 the authority of the *konohiki* was effectively removed, and with that the social cohesion to maintain the social-ecological system for abundance (Howes and Osorio 2010). However, the families of *Hāʻena* self-organized to purchase their *ahupuaʻa*. This research intends to improve social and ecological outcomes by tracing the transitions that occurred between then and the present day when the descendants of those families once again self-organized to revive the cultural and physical features of the land that has fed their family for generations. In the absence of a *konohiki*, modern descendants of the land are relearning the seasonal patterns that make *Hāʻena* unique so that it can continue to physically and spiritually nourish the people who care for it (Cadiz 2017).

2.1.3 *Hāʻena*

Hāʻena is a small 7.7 km^2 traditional environmental management unit on the north shore of *Kauaʻi* in *Hawaiʻi* (

Figure 1). It is situated at the northern end of the road marking the beginning of the *Nā Pali* coastline trail.

Figure 1. Location of *Hāʻena* within the Main Hawaiian Islands



Hāʻena is 7.7 km² and geographically sits at the end of the state highway on the north shore of Kauaʻi.

The social-ecological system of *Hāʻena* is special because the people who care for this place have a history of responding to resource depletion and social change by self-organizing, building consensus, and collectively acting (Andrade 2008). For generations, their acts have been legendary and call people to interact with the land. The name *Hāʻena* refers to the hot breath of the sun that invokes the water cycle each day (Kanahele 2012). Fresh water has been an abundant and important resource in *Hāʻena*. This description of *Hāʻena* will start by discussing where the fresh water flows and follow it to where it meets the sea.

Traditional local ecological knowledge is rich with information about how the physical features of *Hāʻena* function and the values that people held. The steep and jagged ridgeline of *Hāʻena* creates shadows that carry stories of heroes carved in the land. Many Hawaiian legends (*moʻoleo*) that were once only orally passed on from generation to generation describe geographic features of the land such as peaks and gulches in ridgelines. The heroes described in legends about the ridgeline of *Hāʻena* were determined to reach their goals and protect the fruits of their labor. The legend of *Pōhaku o Kāne* (Wichman 1985) speaks of a stone that so badly wanted to climb to a peak, that *Kāne* compassionately boosted him up (Figure 2).

Figure 2. *Pōhaku o Kāne*

There is also the story of *Nou* (Wichman 1985), a young boy who begged the older fire throwers to let him climb to the peak of *Makana*. *Nou* wanted to hurl a firebrand during the *ʻōahi* (fire-throwing) ceremony (Figure 3).

Figure 3. *ʻŌahi* ceremony and the outline of *Nou*

Other legends inscribed on the ridgeline of *Hāʻena* capture stories of people exploiting or protecting their resources. The story of *Nā Piliwale* (Wichman 1985) refers to four sisters who would often visit the chief's court and greedily eat enough food to cause a famine (Figure 4).

Figure 4. *Nā Piliwale* Sisters

The story of *ʻAʻalewalewa* (Andrade 2008) and *Kaiwikuʻi* (Fornander and Thrum 1916) respectively commemorate a *Wainiha* man and a couple who would steal from the *menehune* in *Mānoa* valley. All three legends end with the perpetrators turning to stone inscribed in the ridgeline of *Hāʻena*. These legends remind people not to take without contribution or reciprocation.

One of the most published legends of *Hāʻena* (Ho'omanawanui 2014) is the story of the love triangle between the goddess *Pele*, her sister *Hiʻiaka* and *Lohiʻau* (Nakuina 1904). The drums from *Ka Ulu A Paoa* (

Figure 5), the esteemed hula school at *Kēʻē* enchanted the goddess *Pele* from her home at *Halemaʻumaʻu* crater on the island of *Hawaiʻi*. She fell in love with *Lohiʻau*, a mortal whose house sits above the modern day road behind the beach at *Kēʻē*. At one point in the story she claimed she was from *Kauaʻi*, and to prove it she named 273 winds from *Nīhoa* to *Hāʻena* (Silva 2010). *Pele* described eight winds for *Hāʻena*. One is named *Limahuli*, which means, "turning hand." It is also the name of the main watershed and associated perennial stream within *Hāʻena*.

Figure 5. *Ka Ulu A Paoa*

Mānoa is a narrow valley that lies to the east of *Limahuli*, and it is also the name of the second perennial stream that courses through the *ahupua'a* of *Hā'ena*. In *Pele*'s *kāhea* or listing of the winds she says "*He Pilipali ka makani o Mānoa*" (Poepoe 1911) which describes the main wind of this valley. *Pilipali* means to cling to a cliff, referring to the steep western side of *Mānoa*, which halts the prevailing northeasterly trade wind. The highest point at the *mauka* (in-land) end of *Mānoa* watershed is around 823 meters (USGS 2014), and the wind speed is only about 300 watts per square meter (AWS Truewind 2004). As it slides out of this thin valley along the 2000-foot (USGS 2014) western edge the *Pilipali* wind picks up to a force of 600 watts per square meter (AWS Truewind 2004).

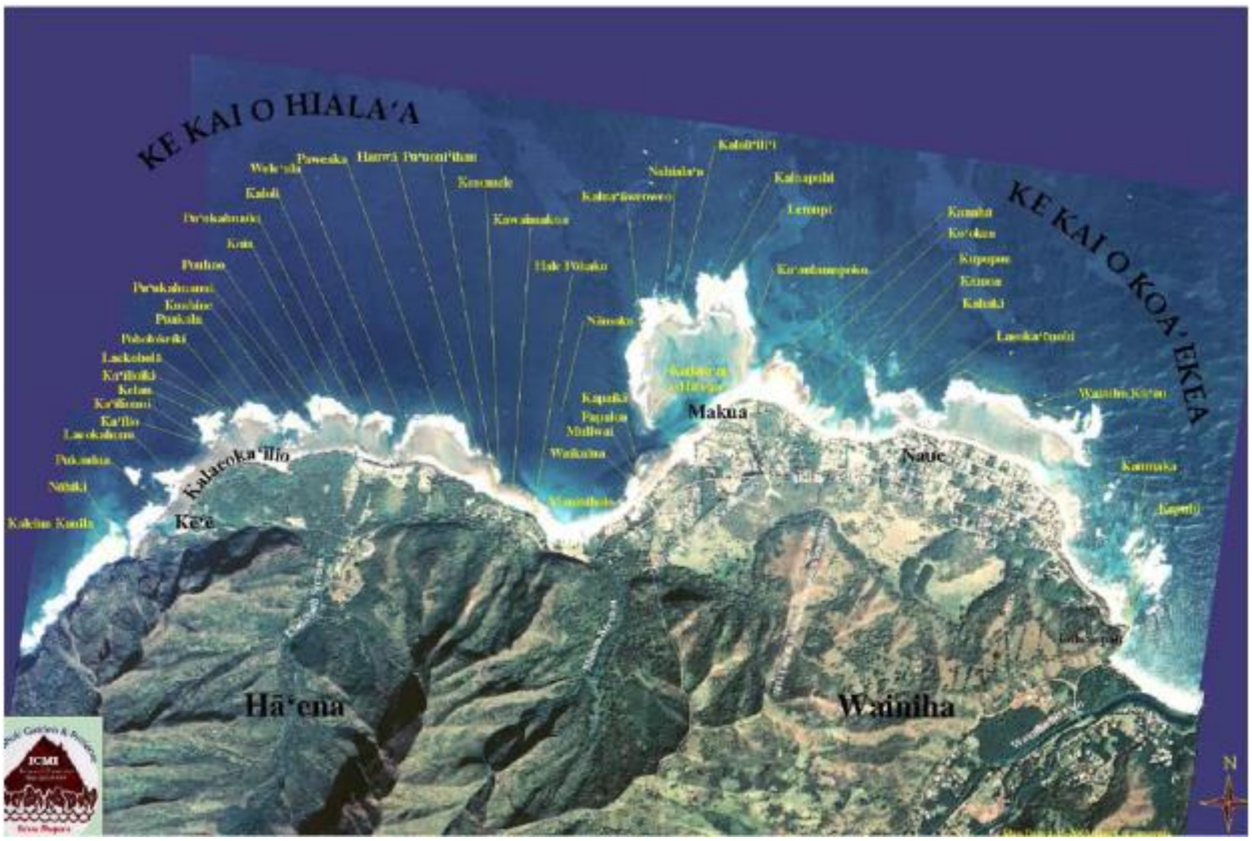
When the wind from the ocean pushes up the precipices of these steep valleys the air cools the moisture, which condenses into orographic rainfall. At the highest and most inland point of *Limahuli* Watershed, *Honoonāpali*, the mean annual rainfall is about 134 inches

(Giambelluca et al. 2013). This is contrasted to the driest part of the *ahupua'a*, *Makua*, the eastern coastal point of *Hāʻena*, which only has an average annual rainfall of 87 inches (Giambelluca et al. 2013). Between *Honoonāpali* and *Makua* flow two perennial streams that run through an intricate and fertile coastal wetland. The flow of fresh water links the intimate relationship between the alluvial plain and the fringing reef.

Limahuli Stream starts as two branches, one beginning at *Honoonāpali* and the second at *Paliʻeleʻele*. The two flows meet at the top of *Limahuli* Falls and drop about 760 feet into a single course. Timbol et al. (1989) did an extensive survey of this stream beginning at *Limahuli* Falls seaward as part of the National Tropical Botanical Garden's preparation to apply for a Conservation District Use status change. His team compiled an aquatic macrofaunal list, made semi-quantitative population estimates, described the stream channel, and identified riparian vegetation on both banks as well as estimated vegetative canopy. Shortly after this survey a statewide assessment of streams was conducted. It provided a comparison of *Limahuli* and *Mānoa* Streams. Both streams are continuous, undammed, and unchannelized (Hawaii Cooperative Park Service Unit 1990). These features are critical for the presence of native Hawaiian stream species. Many native stream species are amphidromous meaning they begin their life cycle in the marine environment and move upstream as they mature (Walter et al. 2012). The aquatic resources for *Limahuli* were rated as 'Outstanding,' whereas *Mānoa* was rated as 'Satisfactory' (Hawaii Cooperative Park Service Unit 1990). This rating was basically an examination of habitat quality for indicator species. Both streams had three out of four primary native indicator species: *Awaous stamineus (ʻoʻopu nākea*), *Lentipes concolor (ʻoʻopu hiʻukole/ʻoʻopu alamoʻo*), *Sicyopterus stimpsoni* (*ʻoʻopu nōpili*), and *Neritina granos* (*hīhīwai*). The only missing species was *Neritina granos* (*hihiwai*) a type of stream snail. The fossils of these snails were abundant in archeological excavations on the easternmost shores of *Makua* (Dye 2005a). In 2000, researchers noticed that the upstream portion of these *ʻoʻopu*'s life cycles could not be completed because half an acre of *hau* (*Hibiscus tiliaceus*) was blocking their path. With intense human effort, this portion of the stream was cleared. This was not an easy feat because machinery could not be brought in to facilitate the process. A persistent species assemblage structure was measured for *Limahuli* Stream. It is considered the benchmark for pristine native Hawaiian streams (Kido 2008). A native species-based index of biological integrity for Hawaiian stream environments (Kido 2013) expanded earlier research.

The roughly six-mile coastal stretch from *Makua* to *Kēʻē* is home to more than 65 named places on the reefs and shore (Figure 6). These names point to resources like *Kalua ʻAweoweo* (*ʻAweoweo* Pit (fish: *Priacanthus sp.*)) (Andrade 2008) or *Welaʻula* (cultivation ground for *ʻula*, the spiny lobster. They also give warning for where kids should not play like *Poholokeiki* (drowning child) (Andrade 2008).

Figure 6. Nā Inoa Kahakai Maintained by Limahuli Garden & Preserve



This map documents place names remembered by elders in the community. Names are still being rediscovered as observations and caretaking of these places is expanded.

Each of these named places was distinctive for people who depended on the natural resources of this area. As land use changes different nutrients enter the reef depending on what is flowing in from the land (Inman et al. 1963). Different nutrients will attract different species of *limu* (algae) and fish. However, the *limu* that grows in *Hāʻena* are more influenced by the ocean tides (Rodgers et al. 2012) and social tides of people that have come to leave their mark on the shoreline.

2.2 SES Framework

2.2.1 Introduction

Ostrom (2009) introduced the SES Framework, which provides a common set of variables for people to discuss and examine different components of social-ecological systems. It provides a complete list of variables to consider when examining human and habitat relationships (Figure 7). At a meta-level these variables can be compared across case studies. The entire list can also be useful when thoroughly investigating one system.

Figure 7. Social Ecological System (SES) Framework

Recreated after McGinnis and Ostrom (2011)

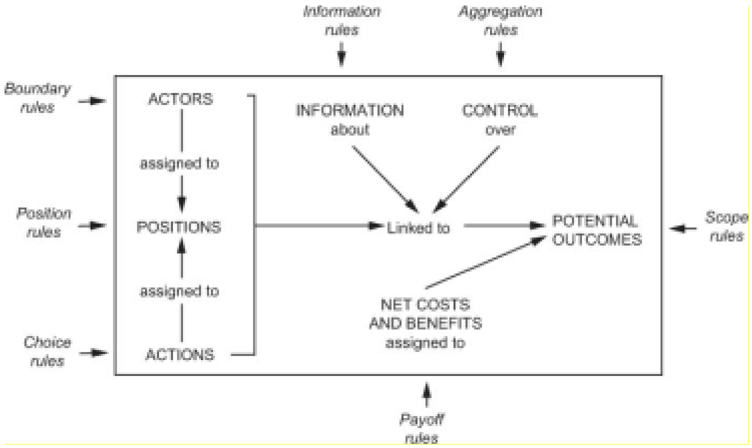
Considering all variables as a system is useful to define the context of environmental degradation and resilience. The ‘Social, Ecological, and Political Setting,’ ‘Governance Systems,’ and ‘Actors’ components in Figure 7 represent the human aspects of a system, while the ‘Related Ecosystem,’ ‘Resource System’ and ‘Resource Unit’ components give biological context. Every natural resource use issue must be considered within its immediate ecosystem, but the characteristics of the resource in question can further aid in diagnosing an issue. This framework brings perspective to the ecological fact that resources are nested in an ecosystem that is influenced by people. The ‘Action Situation: Interactions and Outcomes’ listed in Figure 7, i.e. Harvesting (I1), Information Sharing (I2), etc., represent the types of interdependent relationships humans have over shared natural resources.

2.2.1.1 Institutional Analysis and Development (IAD) Framework

The IAD framework (Ostrom 2011) gives temporal dimension to the SES framework. The SES Framework variables in Figure 7 can only be used to describe the system at a stationary point in time, whereas the IAD framework tries to conceptualize how the SES changes over time based on its attributes. The SES variables from Figure 7 describe the contextual factors (‘Biophysical Conditions,’ ‘Attributes of the Community,’ and ‘Rules-in-Use’) in **Error! Reference source not found.**. ‘Action Situations’ are the result of the unique combination of characteristics happening at a specific period of time in a social-ecological system. The result is either knowledge that is adopted as principle, a formal or informal institution, or the achievement of a goal. The unique combination of contextual factors in a given place at a given time that form a specific ‘Action Situation’ determines how interactions will play out – an identical interaction (e.g., harvesting) in one context will result in totally different outcomes and feedbacks than in another. Another key aspect of the IAD is the importance of understanding how previous ‘Interactions’ and ‘Outcomes’ created the current set of ‘Contextual Factors,’ as this can inform a path toward stable or constantly improving conditions. Unpacking the ‘Action Situation’ requires understanding the juxtaposition of the ‘Actors’. The ‘Actors’ can be considered in the context of all the variables outlined in Figure 7.

Social-ecological system interactions can be systematically understood through the rules that constrain it. Figure 8**Error! Reference source not found.** visualizes the rules that bind ‘Interactions’ in an ‘Action Situation’. These rules are defined in Ostrom (2005).

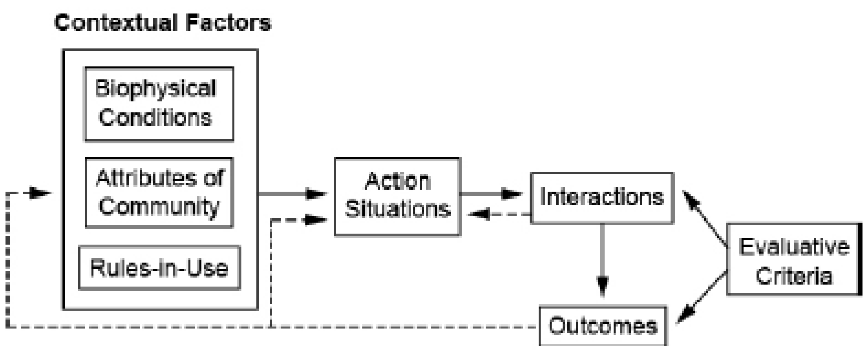
Figure 8. Rules-in-Use Framework



Recreated after Ostrom (2005)

Frameworks such as the SES Framework in Figure 7 and the Rules-in-Use Framework in Figure 8 provide a standardized and thorough list for people to consider when navigating or analyzing ‘Action Situations’ for the purpose of improving the balance between the ‘Contextual Factors’ in Figure 9.

Figure 9. Institutional Analysis and Development Framework

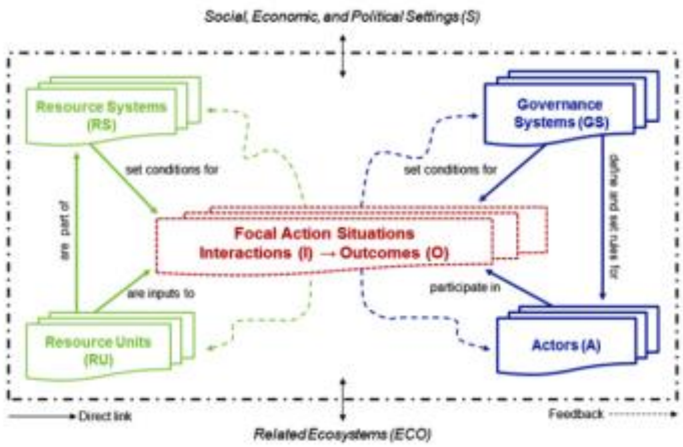


Recreated after Ostrom (2011)

2.2.1.2 Focal Action Situations

McGinnis (2011) revised the SES framework (Ostrom 2009) to better represent the feedback loops that are central to the IAD framework (Ostrom 2005, Ostrom 2011) (Figure 10). This perspective of the social-ecological system is a reminder that the system is a network of interrelated ‘Action Situations’ over time. A social-ecological system is defined in total by the nesting of ‘Focal Action Situations’ over time. The culmination of ‘Outcomes’ from the dynamic interaction of system components will depend upon how all of these SES components relate to one another.

Figure 10. Inter-related or Nested Focal Action Situations for a Social Ecological System



Adapted from McGinnis and Ostrom (2011)

2.2.1.3 Applying the SES Framework Across Diverse Situations

Since the establishment of the SES Framework (Ostrom 2009), researchers have proven its wide applicability (Cole et al. 2014, Basurto et al. 2013, Leslie et al. 2015, Hinkel et al. 2015, Bots et al. 2015). After consideration of the research question for this chapter, how has the social-ecological system of *Hā‘ena* changed over time, a framework was needed to compare the ‘nested focal action situations’ over time in this system (Figure 10). Given the diversity of change over time, a diagnostic procedure for applying the Social Ecological Systems Framework in diverse cases (Hinkel et al. 2015) was used. This diagnostic procedure guides identification of different actors and the resource stocks from which they benefit. It is a series of questions laid out in 10 steps, which are displayed in Table 1.

Table 1. Diagnostic Procedures to Identify Actors and Their Resource Stocks of Benefit

Step	Question
1	What is the research question? Social-ecological systems can only be conceptualized with respect to a research question. The question delineates the system’s boundaries, determines the outcomes of interest, and the level of aggregation at which the system should be analyzed.
2	Which actors (A) obtain which benefits from the SES?

3	Which collective goods are involved in the generation of these benefits?
4	Are any of the collective goods obtained subtractable? (If yes, appropriation action situation + resource units; if no, no resource units.)
5	What are the biophysical and/or technological processes involved in the generation of the stock of the RU? Collectively this is called the resource system (RS).
6	How do the variables of resource system (RS) and resource units (RU) characterize the appropriation-related governance challenges?
7	What kind of institutional arrangements have emerged as a response to the appropriation action situation governance challenge?
8	Which actors contribute to the provision, maintenance, or improvement of the RS and by what input (labor, resources, etc.)? This defines a provision action situation associated with a particular RS. In the case that nonsubtractable collective goods are obtained from the RS, this action situation is the provisioning of a pure public good.
9	How do the variables of RS characterize the provisioning action situation related governance challenge?
10	What kind of institutional arrangements have emerged as a response to the provisioning action situation governance challenge?

Adapted from Hinkel et al. (2015)

These questions help to operationalize the SES framework variables by capturing how each set of actors depend on resource units in the system. Teasing out these interdependencies between actors and the system has been a challenge for past social-ecological systems researchers. Hinkel et al. (2015) suggests describing the appropriation and provisioning action situations separately for each time period. Appropriation refers to when actors collectively avoid overuse of a shared resource. Provisioning refers to the collective challenge of actors to create, maintain, or improve a collective good or a system that maintains a shared natural resource (Hinkel et al. 2015). For each type of 'Action Situation' the governance challenges that arose were identified in addition to the actors involved through the application of the diagnostic question list.

Significant historical events and stories are important to the *Hāʻena* community members that take care of their ancestral natural and cultural resources. The following section will describe the collection of historical observations and creation of a single timeline that identifies important 'Focal Action Situations' for this *ahupuaʻa*. This will be followed by a discussion of mixed methods for synthesizing qualitative data. First the clustering of historical observations will be described followed by the choice of important 'Focal Action Situations' for the social-ecological system. Finally, the diagnostic procedure described above was applied to each 'Focal Action Situations' for the purpose of teasing out actor benefits over time.

2.2.2 Operationalizing SES Methodology

2.2.2.1 Data collection

Observations collected from a reinforced literature review link historical events. This review is reinforced because it went beyond database searches of archived collections to confirm and add information from interviews with people who have intimate knowledge of the place (*kamaʻāina*). *Kamaʻāina* are people native to a place because they were born and raised there, but others become familiar to an area through experience and knowledge from people depend on the resources of the area for food, water, shelter and spiritual rejuvenation. This confirmation of gathered information was also done to engage in knowledge transfer and communal understanding with people who interact with this place on a regular basis. The first round of data collection came from a keyword search for the terms "*Hāʻena*" and "*Limahuli*" in the University of *Hawaiʻi* collections database, Google Scholar, and Web of Science. The number of document types collected is listed in Table 2. The information extracted from these sources was arranged into a single timeline along with cultural practices and species important to the system. The timeline (Figure 11) as well as cultural practices and important species (Appendix A) were verified and reviewed with *kamaʻāina*. Developed communities rarely have access to older generations of people that can describe the raw natural resources of a place. Most of *Hawaiʻi* has access to Hawaiian language newspapers from 1838 to 1944 (Chinn et al. 2014) that could provide more in-depth descriptions of human and environmental interactions. Some social data exists during the time of Hawaiian language papers, but few quantitative ecological indicators that could extend the research presented here.

Table 2. List and Number of Information Resources

Documentation Type	# referenced
Archeological Studies	20
Academic Studies	
Marine Habitat	17
Species Presence (Marine & Terrestrial)	41
Kūpuna Interview Transcripts	25

Kūpuna Lifetimes	32
Environmental Impact Statements	24
Legends About Place	11
Maps	65
Newspaper Articles	110
Photographs (Bishop Museum Collection)	17
Time Series Data Points	297

2.2.2.2 Variable selection

A purposive sample of dates and measurements was collected. The sample is purposive because the observations were not random or stratified (Cox 2015). The researcher's judgment was used to choose the most appropriate observations to include on the timeline and as a time series. The chosen observations are considered a convenience sample because it was entirely based on availability and convenience of collecting the information. Even though the term snowball sample is reserved for human subjects, it can loosely be applied here since collected observations led to other sources and so on.

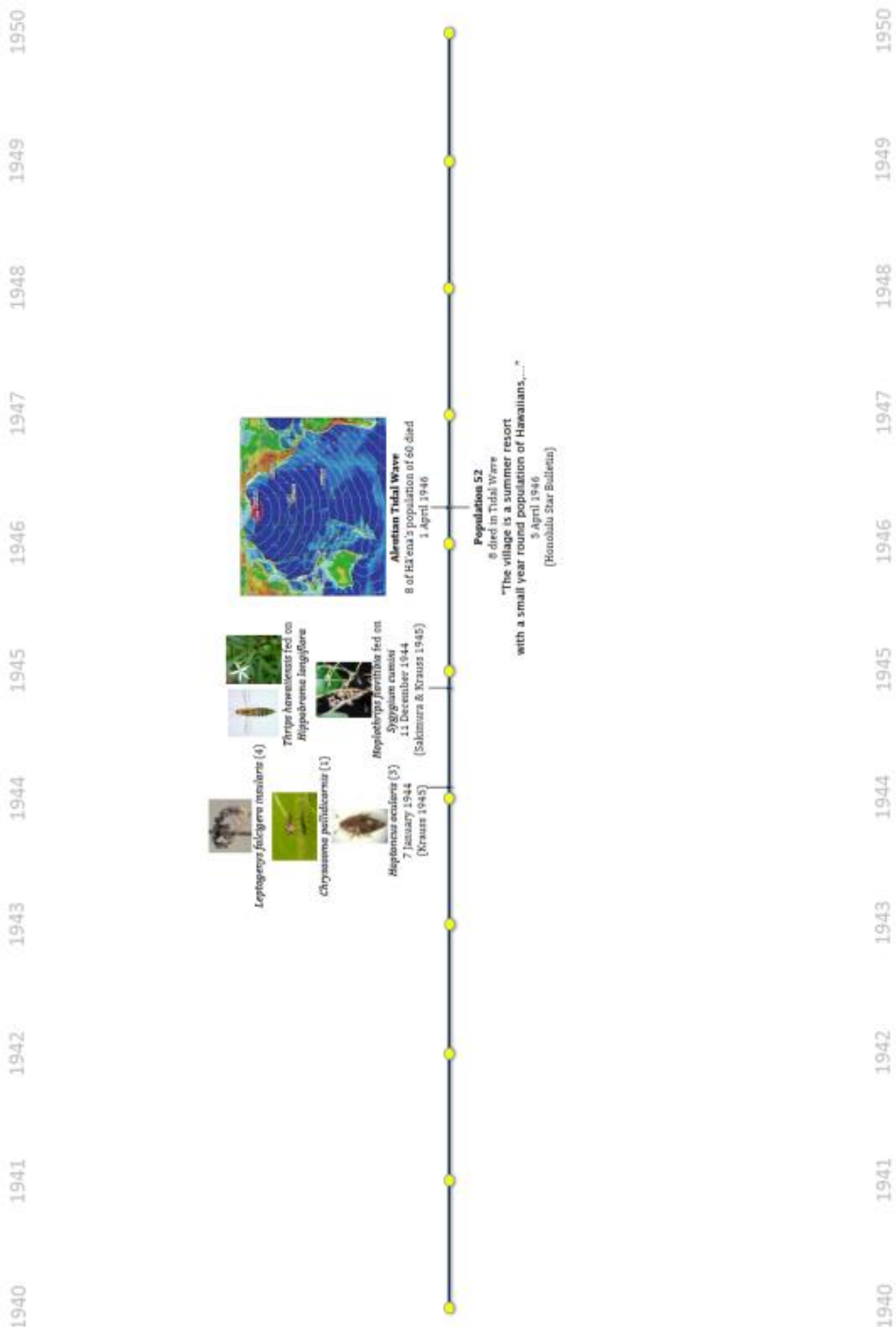
Qualitative information was limited to English only resources, which limited the voice of Hawaiian actors and the social-ecological system itself in this analysis. Qualitative information was clustered in many different ways to identify key information for which to create time series variables. This was done so that this qualitative information could be correlated to quantitative time series data over time. Quantitative data also required a lot of cleaning and reprocessing to produce time series variables. Consistent quantitative measurements over time in a desired format are rare. Collected series of quantitative variables were short and/or inconsistent in measurement frequency and quality. Some quantitative information, especially real property information (market value, assessed value, living area, etc. for taxed plots of land), was available, but required a lot of data reorganization, cleaning, and standardization to operationalize for correlational analysis.

2.2.2.3 Chronologically Ordering Historical Observations

Qualitative and quantitative observations were placed on a chronological timeline, which was then split into seven different timelines based on whether the information fell under the following topical lenses: Culture, Tenure, Development/Tourism, Governance/Management, Climate, Terrestrial, and Marine. Topic lenses were organically created based on data that was collected from the singular timeline in Figure 11.

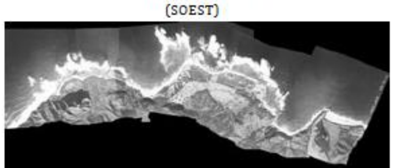
Pivotal events were identified as focal action situations and generalized into decadal time periods from the 1940s to the present. The 1940s was chosen as a starting point because it includes the 1946 Aleutian Tsunami, the oldest extreme climate event in living memory.

Figure 11. Chronological Timeline of Collected Historical Observations



1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960

Shoreline Recorded
22 November 1950
(SOEST)



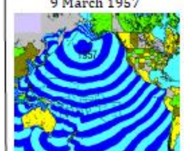
Sarcophaga ceylonensis
(1 male)
Sarcophaga lherminieri
(2 females)
Sarcophaga gessitti
(3 males, 5 females)
Found on Hā'ena beach
1953
(Lopes 1961)

Beach Sand Characteristics Recorded To Understand Effects of Climate and Wave Action
1952
(Inman et al. 1963)

LOCATION	BEACH SLOPE, TANGENT	SIZE DISTRIBUTION: Median Microns	σ_ϕ	α_ϕ
Haena Point	.19	871	.39	+.32
Haena	.16	819 (707)	(.64)	(—.09)
Ke'e	.20	369 (309)	.38 (.35)	—.18 (0.00)
Ke'e		344	.62	—.40
Ke'e		295	.66	—.50

Hui Kuai 'Aina o Hā'ena Partition
1955 to 1967

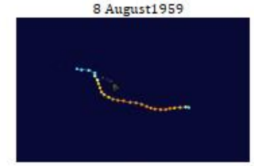
Aleutian Tsunami
9 March 1957



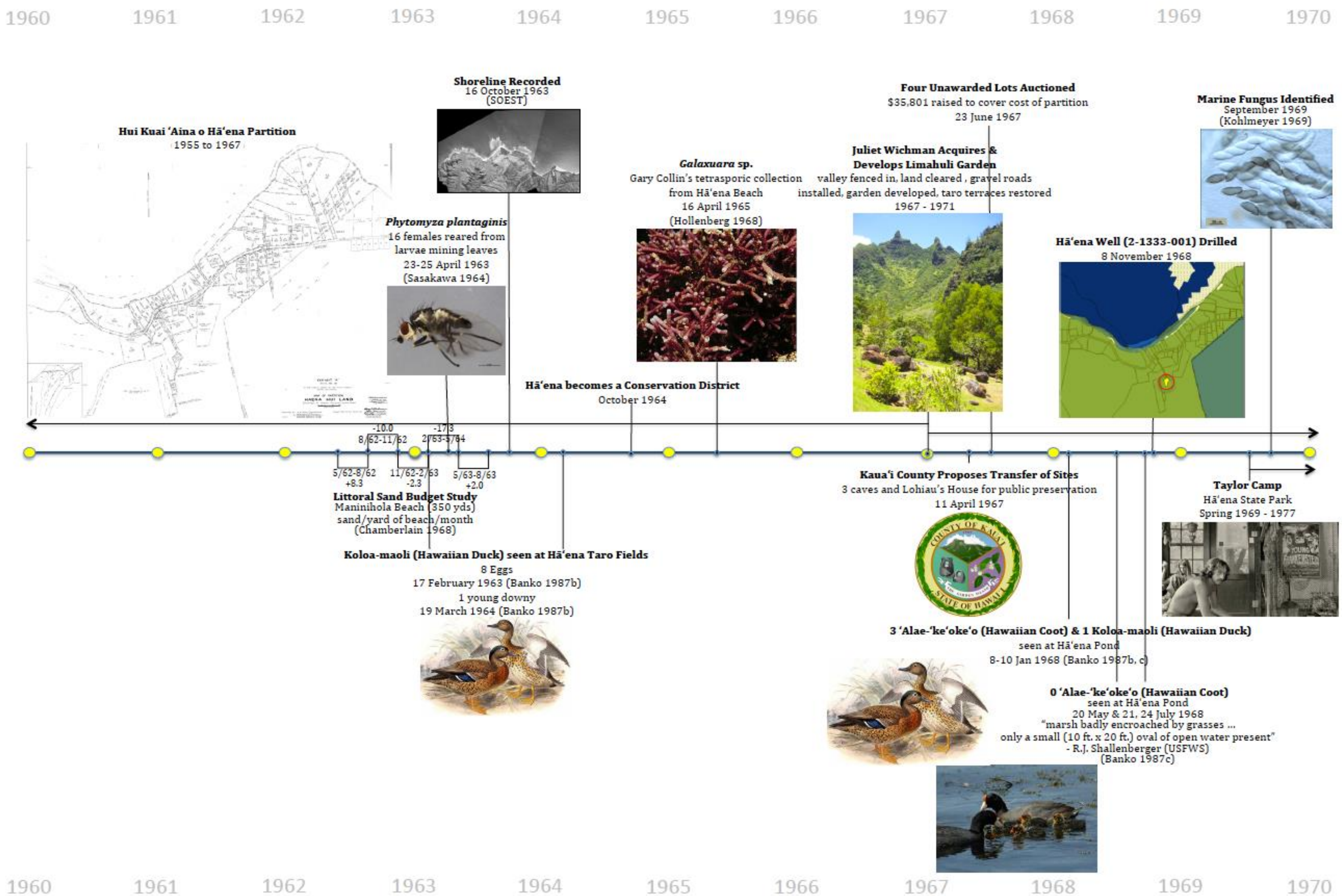
Hā'ena Beach Sand Characteristics Recorded To Understand Origin of Beach Rock
1.30 mm, 1.30 median diameter; Calcareous Composition: 60% Foraminifera, 20% Shells, 20% Calcareous algae
October 1956
(Emory & Cox 1956)

Hawai'i declared 50th State
21 August 1959

Hurricane Dot
8 August1959



1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960


1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
Hui Kuai 'Aina o Hā'ena Partition
1955 to 1967
Shoreline Recorded
16 October 1963
(SOEST)
Phytomyza plantaginis
16 females reared from
larvae mining leaves
23-25 April 1963
(Sasakawa 1964)
-10.0
8/62-11/62
-17.3
2/63-5/64
5/62-8/62
+8.3
11/62-2/63
-2.3
5/63-8/63
+2.0
Littoral Sand Budget Study
Maninihola Beach (350 yds)
sand/yard of beach/month
(Chamberlain 1968)
Koloa-maoli (Hawaiian Duck) seen at Hā'ena Taro Fields
8 Eggs
17 February 1963 (Banko 1987b)
1 young downy
19 March 1964 (Banko 1987b)
Hā'ena becomes a Conservation District
October 1964
Galaxuara sp.
Gary Collin's tetrasporic collection
from Hā'ena Beach
16 April 1965
(Hollenberg 1968)
Juliet Wichman Acquires &
Develops Limahuli Garden
valley fenced in, land cleared , gravel roads
installed, garden developed, taro terraces restored
1967 - 1971
Four Unawarded Lots Auctioned
$35,801 raised to cover cost of partition
23 June 1967
Kaua'i County Proposes Transfer of Sites
3 caves and Lohiau's House for public preservation
11 April 1967
Hā'ena Well (2-1333-001) Drilled
8 November 1968
Marine Fungus Identified
September 1969
(Kohlmeyer 1969)
Taylor Camp
Hā'ena State Park
Spring 1969 - 1977
3 'Alae-'ke'oke'o (Hawaiian Coot) & 1 Koloa-maoli (Hawaiian Duck)
seen at Hā'ena Pond
8-10 Jan 1968 (Banko 1987b, c)
0 'Alae-'ke'oke'o (Hawaiian Coot)
seen at Hā'ena Pond
20 May & 21, 24 July 1968
"marsh badly encroached by grasses ...
only a small (10 ft. x 20 ft.) oval of open water present"
- R.J. Shallenberger (USFWS)
(Banko 1987c)

1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980

Juliet Wichman Acquires & Develops Limahuli Garden (continued)
valley fenced in, land cleared , gravel roads installed, garden developed, taro terraces restored
1967 - 1971

Juliet Wichman Helps Expand Kaua'i Museum
Garden renovation put on hold, invasive plants took over areas previously denuded by cattle
January 1971- July 1971

Taylor Camp
Hā'ena State Park
Spring 1969 - 1977

Cave Fauna Surveyed
Maniniholo Dry Cave and Waikanaloa Wet Cave surveyed for evolutionary research to understand main energy sources in caves
July 1972 to May 1973
(Howarth 1973)

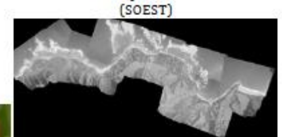
Pantala flavescens
2 males Hā'ena Park, sea level
15-16 March 1974
(Harwood 1976)

Megalagrion vagabundum
1 female Limahuli Stream, sea level
19 March 1974
(Harwood 1976)

Ischnura posita
1 male Hā'ena Park, sea level
20 March 1974
(Harwood 1976)

Anax strenuus
1 male Hā'ena Park, sea level
19 March 1974
(Harwood 1976)

Shoreline Recorded
10 April 1975
(SOEST)



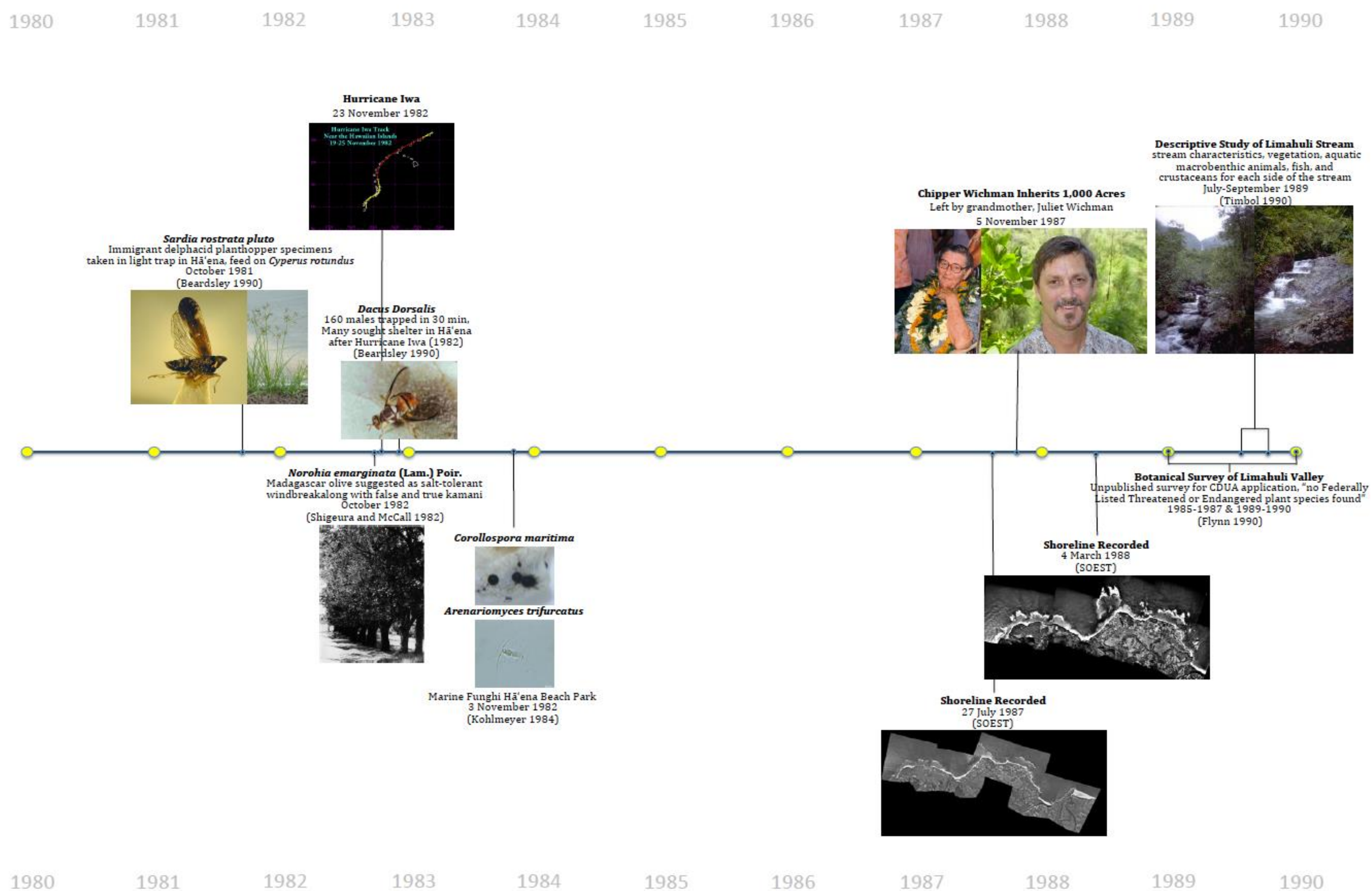
Kaua'i Resident Coastal Use Survey
917 Kaua'i residents surveyed to find shoreline area use frequency,
performance of various water based activities,
opinion of establishing marine conservation areas,
form conservation areas should take and preferred location of such areas.
17-25 July 1975
(Takeuchi 1975)

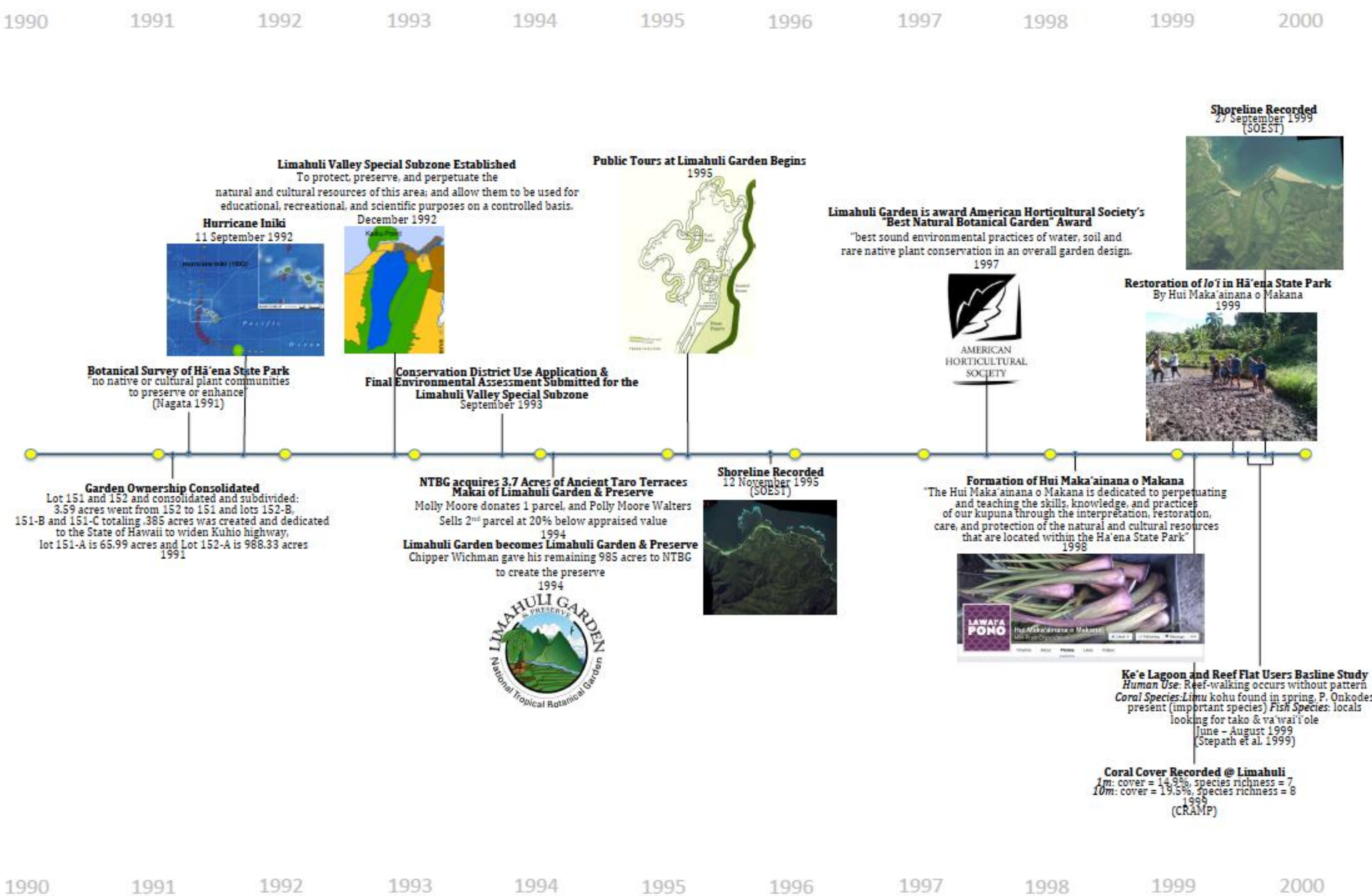
Juliet Wichman donates 15 acres to NTBG
Hui lots 140-5 are donated to preserve the native plants and pristine stream for future generations
1976

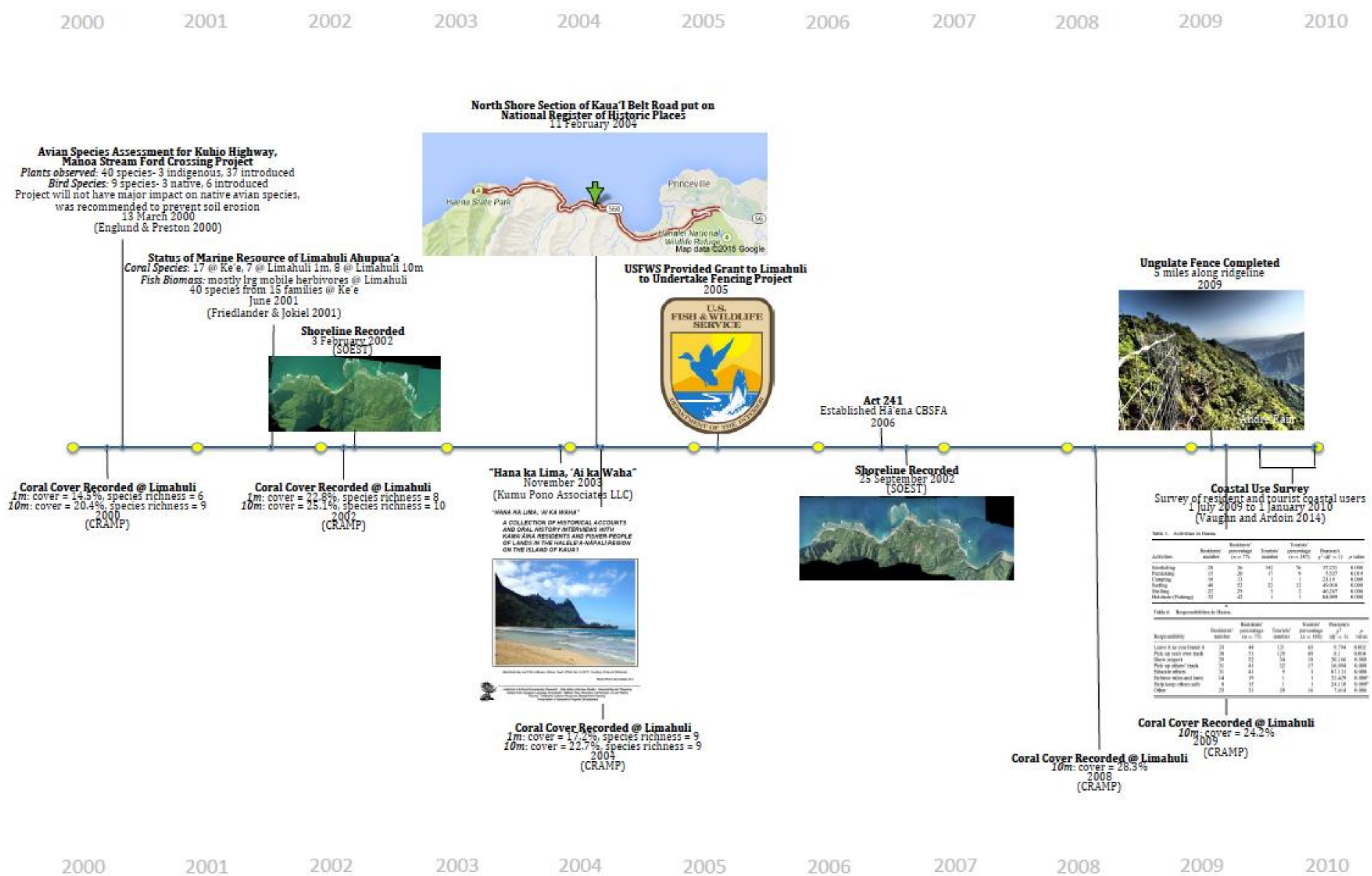
***Erionota thrax* L.**
The banana skipper was found on Kaua'i for the first time causing light to moderate damage from Mana to Haena
1 June 1976
(Nakao and Funasaki 1976)

0 'Alae-'ula (Hawaiian Gallinule) & 0 Kaloa-maoli (Hawaiian Duck)
seen at Hā'ena Marsh
20 May & 21 July 1977
"marsh badly encroached by grasses …
only a small (10 ft. x 20 ft.) oval of open water present"
- R.J. Shallenberger (USFWS)
(Banko 1987a,b)

1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980

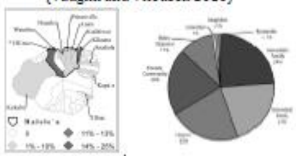

1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
Hurricane Iwa
23 November 1982
Hurricane Iwa Track
Near the Hawaiian Islands
19-25 November 1982
Sardia rostrata pluto
Immigrant delphacid planthopper specimens
taken in light trap in Hā'ena, feed on Cyperus rotundus
October 1981
(Beardsley 1990)
Dacus Dorsalis
160 males trapped in 30 min.
Many sought shelter in Hā'ena
after Hurricane Iwa (1982)
(Beardsley 1990)
Norohia emarginata (Lam.) Poir.
Madagascar olive suggested as salt-tolerant
windbreakalong with false and true kamani
October 1982
(Shigeura and McCall 1982)
Corollospora maritima
Arenariomyces trifurcatus
Marine Funghi Hā'ena Beach Park
3 November 1982
(Kohlmeyer 1984)
Chipper Wichman Inherits 1,000 Acres
Left by grandmother, Juliet Wichman
5 November 1987
Descriptive Study of Limahuli Stream
stream characteristics, vegetation, aquatic
macrobenthic animals, fish, and
crustaceans for each side of the stream
July-September 1989
(Timbol 1990)
Botanical Survey of Limahuli Valley
Unpublished survey for CDUA application, "no Federally
Listed Threatened or Endangered plant species found"
1985-1987 & 1989-1990
(Flynn 1990)
Shoreline Recorded
4 March 1988
(SOEST)
Shoreline Recorded
27 July 1987
(SOEST)
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990


1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Garden Ownership Consolidated
Lot 151 and 152 and consolidated and subdivided:
3.59 acres went from 152 to 151 and lots 152-B,
151-B and 151-C totaling .385 acres was created and dedicated
to the State of Hawaii to widen Kuhio highway,
lot 151-A is 65.99 acres and Lot 152-A is 988.33 acres
1991
Botanical Survey of Hā'ena State Park
"no native or cultural plant communities
to preserve or enhance"
(Nagata 1991)
Hurricane Iniki
11 September 1992
Limahuli Valley Special Subzone Established
To protect, preserve, and perpetuate the
natural and cultural resources of this area; and allow them to be used for
educational, recreational, and scientific purposes on a controlled basis.
December 1992
Conservation District Use Application &
Final Environmental Assessment Submitted for the
Limahuli Valley Special Subzone
September 1993
NTBG acquires 3.7 Acres of Ancient Taro Terraces
Makai of Limahuli Garden & Preserve
Molly Moore donates 1 parcel, and Polly Moore Walters
Sells 2nd parcel at 20% below appraised value
1994
Limahuli Garden becomes Limahuli Garden & Preserve
Chipper Wichman gave his remaining 985 acres to NTBG
to create the preserve
1994
LIMAHULI GARDEN & PRESERVE
National Tropical Botanical Garden
Public Tours at Limahuli Garden Begins
1995
Shoreline Recorded
12 November 1995
(SOEST)
Limahuli Garden is award American Horticultural Society's
"Best Natural Botanical Garden" Award
"best sound environmental practices of water, soil and
rare native plant conservation in an overall garden design.
1997
AMERICAN
HORTICULTURAL
SOCIETY
Formation of Hui Maka'ainana o Makana
"The Hui Maka'ainana o Makana is dedicated to perpetuating
and teaching the skills, knowledge, and practices
of our kupuna through the interpretation, restoration,
care, and protection of the natural and cultural resources
that are located within the Ha'ena State Park"
1998
LAWA'A PONO
Restoration of lo'i in Hā'ena State Park
By Hui Maka'ainana o Makana
1999
Shoreline Recorded
27 September 1999
(SOEST)
Ke'e Lagoon and Reef Flat Users Basline Study
Human Use: Reef-walking occurs without pattern
Coral Species: Limu kohu found in spring, P. Onkodes
present (important species) Fish Species: locals
looking for tako & va'wai'i'ole
June – August 1999
(Stepath et al. 1999)
Coral Cover Recorded @ Limahuli
1m: cover = 14.9%, species richness = 7
10m: cover = 19.5%, species richness = 8
1999
(CRAMP)
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Avian Species Assessment for Kuhio Highway, Manoa Stream Ford Crossing Project
Plants observed: 40 species- 3 indigenous, 37 introduced
Bird Species: 9 species- 3 native, 6 introduced
Project will not have major impact on native avian species, was recommended to prevent soil erosion
13 March 2000
(Englund & Preston 2000)
Status of Marine Resource of Limahuli Ahupua'a
Coral Species: 17 @ Ke'e, 7 @ Limahuli 1m, 8 @ Limahuli 10m
Fish Biomass: mostly lrg mobile herbivores @ Limahuli
40 species from 15 families @ Ke'e
June 2001
(Friedlander & Jokiel 2001)
Shoreline Recorded
3 February 2002
(SOEST)
North Shore Section of Kaua'I Belt Road put on National Register of Historic Places
11 February 2004
Princeville
Haena State Park
Hanalei National Wildlife Refuge
Map data ©2016 Google
USFWS Provided Grant to Limahuli to Undertake Fencing Project
2005
U.S. FISH & WILDLIFE SERVICE
Act 241
Established Hā'ena CBSFA
2006
Ungulate Fence Completed
5 miles along ridgeline
2009
Coral Cover Recorded @ Limahuli
1m: cover = 14.5%, species richness = 6
10m: cover = 20.4%, species richness = 9
2000
(CRAMP)
Coral Cover Recorded @ Limahuli
1m: cover = 22.8%, species richness = 8
10m: cover = 25.1%, species richness = 10
2002
(CRAMP)
"Hana ka Lima, 'Ai ka Waha"
November 2003
(Kumu Pono Associates LLC)
"HANA KA LIMA, 'AI KA WAHA"
A COLLECTION OF HISTORICAL ACCOUNTS AND ORAL HISTORY INTERVIEWS WITH KAMA'ĀINA RESIDENTS AND FISHER-PEOPLE OF LANDS IN THE HALELE'A-NĀPALI REGION ON THE ISLAND OF KAUA'I
Coral Cover Recorded @ Limahuli
1m: cover = 17.2%, species richness = 9
10m: cover = 22.7%, species richness = 9
2004
(CRAMP)
Shoreline Recorded
25 September 2002
(SOEST)
Coastal Use Survey
Survey of resident and tourist coastal users
1 July 2009 to 1 January 2010
(Vaughn and Ardoin 2014)
Coral Cover Recorded @ Limahuli
10m: cover = 28.3%
2008
(CRAMP)
Coral Cover Recorded @ Limahuli
10m: cover = 24.2%
2009
(CRAMP)

2010 2011 2012 2013 2014 2015

Non-Commercial Seafood Catch & Distribution
Survey of nearshore seafood distribution
March 2011 to September 2012
(Vaughn and Vitousek 2013)



Revival of ʻŌahi Ceremony
Over 80 years later Moku Chandler, Moku-Boy
and Kaʻimi Hermasura climb Makana with firebrands
31 December 2011

Hāʻena CBSFA Management Plan Approved
November 2014

Historic Hawaiʻi Foundation honors
Hāʻena State Park Loʻi Kalo Restoration
Recognized collaborative effort by Hui Makaʻāinana
Makana, Kauaʻi Division of State Parks and
Limahuli Garden & Preserve
30 May 2014

Makua,, Hāʻena – Water Quality Monitoring Project≠
Four sites chosen for fresh water influx were sampled for
enterococci which was much higher during storm events
Aug to Dec 2014
(Stauber 2014)

2010 2011 2012 2013 2014 2015

2.2.3 Results of SES Framework

2.2.3.1 'Nested focal action situations'

Seven focal action situations emerged after examining the collection of historical observations. A significant action situation occurred about every decade from 1940 to the present (Table 3). Throughout each time period, the codes in parentheses describe the part of the SES being discussed and coincide with those in Figure 7. The codes are not exhaustively addressed, but the list was systematically referred to as the description for each time period was compiled. It was useful to ensure the system was being considered holistically.

Table 3. Time Periods and Focal Action Situations

Time Period	Focal Action Situation	Years
1 (T_1)	Land Privatization	pre-1850
2 (T_2)	Formation of the *Hui Kuʻai ʻĀina o Hāʻena*	1875 to 1945
3 (T_3)	Aftermath of 1946 and 1957 Aleutian tsunamis	1946 to 1960
4 (T_4)	Land Partitioning Process	1955 to 1967
5 (T_5)	Creation of *Hāʻena* State park	1968 to 1977
6 (T_6)	Rise of Tourism and Coastal Development	1980s – 1990s
7 (T_7)	Formation of *Hui Makaʻāinana o Makana*	1998 to Present

Time Period 1 (T_1)- Land Privatization pre-1850

The *ahupuaʻa* of *Hāʻena* (RS1) had geographic boundaries formally understood and named (RU6) by the resource system users (*makaʻāinana*) (RS2). The system functions from its highest peak to the alluvial plain at the coastline (RS3). Resource system users built irrigation ditches that took advantage of the above ground geographic contours and underground aquifer (RS4). The system was designed to be abundant with fish from the near shore reef and inland fishponds. These fish were being supplied with nutrients from plants growing within flooded taro patches as well as other plants that grew in the variety of microclimates from the ridgeline to coast (RS5). These items of subsistence were abundant because the fresh water was abundant (RS6). A non-monetized culture of sharing (A2, A6), (RS7), vigilant monitoring, and information sharing by a natural resource manager (*konohiki*) (A5) provided consistent food. As long as the fresh water flowed abundantly food could remain in the fishponds (*loko*), flooded agricultural patches (*loʻi*), and reef (*ʻāpapa*) (RS8). People lived from the seafood, plants, and animals that existed within the *ahupuaʻa* of *Hāʻena*. Rules, laws, and pentalties managed individual use of the resource system.

Appropriation action situation*:* Appropriation of fish and plants (I1) was not an issue as these stocks were abundant (O2), and in times of extreme climate events or war, allies within other *ahupuaʻa* were available (O1). The number of relevant actors probably exceeded today's current resident count (A1). Human management of the *loko* enhanced food supplies from the near shore reef creating abundance and increased resilience. This abundance also applied to *loʻi* and other sources of edible plants. However, in the face of extreme climate events like tsunamis the infrastructure becomes damaged, which is when communal labor was essential (I7, I5, I8).

Institutional response to appropriation action situation*:* The *konohiki* was appointed by ruling chiefs (*aliʻi*) (GS1) to manage natural resources within an area amongst the tenants of the land (GS2). The *konohiki* consulted with expert marine and agricultural tenants on local spawning and harvesting cycles (I9) (Andrade 2008a). He or she also orchestrated human resources for infrastructure repair, planting, harvesting, and extemporaneous large-scale community fishing efforts (*hukilau*) (GS3, I2, I7, I8) (Handy 1989). People tended to the land in this way because they were communally invested in it (I7), and thus never needed a system that delineated individual property rights. Their right to the land and its fruits were hinged on how they cared for it (GS4, I5). Each family or household had areas where they resided and maintained, but this was based on their participation in larger infrastructure projects (GS5) (Andrade 2008b). Tenants or *makaʻāinana* were active participants in management. They were consulted for their expertise (GS6, I5). If a tenant had overwhelming conflict with the *konohiki* they were free to leave since they are not bound by title or contract (GS7, I4). Within this system experts passed on their knowledge to apprentices and younger generations as a way of constantly monitoring the place and sanctioning this method for future generations (A7, GS8).

Provisioning action situation*:* A familial care-taking relationship with the land (A8) created benefit for both the tenants (*makaʻāinana*) and ruling class (*aliʻi*). The relationship between *aliʻi* and *makaʻāinana* was not oppressive. The *konohiki* created a bridge between the ruling class, the people, and the land (Howes and Osorio 2010). People in this system lived to serve the land because it is what nourished them (A8, I5).

Institutional response to provisioning action situation: A strong connection between the *aliʻi*, *makaʻāinana*, and *ʻāina* resulted in an abndance of resources, a physical manifestation of the state of *pono* (GS3, GS6) (Botset al. 2015). Constitutional rules (GS7) reinforced the collective-choice (GS6) and operational rules (GS5).

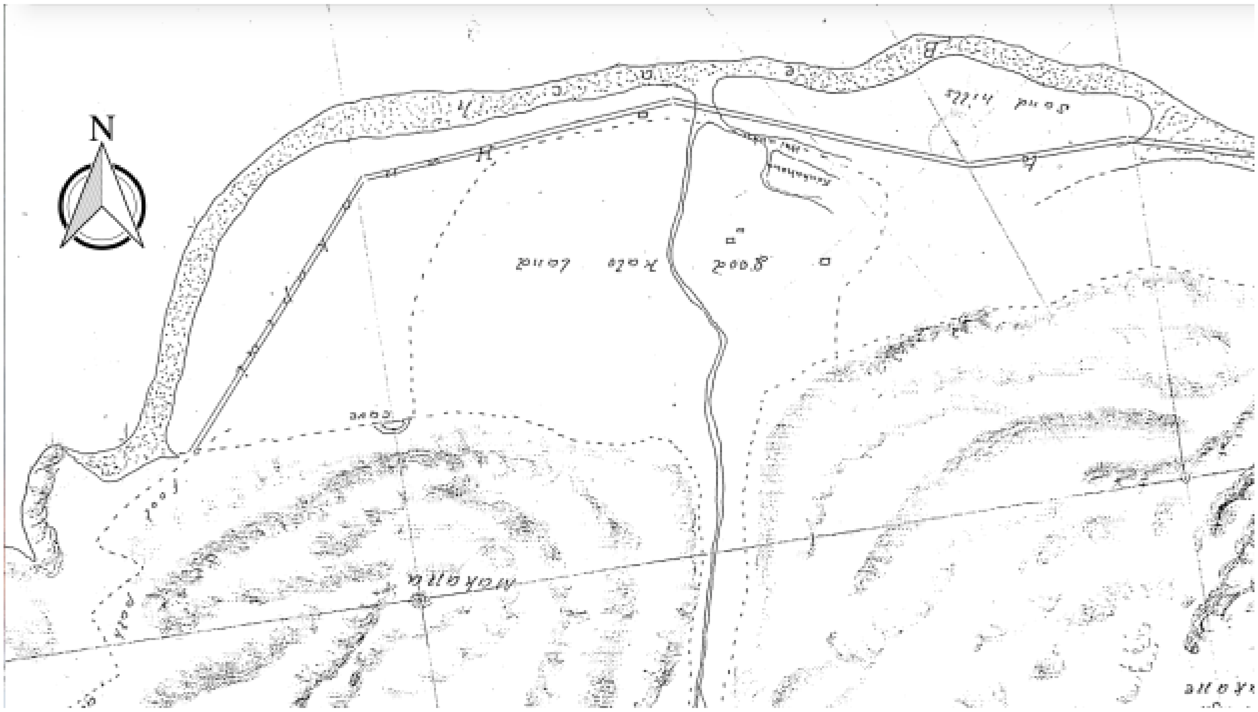
Time Period 2 (T_2)- Purchase of Hāʻena by Hui Kuʻai ʻĀina o Hāʻena in 1875

The introduction of land privatization (S1, S5) required the implementation of new governance systems (S4) inevitably disrupting political stability (S3). After land privatization the informal boundaries of many *ahupuaʻa* became etched in print for the first time (RS2). *Hāʻena*'s boundaries (RS1) lined up with the traditional informal understanding (RS3). Originally land was given to a ruling chief, Abner Pākī. After his death, the land was sold twice to people who were not native to or residing in the area (GS4). After 25 years, 38 native families pooled their money to obtain the ownership rights (I5).

The change in property-rights systems (GS4) drove a change to the network (GS3) between the ruling class (*aliʻi*) (GS1) and the resource system users (*makaʻāinana*) (GS2) by removing the role of the land manager (*konohiki*). The change in property-rights (GS4) was driven by the agreement of the Kingdom of *Hawaiʻi* to privatize land. This led to a change in constitutional rules (GS7), which severed the *konohiki* right to the labor of *makaʻāinana* (RS6, GS3, I2). This altered the social and ecological equilibrium (RS6) since many human-constructed facilities such as flooded agricultural patches and ditches required the building of social capital (A6) in order to orchestrate the human capital (RS5, RS7).

A decade after this purchase ranching on the north shore of *Kauaʻi* had been established. George and Julius Titcomb were listed in an 1892 directory (Polk 1892) respectively as a 'stockraiser' and 'rancher.' Mahuiki and Company grew commercial taro within *Hāʻena* (S5) (Polk 1880). This increased subtractability of the land for ranching and agriculture. Additionally, some missionary families had built homes in the area (Rice 2012). Figure 12 is a map made one year before the *hui* formally purchased the *ahupuaʻa*. The map outlines the outlet of *Limahuli* stream and the surrounding *kalo* land which is currently under curatorship by the descendants of *Hui Kuʻai ʻĀina o Hāʻena*, *Hui Makaʻāinana o Makana*. This group has an agreement with the State of Hawaii Department of Land and Natural Resources (DLNR) to restore cultural features within *Hāʻena* State park.

Figure 12. 1871 Map of Alluvial Plain fed by Surrounding *Limahuli* Stream



This is a zoomed in portion of an Hāʻena coastline map. It has been rotated 180 degrees. James N. Gay completed it on October 10, 1871.

Appropriation action situation: Without the direction of a *konohiki* (A5) previous communal gathering efforts needed to stay intact without the formal appointment of a land manager. Collective-choice (GS6) rules were developed and maintained without formal constitutional rules (GS8). To do this the 38 families took collective action and created an institutional entity, *Hui Kuʻai ʻĀina o Hāʻena* (The Association to Buy the Land of *Hāʻena*) (GS2). Their motivation was to maintain the abundant resources they were accustomed to from their communal management efforts (O2). Communal caretaking also provided the reassurance of a social network (GS3) that securitizes food and familial connections (O1). Land still remained open and undivided. Fences were built to keep cows out of homes and agricultural patches, versus creating corrals (Andrade 2008) (RS2). However, between 1900 and 1940 residents stopped listing farming and fishing as occupations (US Census 2016).

Institutional response to appropriation action situation: The *hui* pooled their money (I7) and created new operational rules (GS5) or bylaws to maintain the way of life they led under the previous property-rights system (GS4). Deliberation processes (I3) were endured to create the operational rules (GS5), appoint leadership (A5) that maintained human-constructed facilities (RS4), and share information (I2) to maintain the network structure (GS3) required for large subsistence food-gathering efforts (I1, I7).

Provisioning action situation: The tenants of the land needed to continue monitoring (I9) and evaluating (I10) the health of the ecosystem, so they could continue to depend on the *ahupuaʻa* (RS1) as an entire system (A8). Without appointment of a *konohiki*, leadership would need to be collectively decided (A5). The law and Territorial Government replaced the relationship between the *aliʻi* and *makaʻāinana* that was created through the *konohiki* (I3). People were left without a direct connection to constitutional rule makers (GS7) (Howes and Osorio 2010).

Institutional response to provisioning action situation: Members of the *hui* had to find a new way to synthesize and share ecological information among the group (GS3, I8) as well as deliberate collective processes (I3), and internal conflicts (I4). The *hui* also needed to pass on the knowledge (I2) of how to maintain the ecosystem as a whole, and why it is valuable to do so.

Time Period 3 (T_3)- Aftermath of 1946 and 1957 Aleutian tsunamis

The *ahupuaʻa* of *Hāʻena* (RS1) was once a singular resource unit that functioned as a whole system. Slowly it was being divided by competing land uses (RU3) such as agriculture, ranching, and housing. The boundaries within the system were informal (RS2), but gaining economic value because of new relevant actors (RU4). Some actors had the money to buy food and land they did not manage (A2). Other actors not native to *Hawaiʻi* now practiced subsistence gathering (A1).

Major changes to the social, economic and political settings (S) triggered changes to the governance systems (GS) and actors (A). People were now dependent on an economic system based on financial capital. Money was required to pay taxes and buy certain goods required to participate in the modern economy (S5). Local infrastructure jobs such as park ranger, local power plant worker, or road construction were available (A2). As world wars ignited globalization (S3), people began to seek educational and employment opportunity in more metropolitan areas or through the military. Less people had less time to care for the land in the way it had traditionally been done (A1).

The 1946 Aleutian Tsunami marks the oldest extreme climate event in the living memory of people from *Hāʻena* (ECO). Another major tsunami happened 11 years later in 1957. The agricultural infrastructure (RS4) required social and human capital to repair the productivity of the system (RS5). People were leaving in response to the greater social, economic, and political settings (S). The burden of these extreme climate events tested the strength of the *hui*'s (GS2) network structure (GS3).

Appropriation action situation: Communal gathering activities were still conducted, but not to the same degree (RS5) since many people moved away and new residents from foreign countries such as Japan, China, and the Philippines were settling in the area (S2, A1, A2). These people began building homes (RS4) and also fishing and gathering for subsistence. This increased the monetary value of the land because of competing uses that were not necessarily congruent with the ecosystem. Additionally, two big tsunamis swept through the area. Large amounts of communal labor were required to rebuild the natural functions of the land. Many agricultural and cultural features were lost (RS4, A8). Also less native families existed in the place and gathered natural resources (A2). This meant there were less people participating in the labor-intensive activities previously orchestrated by the *konohiki* (A1).

Institutional response to appropriation action situation: As people left, they had the option to sell their shares to people outside the original 38 families who purchased the land in 1872 (RU4, I5). Additionally, as people from the original families died, their portions were divided into fractional shares sometimes amongst family members who did not communicate or know each other (I8, GS3). The intergenerational knowledge about where and when to extract natural resources was not being passed on as often (GS8, A8). By the early 1900s (Pilsbry 1917) ecological scientists entered the social-ecological system by publishing scientific studies about this area.

Provisioning action situation: The voice of a strong leader (A5) to justify previous communal caretaking and harvesting practices (I1, I7) was not present at this time. By 1955 a new actor, John G. Allerton from Monticello, Illinois was a major shareholder. He was able to organize (I7) enough shareholders to advocate (I6) for legal partitioning of land into private parcels each with their own commercial value.

Institutional response to provisioning action situation: The new government never created an entity like the *konohiki* to locally manage the land and orchestrate capital (A5). The relationship between the tenants (*maka'āinana*) and the land (*'āina*) suffered without a replacement for the *konohiki*. With the government under transition natural resource management was not a priority (GS1, GS7), since the sale of land also meant additional property taxes for the State (RU4, GS4).

Time Period 4 (T_4)- Land Partitioning Process from 1955 to 1967

The 12-year partitioning deliberation (I3) highlights the overall change in socioeconomic attributes (A2) and lack of importance of the overall natural resource system to newer actors (A1). The resource system, once a singular unit, was divided into 153 lots (RU5). The privatization of smaller-sized plots (GS4) increased the economic value of each unit (RU3) allowing for newer resident actors to maximize their benefit at the expense of access for previous actors. People could now increase the market value of their land by building homes and managing their own private spaces (RS4). An increase in market value also meant that the State government would receive higher property taxes. This ended the communal caretaking that brought about the former productivity (RS5), equilibrium (RS6), and predictability (RS7) of the system. Native families, subsistence gatherers, and ranchers formerly depended (A3) upon this system.

Appropriation action situation: Land has now become the most sought-after benefit from *Hā'ena* (RU1). Shareholders were demanding that land be partitioned so it could be monetized and sold (RU4). With the departure of so many native Hawaiian families the existence of an intact social-ecological system was no longer a priority (A8). The overharvesting of fish was not yet a concern (RS5), but access to the irrigation ditches that maintained flooded agricultural patches was no longer available (RS6). This essentially halted the dependence on taro grown within the *ahupua'a* (RS5). As land became divided cows were being fenced and contained

(RS4). A public well in *Mānoa* Valley was created to deliver fresh water (A3) as demand for housing started.

Institutional response to appropriation action situation: The creation of fee simple plots greatly compromised the ecosystem functions produced by the resource system as a whole. The lack of access to take care of the system as a whole impinged upon the reciprocal familial relationship people had with the land (A6, GS5, GS8). Subsistence gathering was supposedly protected by constitutional rules (GS7), but, in reality, lack of customary access to the functions of the whole ecosystem affected how taro was grown and what plants could be obtained.

Provisioning action situation: The institutional role of the *hui* to organize capital for overall social and ecological benefit was replaced by fee simple land ownership. This system favored monetized housing and individual plots over natural ecological functions (A8). Without leadership (A5) there was no one to guardian the overall ecosystem functions of the land. Owners of *Hāʻena* were now uncoordinated actors who felt it was easier to operate independently (RU3) without an overall strategy for the resource system.

Institutional response to provisioning action situation: Some native families and long-time residents still valued the resource system as a whole. Juliet Wichman became the owner of the largest continuous tract. It contained most of *Limahuli* valley inland of the coastal alluvial plain. In the interest of the land she removed all the cattle and began to construct a garden resembling the landscape before invasive plants and animals altered the ecosystem (RS4). Now that land was formally privatized and recognized by the real property tax office, it was easier for residents and native Hawaiian families to obtain monetary benefits from *Hāʻena*. The government was able to collect more taxes under this system since estranged *hui* shareholders were delinquent on tax obligations. Individual plots increased the overall monetary value of the area. The hope is that higher taxes would lead to improved caretaking on the government's part, but the extra tax revenue was not directed towards those efforts.

Time Period 5 (T_5)- Creation of Hāʻena State park in 1977

The *ahupuaʻa* as a resource system was almost unrecognizable at this point. More people were interested in the market value of sectioned plots, than on the value of the resource system's ecological productivity as a whole.

In 1968, a United States citizen named Howard Taylor, allowed transients to live on his plot of land (A1). This plot was of little use to him because the State would not approve permits for him to build a structure on the ground. The State of Hawaii claimed that the land was zoned for conservation, and it had plans to build a State park on that land. In protest Taylor told transients to live there in tree houses off the ground (A2). The camp lasted for almost a decade. It became known as a refuge for the civil unrest sparked by social injustices on American soil and around the world. Taylor Camp was known for its collective-choice rules that promoted a utopian society free from oppressive rules (A6).

Long-time residents who were not necessarily native to *Hawaiʻi* began participating in policy-making on behalf of their interests in the community. These actors were driven by future community development, versus maintenance of a familial relationship with the land (A2). This group of people understood the policy process, and advocated for the end of Taylor Camp.

Ranchers were no longer a considerable actor group because Juliet Wichman removed cattle from her large tract, and remaining cattle and horses were secluded to ranch land in the eastern third of the *ahupuaʻa.* The Robinson family owned the majority of this area.

Appropriation action situation: The camp sat on top of what were fertile agricultural patches that formally fed the whole resource system. This area was being documented at the time by researchers (Earle 1978), but never recognized by the new residents as something to revive or maintain (A8). Archeological evidence taken after the end of Taylor Camp shows a dependency on store bought goods by residents of the camp (Riley 1979). Houses became the stock of concern, instead of fish and cows. The ability to provide financial capital for outside investors was the most desired benefit (A8).

Institutional response to appropriation action situation: Ultimately in 1977, the State formally evicted the inhabitants at "Taylor Camp" by torching the area and creating the modern day *Hāʻena* State park. The State installed a well in 1966 that provided public water supply to individual plots. This promoted the building of residential structures.

Provisioning action situation: The creation of the State park now signaled a true change in services provided by the ecosystem. Food provisioning, as a benefit, was overshadowed by recreation and financial gain. Holistic ecosystem based management was no longer being practiced by this new set of actors (A6).

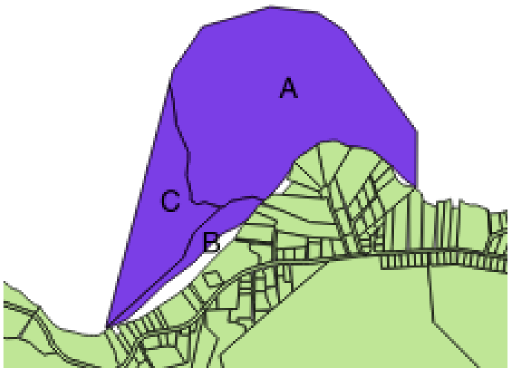
Institutional response to provisioning action situation: The State justified creation of the State park as a way to maintain and provide access to important cultural resources such as the *hula* grounds, caves, and previous agricultural features (A8). The park provides other resources such as lifeguards, public restrooms, and showers. The public sewage and water infrastructure has an unmeasured impact on ecological resources (A7).

Time Period 6 (T_6)- Rise of Tourism and Coastal Development through the 1980s and 1990s

The *ahupuaʻa* resource system of *Hāʻena* could not be maintained across multiple private lots (A3, RS5, RS6, RS7, RS8). New actors from across the globe were attracted by stories of "Taylor Camp" (A1, A2) and remote vacation homes. These new actors had different relationships with the environment that did not require holistic ecosystem based management (A7, A8). Individual plots were clearly defined (RS2), which promoted the construction of vacation homes for temporary residents and commercial rental units (RS4).

During this time the State provided constitutional rules (GS7) regarding recreational boat use around a large reef named *Makua*, which means 'parent' in Hawaiian *("Nā Puke Wehewehe ʻŌlelo Hawaiʻi*" 2017) (RU6) (See Figure 13). An ecosystem service is the direct and indirect benefit ecosystems contribute to human well-being (TEEB 2017). The shift in ecosystem services from food provisioning to recreation was clear and confirmed through constitutional rules (GS7). This type of near shore legislation was a stark contrast from the way Hawaiians cared for and distributed their surrounding natural resources.

Figure 13. HAR §13-256-40 (1988) Hāʻena Ocean Waters

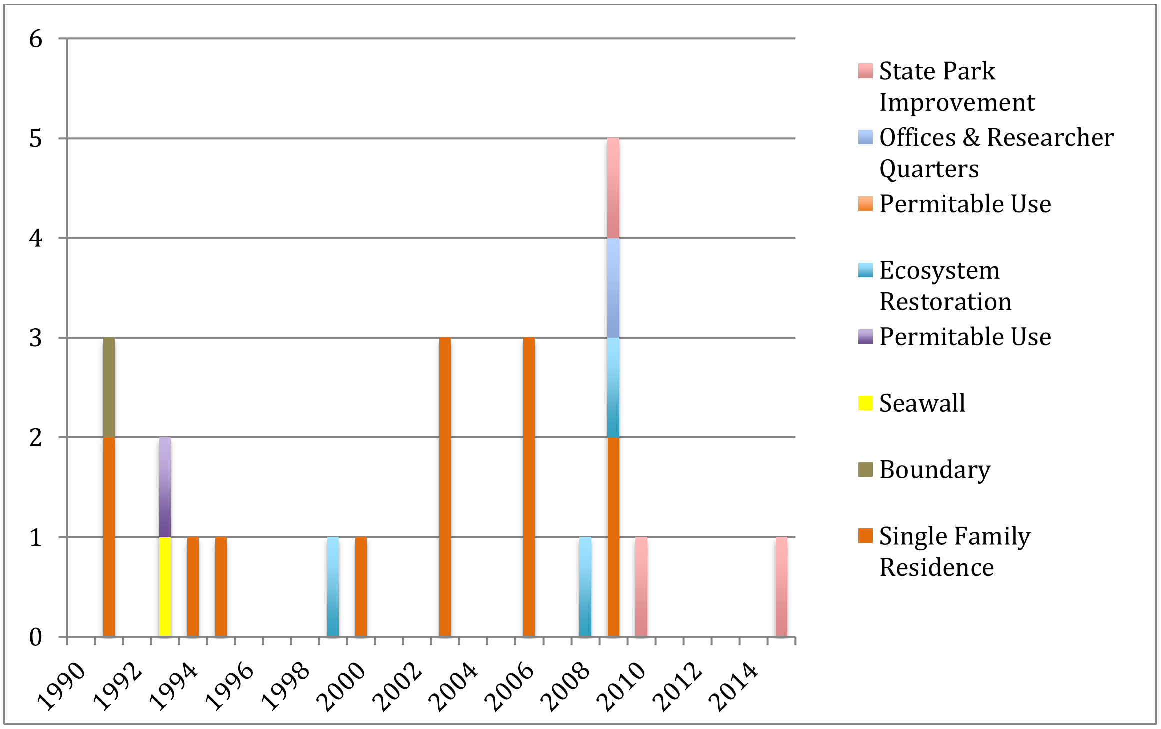


The purple area is Makua reef. The green area are the TMK plots on land. Zone A and B are designated for snorkeling or scuba diving recreational use, no commercial motorized vehicles are allowed in Zone A and B. Zone C is designated for the use of motorized vessels that were confined to 3 mooring buoys along the outer edge of the inner reef. Anchoring was only allowed during daytime hours.

Appropriation action situation: The government did not know the importance of subsistence fishing to native families (Takeuchi 1975). Food provisioning was no longer a major benefit sought by actors across the SES. Rules were centered on real estate. The new property-rights system (GS4) favored building as it increased tax revenue. Vacation homes were built on land formerly used for agriculture. The needs of residents and repeat users overshadowed those of fishers, subsistence gatherers, and native Hawaiian families.

Institutional response to appropriation action situation: Temporary residents and plots with commercial rentals are taxed higher creating more revenue for governments (A2). The first Environmental Impact Statements (EISs) that justified the building of homes started in the early 1990s (Figure 14).

Figure 14. Environmental Impact Statements Per Year



The y-axis represents the number of environmental impact statements filed that year. EIS do not necessarily indicate development, but verify the desire to alter the landscape. There were no EIS filed for building within Hāʻena boundaries before 1991.

Provisioning action situation:

The majority of EIS statements in *Hāʻena* were for single-family residences. One of the first EIS statements was for shifting boundaries. The importance of delineated boundaries points to a shift away from holistic ecosystem management. Constitutional rules also did not account for natural phenomena such as sea level rise and tsunami history. As you can see in Figure 15 coastal development is allowed within the tsunami evacuation zone.

Figure 15. 1946 Tsunami Heights and Current Tsunami Evacuation Zone

The numbers represent the height of the highest wave at the shoreline measured above sea level at the time of the tsunami for those locations during the 1946 Aleutian Tsunami (Loomis 1976).

Institutional response to appropriation action situation: EIS statements are still filed to justify development and loss of the view plain. Non-native vegetation created privacy for new homes, but insidiously took away the open view over the coastal alluvial plain. Repeat users are welcomed and encouraged to visit cultural areas now contained within the State park. Coastal home construction is permitted near marine spawning areas (Friedlander 2011, Friedlander et al. 2013). Additionally a seawall contributes to erosion (Fletcher et al. 1997).

Time Period 7 (T_7)- Formation of Hui Makaʻāinana o Makana in 1998

By creating the garden, Juliet Wichman preserved a sense of how productive the system (RS5) could be and what the place looked like when people lived as companions of the land (RS6). They revived *loʻi* (RS8) and the irrigation network (*ʻauwai*) (RS4) being taken over by invasive species. The large tract of land combined with industrious caretaking (A5) kept functions of the ecosystem alive for future generations to know (I2). The caretakers of the garden are perpetuating knowledge by documenting long-term cyclical changes in the ecosystem. The garden and preserve attract researchers from a variety of social and ecological fields. The institution of *Limahuli* Garden and Preserve has become the collectors, disseminators, and keepers of this knowledge created by this place (I2). In conjunction with *Hui Makaʻāinana o Makana*, *Limahuli* Garden and Preserve are fulfilling the information sharing (I2), leadership (A5), and social capital creation (A6) capacities found in a *konohiki*.

This is in contrast (RU3) to the adjacent *Mānoa* valley, which is another large continuous tract of land with a single owner. No major development or physically altering management has taken place. The current owner is the second occupier since land partitioning in 1966. The publically listed owner lives on the continental United States. Owners of this plot have the same ability to transform the land and revive previous natural functions as Juliet Wichman. The area is known to be abundant with edible plants. Also, it once provided access to the upper parts of the *ahupuaʻa* where bird-catching took place.

The creation of separate parcels eventually led to the formation of the State park (RS2). It was the gateway for new repeat users such as vacation homeowners and other tourists who would come once or return many times (RS9). It was also a gateway for descendants of the 38 families who legally purchased *Hāʻena* in 1875 voice their disappointment in the condition of sacred places the State claimed they would protect.

Appropriation action situation: Native Hawaiian Families reclaimed their relationship with the land through their access to *loʻi* in the State park.

Institutional response to appropriation action situation: Descendants of *Hui Kūʻai ʻĀina o Hāʻena* members formed a 501(c)(3) called *Hui Makaʻāinana o Makana*. They created this formal institution in order to approach the State about forming a curatorship to revive cultural features in the State park. They began with a few *loʻi*, which required the manual removal of many large invasive trees. Once they began maintaining this area and expanding their restoration efforts, they spread their efforts to the state of the near shore reef. Interviews of people native to the land discuss a decline in some marine species (Maly and Maly 2003). Once again, the *hui* self-organized (I7) and took leadership in creating a Community Based Subsistence Fishing Area (CBFSA) in *Hāʻena* which was eventually established in 2006. It took over a decade from that point for them to identify and negotiate with relevant actors (A1) to create operational rules (GS5) within the boundaries of the CBFSA (Ayers and Kittinger 2014). As more CBFSA go through this process, adminstrative rules (GS7) for creating operational and collective rules will emerge. As these rules are tested, monitoring, and sanctioning schemas should be developed and adapted per location.

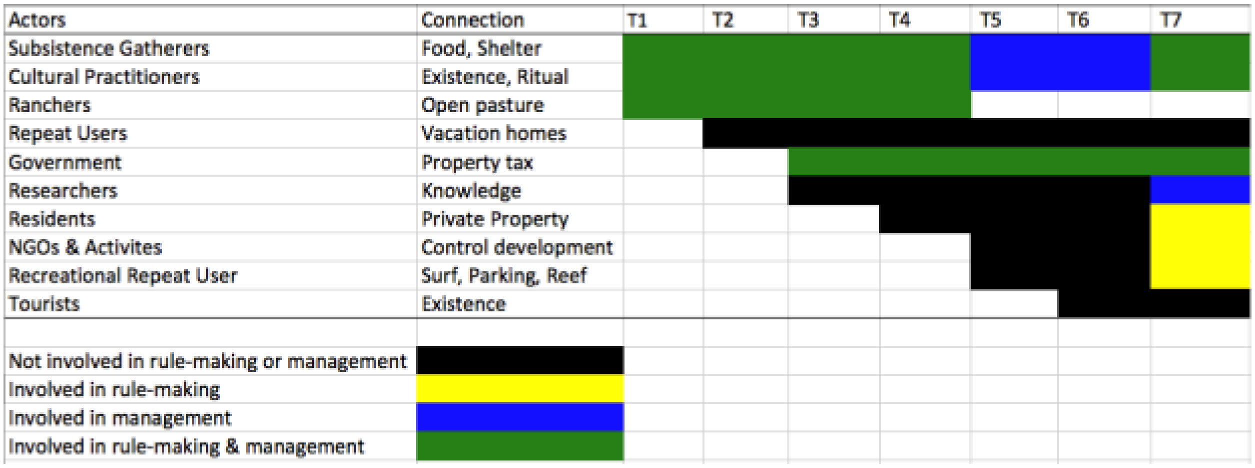
Provisioning action situation: The staff of *Limahuli* Garden & Preserve work in cooperation with *Hui Makaʻāinana o Makana*, other community activists, and repeat users to share information (I2) that improves the overall function of the *ahupuaʻa*. The Department of Land and Natural Resources creates rules that cannot yet straddle both marine and terrestrial ecosystems. However, as the *hui* works with the state to co-manage natural resources the people who care for *Hāʻena* are exemplifying how natural it is to consider the dynamics of ecosystems as a whole. By re-establishing their relationship with the land they hope to teach others how to interact with the place in a respectful way that perpetuates abundance (I2).

Institutional response to appropriation action situation: The policy efforts of *Hui Makaʻāinana o Makana* mark the revival of the connection between the tenants of the land (*makaʻāinana*) and governing powers. Co-management requires an adaptable policy space that adjusts based on feedback from implementing different policies. This feedback can be based on information from monitoring (I9) and evaluating (I10) programs. It is a process that requires a long time and lots of patience (Vaughan and Ayers 2016, Vaughan et al. 2017).

2.2.3.2 Nested actors

One goal of this research is to identify the actors that need to be considered or included in the caretaking and rulemaking processes. To be inclusive of all actors, this analysis considered interactions where users indirectly benefit from the state of a resource system without extracting from a stock of goods. **Error! Reference source not found.** summarizes the actors identified per t ime period. Each group is defined by their connection to *Hāʻena*. The participation of each actor group in rule making and management is color-coded per time period. All actors connected to the place should be considered in the creation and enforcement of the rules. The actors with the longest institutional experience should especially be considered for their knowledge of ecosystem function.

Table 4. Actor group participation and time period introduction



Rulemaking refers to direct involvement with local management. Management refers to caretaking of natural resources. Open pasture is empty for periods T5, T6, and T7 because it is no longer an available benefit due to dense residential development.

The diagnostic procedure provided in Hinkel et al. (2015) (See Table 1) was applied over time to the resource system of *Hāʻena*. As questions were answered the SES Framework variables (Figure 7) were noted and analyzed for change over time. With the resource system (RS) fixed on the *ahupuaʻa* of *Hāʻena* we can see the target outcome (O) of resource abundance change as the social, economic and political settings (S) unfold and the governance systems (GS) and actors (A) change through different interactions (I). This procedure defines the community during each time period by their connection to *Hāʻena*. Identifying each actor group's connection is important for creating inclusive rules that match their dependency on the place. The time periods represented in the top row of **Error! Reference source not found.** by T1, T2, etc., c orrespond with the time periods defined in Table 3. Time periods are filled in according to when each actor group entered the system. The colors represent each actor group's role in rule making and/or management during that time period. This is one way to examine the diversity of spatial and governance levels. This hindsight perspective also allows for assessment of outcomes for each 'focal action situation' represented in each time period. In Time Periods 5 and 6, subsistence gatherers and cultural practitioners were excluded from rulemaking after land partitioning unless they were landowners. The separation of these groups from the land coincided with dramatic shifts in natural resource use and caretaking. These shifts were described in the time period analyses above. **Error! Reference source not found.** shows the number of actor g roups that are now included in the system. The most recent time period shows the inclusion of more actors in the rulemaking process.

Teasing out the actors by operationalizing the SES Framework allows systematic consideration of institutional rules for all actors according to the IAD Framework (Ostrom 2005, Ostrom 2011). Policy deficiencies can be found when a rule-in-use is not found or enforced for a particular actor group or position (Ostrom 2005). Each actor group defined in this research can be considered a position with position rules. Boundary rules define the actors, and the choice rules they create bind their actions. The combination of their actions is dictated by the information rules, payoff rules, and control over a situation (aggregation rules). These situations are bound by the scope rules for each position and every resource system contains multiple positions interacting (Ostrom 2005, Ostrom 2011). (See Figure 9)

Identifying all actor groups and their benefits also helps in creating rules that are congruent for each actor and would lead to a collective-choice arrangement (Ostrom 1990). Including important actors in the early stages of rulemaking allows all parties to be represented in the process of creating institutions and policies (Vaughan and Caldwell 2015). Appropriate monitoring can be defined by who needs to know the information for provisioning purposes and who is benefitting. Knowing benefits allows for effective setting of sanctions that can be graduated as actors break rules multiple times. Also, providing a low-cost dispute resolution mechanism becomes easier when the network of actors and their relationship to the governance system is understood. Additionally, recognition by the governance system of all appropriators and their right to self-organize is in itself a design principle for successful common pool resource management (Ostrom 1990). Lastly, sustainable management for common-pool resources requires nested enterprises meaning responsibilities regarding appropriation, provisioning, monitoring, enforcement, conflict resolution, and governance is organized in multiple layers across entities with jurisdiction over various scales.

Involving multiple actor groups allows for redundancy of responsibilities. Diversity, redundancy, and modularity of a social-ecological system can enhance robustness and adaptive capacity (Anderies and Janssen 2013). Robustness refers to the system's capacity to suffer a disturbance and still function without losing its basic structural or functional integrity (McGinnis 2011). Adaptive capacity refers to the ability to change processes based on changes to the environment. This integrity of social and ecological system structure results from institutional memory and shared values within and across enterprises (Folke 2007; Berkes, Colding, and Folke 2000). When actors and institutions incorporate lessons from previous management transitions, they can adjust policy towards shared long-term goals. Operationalization of the most up-to-date SES Framework (McGinnis and Ostrom 2014) in this section uncovered 'nested focal action situations,' and the breadth of possible actor stakeholders in current common pool natural resource issues. Nested actors and the corresponding resource units from which they benefit are illuminated in each 'nested focal action situation,' through a list of diagnostic questions (Hinkel et al. 2015). The next section will cover how the MTF was used to examine the resource system and take a finer look at the nested governance systems.

2.3 Management Transition Framework

2.3.1 Introduction

The newest evolution of the IAD framework (McGinnis and Ostrom 2011) is the Management Transition Framework (Pahl-Wostl et al. 2010). It was designed to adaptively improve water governance regimes. It emphasizes considering not only the actors and outcomes of each situation, but the spatial level and policy phase as well. It is also helpful when considering if action situations are leading to more interactions across actors and domains[1].

The MTF digs deeper into the IAD framework's notion that outcomes feedback into subsequent action situations by integrating the concept of social learning. The Management Transition Framework was developed in the context of social learning for improving water management (Pahl-Wostl and Kranz 2010; Brown et al. 2009). Social learning is the theory that social change occurs by people observing each other in ways that benefits wider social-ecological systems (Reed et al. 2010). It is also sometimes referred to as triple-loop learning (Hargrove 2008). It is the result of adaptive shadow networks (Berkes 2009, Institute and Assessment 2006) and bridging organizations (Vaughan and Caldwell 2015) that temporarily act to bring together unconnected networks or create and manage capacity across groups. These network catalyzers improve processes and behaviors, which is single-loop learning. Eventually these innovations lead to double-loop learning, which reframes societal thinking and assumptions. This change in the way society thinks will ideally snowball and create a paradigm shift for social-ecological systems (Pahl-Wostl 2009).

Figure 16 models how the MTF tracks spatial scale (y-axis) of related 'focal action situations' over time through different policy phases (x-axis). The path of the blue dots in Figure

[1] The term domain refers to the spatial or governance levels included in the analysis. The state level, water catchment basin level, or at the plot level are examples of domains.

Figure 16 shows the implementation of a top-down policy being pushed to more local levels for implementation. This figure illustrates that feedback is given while measurements are being decided, which briefly set back social learning (the green dots). Eventually social learning catches up to policy, which is then instituted at a more local level where it is confirmed for external adoption at broader scales. These types of cross-domain interactions indicate a strengthening of cooperation across actors and social networks. Along with this cooperation comes social capital (Burt 2000). McGinnis (2011a, p. 176) defines social capital as, "resources that an individual can draw upon in terms of relying on others to provide support or assistance in times of need;" or "a group's aggregate supply of potential assistance, as generated by stable networks of important interactions among members of that community."

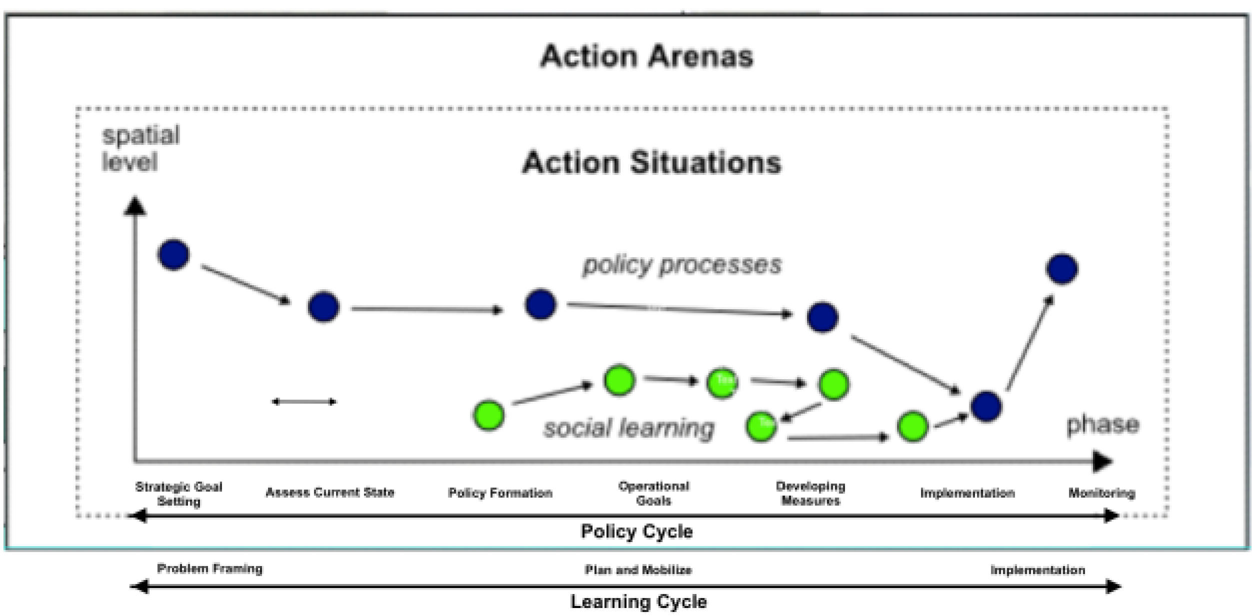
At a certain point knowledge is adopted as principle, informal institutions are formed, and goals are aligned to create formal institutions through policy. This is the path of the policy cycle, which is not always linear. However, it is presented this way in the MTF as an analytical tool as opposed to a normative path (Pahl-Wostl et al. 2010). Soon processes and behaviors are taught and improved to the level that aligned goals have become intrinsic in societal thinking. Collectively people define the goal to the point where progress can be measured and monitored. Eventually this monitoring process and way of understanding the system becomes the paradigm for how people interact with the each other and their shared habitat. The learning process is not smooth and linear either. This is exemplified by the directional shift in the path of green dots in Figure 16. It takes a lot of time and social persistence to prove and substantiate knowledge. Institutions must adapt and stay resilient.

An *ahupuaʻa* is an ideal social-ecological system to observe historically overtime. The social-ecological system paradigm of the *ahapuaʻa* required generations of continuous monitoring and adaptation (Beamer 2005). As shown in the previous section the introduction of new actors and governance systems instigated transformative social change that spun new policy and learning cycles for all actors in the system. The spectrum of these looped policy and social learning cycles is visualized at the bottom of Figure 16. Collective understanding moves from transforming peoples shared visions of common pool natural resource use to sustaining a system that is monitored adaptively. The system is sustained because knowledge is transferred accordingly and continuously to successive caretakers.

A key component to creating collective understanding and functionality as a community was the *konohiki*. This natural resource director is a social construct unique to the pre-Western governance of Hawaiʻi (Earle 1978) that was described in more depth in in Section 2.1.2. This person brokered interactions across the social-ecological system of an *ahupuaʻa*. Even the etomology of the word *konohiki* (*kono*, to entice, and *hiki*, possibility (Andrade 2008)) implies that the purpose of this role was to entice possibility by linking actors and family networks within the *ahupuaʻa*. This was mainly done through information sharing. The *konohiki* acted as an intermediary that vetted the information to create a shared understanding for how the ecosystem is cared for and how it is shared socially.

Social-ecological systems will always undergo flux and adaptation brought about by social or ecological changes. However, caretaking of essential common pool resources, like fresh water, can be sustained through continuous monitoring, adaptation, and knowledge transfer. This is the essence of sustainable natural resource practices. Perpetuation of these practices determines how humans co-evolve with the environment. Examining these prior natural resource practices can point to human uses that have positive ecological and social outcomes. Creation of this shared understanding of prior human-environmental interactions re-opens practices, such as *loʻi*, *loko,* and *ʻauwai* maintenance, as possible shared desired outcomes.

Figure 16. Management Transition Framework



Recreated after Pahl-Wostl (2015)

2.3.2 Operationalizing the Management Transition Methodology

To operationalize this framework each observation plotted on the timeline in Figure 11 was linked to other related events. This created another clustering of the observations. Clustering or linking the observations in this way did not create multiple networks of linked events. The collected events fell into storylines or concurrent sub-plots to the history of the social-ecological system. These sub-plots correspond to fresh water resource management units that underwent stable and transitional human-environmental interactions. The results table presented in the next section is structured into six different resource management unit sub-plots. For each resource management unit, the current state is established based on the most recent observations collected to create the chronological outline. Some previously sustained human-environment relationships were identified for each resource management unit. Finally, a selection of transitional action situations is listed for each resource management unit sub-plot. To describe the current state, previously sustained relationships, transitional focal action situations, the action situation's outcome type, policy phase, learning phase, and major governance actors are described. The categorical definitions for outcome type, policy phase, and learning phase can be found in Pahl-Wostl et al. (2010) and are represented at the bottom of Figure 16. To analyze this table patterns were sought within resource management unit sub-plots and then across sub-plots.

2.3.3 Results of Management Transition Framework Application

This inductive methodology allowed for linked observations in six cohesive sub-plots of *Hā'ena*'s history. Each sub-plot is centered on an area where fresh water is managed:

1) *Limahuli* Valley
2) *Mānoa* Valley
3) Streams
4) Alluvial Plain (State park)
5) Coastline
6) The Aquifer (fresh water storage)

Table 5. Resource Management Units that Emerged from MTF Application

Resource Management Units	Current State & Phase	Outcome	Policy Phase	Learning Phase	Major Governance Actors	Previously Sustained	Diminished	Outcome Type	Policy Phase	Learning Phase	*Major Governance	Year	Transitional Action	Outcome	Policy Phase	Learning Phase	Major Governance Actors
Limahuli Valley	Set goal to bring people back to the forest	Institution	Assess Current State	Plan & Mobilize	State (DLNR), Institutional Landowner (NTBG), Research	Caught *ʻUaʻu* in Upland Forests	Bird species now endangered	Knowledge	Monitoring	Monitoring	Community of Caretakers	1800s	Cattle	Institution	Monitoring	Implement & Evaluate	Kingdom, Island, Resource Manager (Konohiki), Community of Caretakers =>
						Hala after cleared	Greatly diminished	Institution	Monitoring	Monitoring	Community of Caretakers	1967	Juliet Wichman removed cattle	Operational Outcome	Implementation	Implement & Evaluate	Private Landowner
						Human dependence on forest resources	Greatly diminished	Knowledge	Monitoring	Monitoring	Resource Manager (*Konohiki*), Community of Caretakers => Private Landowner => State (DLNR), Institutional Landowner (NTBG)	1976	NTBG	Institution	Implementation	Implement & Evaluate	Institutional Landowners (NTBG)
												1998	Loʻi revival	Operational Outcome	Implementation	Implement & Evaluate	Institutional Landowners (NTBG)
												1995	Public garden tours	Knowledge	Implementation	Implement & Evaluate	Institutional Landowners (NTBG)
												2010	Upper preserve fenced & monitored	Operational Outcome	Implementation	Implement & Evaluate	Institutional Landowners (NTBG)
Mānoa Valley	New Ownership (Barry)	Institution	Assess Current State	Problem Framing	Private Landowner	Menehune gardens	Slow overgrowth/Lack of use	Knowledge	Monitoring	Monitoring	Community of Caretakers	1967	Robinson ownership	Institution	Monitoring	Implement & Evaluate	Private Landowner
Streams	Native Species Index	Knowledge	Assess Current State	Plan & Mobilize	State (DLNR), Institutional Landowner (NTBG), Research	Continuous flow	Slow overgrowth of *hau*/Lack of use	Operational Outcome	Monitoring	Monitoring	Resource Manager (*Konohiki*), Community of Caretakers => Private Landowner => State (DLNR), Institutional Landowner (NTBG)	1973	Decreased ʻoʻopu harvesting	Knowledge (Loss of)	Lack of Policy	Loss of Intergenerational Knowledge Transfer	Community of Caretakers
	Change in hydrological flow with riparian overgrowth (*hau*)	Knowledge	Operational Goals	Plan & Mobilize	State (DLNR), Institutional Landowner (NTBG), Research	ʻOʻopu consumption	Greatly diminished	Knowledge	Monitoring	Monitoring	Resource Manager (*Konohiki*), Community of Caretakers => Private Landowner => State (DLNR), Institutional Landowner (NTBG)	1989	Extensive study of the stream	Knowledge	Assessing Current Situation	Problem Framing	Institutional Landowners (NTBG), Research, Community of Caretakers
												1999	Removal of *hau* overgrowth in *Limahuli* Stream	Knowledge	Implementation	Implement & Evaluate	Institutional Landowners (NTBG), Research, Community of Caretakers
Alluvial Plain (State Park)	State Park Management Plan	Institution	Policy Formation	Plan & Mobilize	State (DLNR), Community of Caretakers	*Loʻi Loko ʻAuwai*	1967	Operational Outcome	Monitoring	Monitoring	Community of Caretakers	1957	Tsunamis/Emigration	Operational Outcome	Lack of Policy	Loss of Intergenerational Knowledge Transfer	State, Landowners, Community of Caretakers
												1968	Taylor Camp	Institution	Lack of Policy	Loss of Intergenerational Knowledge Transfer	State, Landowners, Community of Caretakers
												1977	State Park	Institution	Implementation	Implement & Evaluate	State
												1990s	Loss of view plain because of trees and houses	Operational Outcome	Lack of Policy	Loss of Intergenerational Knowledge Transfer	State, Landowners
												1998	*Hāl* curatorship to restore cultural functions	Institution	Implementation	Plan & Mobilize	State, Community of Caretakers
												2010	New Restrooms	Operational Outcome	Implementation	Implement & Evaluate	State, Research, Community of Caretakers
Coastline	Community Based Subsistence Fishing Area	Institution	Developing Operational Goals & Measures	Plan & Mobilize	State (DLNR), Kauaʻi County, NGOs, Fishing Associations, Institutional Landowner (NTBG), Researchers, Residents, Community of Caretakers	*Konohiki* management	1848	Institution	Monitoring	Monitoring	Kingdom, Island, Resource Manager (*Konohiki*), Community of Caretakers => Kingdom, Foreign Business, Community of Caretakers	1848	Māhele	Institution	Implementation	Implement & Evaluate	Kingdom, Island, Resource Manager (Konohiki), Community of Caretakers => Kingdom, Foreign Business, Community of Caretakers
						Steady *Aukilau*	1980s	Knowledge	Monitoring	Monitoring	Community of Caretakers	1975	Subsistence fishing overlooked by County	Knowledge	Assessing Current Situation	Problem Framing	State (DLNR)
												1977	Tourism	Operational Outcome	Goal Setting	Plan & Mobilize	State, Private Businesses
												1988	Recreational zones (HAR §13-256-40 Haena Ocean Waters)	Institution	Implementation	Implement & Evaluate	State (DLNR)
												1990	Increased published marine studies	Operational Outcome	Assessing Current Situation	Problem Framing	Institutional Landowners (NTBG), Research, Community of Caretakers
Fresh Water Transport & Storage	Evidence of nitrification from effluent (Develeux 2017)	Knowledge	Assess Current State	Problem Framing	County (Board of Water Supply)	*Loʻi/Loko/ʻAuwai*	1967	Operational Outcome	Monitoring	Monitoring	Community of Caretakers	1966	Well	Operational Outcome	Implementation	Implement & Evaluate	County (Board of Water Supply), Residents
	Possible saltwater intrusion	Knowledge	Assess Current State	Problem Framing	County (Board of Water Supply)							1968	Cess Pools	Operational Outcome	Implementation	Implement & Evaluate	County (Board of Water Supply), Residents
												1989	Septic Tanks	Operational Outcome	Implementation	Implement & Evaluate	County (Board of Water Supply), Residents
												2012	Aerobic Tanks	Operational Outcome	Developing Measures	Implement & Evaluate	County (Board of Water Supply), Residents

2.3.3.1 Current States

Each fresh water management area sub-plot has a current state provided by the most recent documents discovered in the reinforced literature review. An institutional owner, The National Tropical Botanic Gardens, manages *Limahuli* Valley. They submit plans to the State of Hawaii to conduct large restoration projects on State zoned conservation lands. According to the current director of *Limahuli* Garden and Preserve, one of the main goals for future management is to bring people back into the forest to gather food and materials (Zelkovsky 2014). This goal allows management to have criteria for assessing the current state and creating a plan to establish access for resource users. The plant species that will be cared for must be of use to specific communities of people. NTBG already implemented operational outcomes to create a habitat for such species by installing two ungulate fences surrounding the valley.

Mānoa Valley is currently under private ownership. Development plans for this area are unknown until an environmental impact statement is filed for significant changes on State conservation land. Currently the owner has not framed any policy issue, nor have other actors in the resource system. The current state and maintenance of *Mānoa* Stream is unknown. The last Statewide assessment of streams was conducted in 1990 by the State Commission on Water Resource Management and the National Park Service. *Mānoa* stream was deemed 'satisfactory.'

More recent stream observations have been made about *Limahuli* Stream. A native species index of biological integrity for Hawaiian streams uses *Limahuli* Stream as a benchmark upon which to measure all other streams in the island chain (Kido 2013). This assessment of the current state provides a monitoring protocol that can also reintroduce human relationships with stream species that thrived in streams. These healthy streams fed areas of major food production. Chapter 4 will present results that point to human-environment relationships with the stream that can maintain purposeful flow of freshwater.

The State of Hawaii has proposed a management plan for *Hāʻena* State Park that limits car congestion, protects cultural sites, and educates visitors. Currently *Hui Makaʻāinana o Makana* is working to be an integral part of that planning as they continue their curatorship with DLNR to maintain cultural features. The management plan is meant to move policy formation forward as stakeholders plan and mobilize.

Hui Makaʻāinana o Makana has been instrumental in bridging policy that re-establishes the connections between the coastal plain and fringing reef. This institution is a driving force behind the Community Based Subsistence Fishing Area, and the work to establish appropriate monitoring protocol with the State. Social-ecological relationships are also being maintained through family *lawaiʻa* camps, passing on fishing practices appropriate for the area, and monitoring practices that perpetuate respect for natural environmental cycles.

The aquifer is its own fresh water management area that stores water transported for human consumption. This is a direct and controlled human-environment interaction not currently being monitored for responsive adaptation. Knowledge put forth by recent research points to possible nitrification from effluent discharge (Knee et al. 2008, Whittier and El-Kadi 2014, Develeux 2017). Chapter 4 of this dissertation provides results that point to possible impending saltwater intrusion of the aquifer. These knowledge outcomes assess the current state of the system and spotlight issues that should be investigated. From this assessment of the current state, operational goals and measurements can be agreed upon from which to formulate policy such as monitoring or creating incentives and regulations.

In general, establishing current states allows for feedback from known and unknown stakeholders who may bring forth new issues to consider. Establishing these current states can also help create a shared problem statement that disparate actor groups can address and move forward on. Problems may not be widely known or understood early in the policy and learning phases. In order to motivate policy and collective social learning, it is useful to have a shared understanding of how the current action situations developed and the shared desired outcomes.

2.3.3.2 Previously Sustained Human-Environment Interaction

Much insight is provided from knowing local legends and referencing interviews from elders (*kūpuna*). In particular, on human-environment interactions that sustained for a long time while perpetuating people and the habitat. In *Limahuli* Valley seabirds, specifically *ʻuaʻu* (*Pterodroma sandwichensis*), were often caught in the upland reaches of the valley. Learning the patterns of these upland nesting bird species must have required generations of observation that eventually turned into knowledge passed on to feed local dwellers. External forces helped to drive down the populations of these species to endangered levels. Understanding their required habitat and feeding patterns can point to other conditions for a healthy ecosystem.

Menehune were a race of people that resided in *Mānoa* Valley before the arrival of Hawaiians (Andrade 2008). They were known for making use of the fertile valley with gardens. The fragrant ‘*Moani*’ wind that escapes from this valley refers to the smell of rotting vegetation wafting out. When humans no longer interact with certain plant resources, overgrowth can change overall system function.

Overgrowth of riparian tree species can cause a blockage of stream flow. Chapter 4 will show a dramatic decrease in groundwater levels after a blockage was removed. When humans do not use forest species, especially riparian ones, there is overgrowth that creates a canopy over the stream. This change in available light changes the algae and in turn macrofaunal species in the stream (Sherwood and Kido 2002). People regularly ate *ʻoʻopu* from the stream, but this practice has greatly diminished due to internal and external drivers. Understanding conditions for previously consumed species and tracking their population can lead the way to healthier stream environments.

Prior to the installation of the well, fresh water was obtained from surface flow. At a certain point waste from people and animals was accumulating with other human-induced non-point source pollution. The well was built so clean water could be delivered to partitioned plots. The land was partitioned in a way so that irrigation ditches (*ʻauwai*) could not be easily accessed for clearing and maintenance. This prohibits surface water from filling *loʻi* and *loko*. The physical partitioning of the system disrupted the social-ecological relationship around maintaining *loʻi* and *loko*.

The coastline was a central stage for the *konohiki* of a coastal *ahupuaʻa*. This resource manager orchestrated impromptu community fishing efforts called *hukilau*. The endeavors required capable swimmers or people with boats to surround schooling pelagic fish that come close to shore. The *konohiki* would direct the trapping of the school from an elevated location called a *kilo* so activity in the water could be observed. From that vantage, he or she instructed dozens of people to pull the net full of fish back onshore. Living *kūpuna* can remember a time when their families did not have to individually fish because they could depend on consistent *hukilau* (Maly and Maly 2003). This social-ecological interaction required a lot of social capital and information sharing that was directed by the central role of the *konohiki*.

By sharing information human capital was mobilized to undertake natural infrastructure projects such as building and maintaining *loʻi* and *loko*. This person also shared information on harvesting and hunting cycles. Without this person large projects were not easily orchestrated, and information about natural cycles were no longer widely passed on. As external factors such as foreign technology and the market economy came to influence the system, coevolution between humans and local species was disrupted. Concurrently habitat changed for plants and animals due to alteration of the environment or lack of natural resource use.

2.3.3.3 Transitional Action Situations

The far-right side of **Table 5** highlights transitional action situations for each resource management unit. The breadth of different land uses for each area can be followed. Most of the transitional action situations in **Table 5** were mentioned in the time period-actor analysis in Section 2.2.3.1. Juliet Wichman became owner of *Limahuli* Valley after the 1967 land partitioning. She removed the cattle to reignite relationships with plant and animal species that formerly dominated the area. Eventually she gifted a portion of her plot to the National Tropical Botanic Gardens, which allowed for greater participation with research and public communities. Ungulate fences were placed on the ridgelines to protect and co-evolve with plant species susceptible to browsing and trampling by ungulates.

As mentioned above, the stream was once a source of food, but popularity of *ʻoʻopu* has greatly diminished. As people stopped utilizing the stream for food, less people monitored its flow and maintained its natural course. As NTBG took on larger restoration projects, the State required conservation district use applications that included environmental assessments. This triggered in-depth observations to set the baseline for how the stream functions. Almost a decade later it was recognized that overgrown *hau* was prohibiting amphidromous species such as *ʻoʻopu* to complete their upstream life cycle (Cabin 2011). The *hau* was removed, and with that possibly came unforeseen changes to the hydrology of the system.

The State park justified its absorption of some claimed and unclaimed parcels containing important cultural sites. The State claimed they would oversee these plots to preserve them for future generations of public visitors. The State park allowed for public ownership of the area so that caretakers could negotiate access to revive the vitality and productivity of these cultural sites. This innovative use of policy allowed for the perpetuation of the human-environmental interaction that occur when *loʻi, loko, and ʻauwai* are maintained and monitored. The site provides a gathering space for caretakers and a place to educate and pass on cultural human-environmental relationships.

The transition on the coastline was traced through ‘nested focal action situations’ described in this section and **Table 5**. Transitions were also traced by pulling out any mention of a human-environmental interaction or cultural practice from *kūpuna* (elder) interviews (Maly and

Maly 2003). These practices were listed on large posters for discussion at a bi-monthly workday for caretakers of *Hāʻena*. It was a multigenerational audience of men and women. Fishing practices were discussed along with who is locally known for these practices, and whether these practices are still employed. All practices were still known, but the technology and materials have changed. Some natural materials were replaced with manufactured implements, but people never stopped fishing along the shore (see Appendix A). In 1975, the State authorities in charge of managing coastlines did not consider that people still depended on fishing as a means of subsistence. The Department of Aquatic Resources neglected to include subsistence fishing as a shoreline use in a 1974 residential survey about potential marine protected areas (Takeuchi 1975). Forty years later, generations of people have come together to fight for the coastal fish and plant species upon which they rely. Today, local communities of caretakers are inserting their knowledge about coastal habitats in State-sanctioned management plans. To do this they had to partner with scientific researchers, other shoreline users, and the government. Synergizing more governance actors moved the policy and social learning process along, but there is a tradeoff since managing many disparate groups can be stifling. A single private owner like Juliet Wichman or the new owner of *Mānoa* Valley can also move policy forward. However, institutional owners and groups tend to have momentum, especially through information sharing and capacity building.

The fresh water transport and storage area is comprised of the aquifer and where groundwater flows. Groundwater flows through soil and underground aquifers as well as through utility plumbing. New construction of cesspools is now prohibited in the State of Hawaii. Old systems still exist close to the shore in *Hāʻena*, but there is a tax credit to upgrade cesspools within 200 feet of the ocean, streams or marsh areas, or near drinking water sources. By 1989 reduced prices in technology and the impacts of failed cesspools led to the installation of septic tanks. Septic tanks are now the standard. However, this technology has improved with the invention of aerobic treatment systems. This system produces a cleaner effluent discharge than septic tanks. The first aerobic treatment system was installed in *Hāʻena* in 2012. This gradual upgrade in technology by multiple actors shows that residents are aware of the impact that on-site disposal systems have on water quality. Some are willing to pay for improved systems without government mandate or incentive. This awareness is evidence of social learning brought about by either information sharing or evaluation and monitoring of the system.

2.3.3.4 Robustness

Four of the six resource management units identified using the Management Transition Framework are held in public trust by the State of Hawaii for the benefit of the people and future generations. *Mānoa Valley* has a private owner, while *Limahuli Valley* is an institutional owner. Other areas in the *ahupuaʻa* that were not identified by the Management Transition Framework are privately owned residences. Both types of owners do not have to disclose their environmental interactions unless the activity triggers filing of an environmental impact statement. Institutional owners such as *Limahuli* Garden and Preserve involve and interact with multiple actor groups. *Hāʻena* is one of the most researched areas in *Hawaiʻi*. *Limahuli* Garden and Preserve is working to cull that information and share their knowledge for the benefit of the research community and the local community of people who care for the place. Citizen feedback could improve management of these public trust areas, especially feedback from those who have knowledge and experience with the natural ecologic and hydrologic functions of the system. The motivation behind the Community Based Subsistence Fishing Area in *Hāʻena* was to support the State Department of Aquatic Resource officers teach respectful shoreline interactions and monitor water quality as well as natural cycles.

Involving multiple actor groups allows for redundancy of responsibilities. Diversity, redundancy, and modularity of a social-ecological system have been shown to enhance robustness and adaptive capacity (Anderies and Janssen 2013). Robustness refers to the system's capacity to suffer a disturbance and still function without losing its basic structural or functional integrity (McGinnis 2011). This integrity of social-ecological system structure results from institutional memory within and across enterprises. When actors and institutions incorporate lessons from the management transitions that led to the current state, they can better adjust policy towards shared long-term goals.

2.3.3.5 Social and Environmental External Drivers

Robustness of a social-ecological system is important when unforeseen or gradual change from external drivers impact actors and resources. These drivers are represented in Figure 7 by the 'ECO' and 'S' components, and can disrupt social and ecological functions of a system. Some examples would be the 1848 land governance change in *Hawaiʻi* or a tsunami. A robust system will adapt to change so that important services from the ecosystem continue. However, robustness does not guarantee permanence. Robustness helps to keep important functions in place, but social-ecological systems will always be in flux. Information sharing plays an integral role in maintaining these services. Knowledge about these services and how they function must be shared in order to perpetuate healthy interactions with the ecosystem.

2.3.3.6 Knowledge Sharing

External drivers often involve the introduction of a new actor group. In **Error! Reference source not found.** we showed how pivotal action situations and time periods were marked by the introduction of new actors. The Previous Human-Environment Relationships in **Table 5** existed in an insular society where actors have similar values and experiences. The transitional action situations often involve the introduction of new actors with different uses for the environment. Some transitions involve a decline in use because actors were not taught how to use certain natural resources, such as *ʻuaʻu* for food and *hau* for building material. Transitional action situations can create positive re-adaptations such as the *loʻi* revival and the upgrading of on-site disposal systems.

New actors, like researchers, can also introduce knowledge that frames problems to be addressed by multiple actor groups. This was the case for the establishment of the CBSFA. Cooperation between *Limahuli* Garden, the community of caretakers, the State government, and academic researchers was necessary to understand, test, and frame the resource issue based on systematically gathered data. Through these types of action situations social awareness is built and knowledge is shared across actor groups.

The previously sustained human-environment relationships were maintained during monitoring phases for both policy and social learning. At some point, all of these relationships declined either gradually or abruptly, indicating a loss of robustness. However, striving for these phases is helpful to provide a path for effective policy creation. If implementation and evaluation of a policy has not led to adaptive monitoring then perpetuation of the outcome will be questionable. As systems evolve some form of adaptation is required, but positive practices can be protected if the knowledge is shared.

Some transitional action situations arise from gradual change allowed by a lack of policy and transferring of knowledge that maintained certain relationships people had with the place. The decrease in consumption of *ʻoʻopu* and loss of an open view of the coastal plain happened so subtly that policy was not required. The change was not an issue for new actors who entered the system. The rise of Taylor Camp was more abrupt because the cause was known. Howard Taylor purchased a piece of land for which the State had already planned for a State park. Taylor exercised his ownership rights and freely let people use his private plot. An informal institution of actors gained enough momentum to become established for almost a decade. Newer actors had no prior knowledge about the system, and therefore had different interactions and relationships with the land. A more gradual change in actors occurred after the 1946 and 1957 tsunamis. Younger generations were being drawn to new more global opportunities, while the world was also coming to *Hāʻena*. A whole new combination of actors had to agree on policy for their shared system. New ways of interacting with the land arrived, and old relationships were not as widely practiced. This new amalgamation of actors expanded the realm of shared desired outcomes. This expansion tested the robustness of the system because the value of previously sustained ecosystem functions changed. Important functions will remain as long as the knowledge and value of previously sustained services is passed on.

2.4 Conclusion

The creation of a common lexicon for social-ecological systems has allowed for the comparison of common pool natural resource issues across the globe. This led to principles for the successful design of governance (Ostrom 1990). This lexicon provides a tested pathway for other social-ecological researchers to diagnose natural resource degradation issues and suggest policies that are place- and system- specific. A goal of this research is for these methods used in *Hāʻena* to be duplicated for other *ahupuaʻa* and social-ecological systems at the brink of locally co-managing resources.

The SES framework is a thorough list of traits to consider when evaluating a social-ecological system. It can be used to compare systems, as Ostrom (1990) did in order to identify traits of systems where common pool resource management has been successful. It can also be used to diagnose appropriation and provisioning issues, especially using the diagnostic questions created by Hinkel et al. (2015) that tease out actors and their interactions with the ecosystem. Identifying all actors affected by a system is an essential component of efficient rulemaking for a common pool resource. Rules created without consultation of all affected parties will inevitably run into opposition. Alternatively, if this step of stakeholder identification is thoroughly undertaken with historical context, then shared, desired outcomes and negotiations of benefits and concessions could be sought from the outset. Using history allows participants in rulemaking to consider the waves of different actors as they were introduced to the system. It may seem unnatural to invite opposing parties to rule making negotiations, but inclusion is a risk that can pay off in the long run. Rules can be approved without any last-minute surprises to thwart years of effort with the additional benefit of strengthening a sense of community across resource users.

The term 'actor' in the SES framework generally refers to human participants. This operationalization of the SES framework also only considered human actors. However, an often-overlooked participant is the living resource system itself. This operationalization of the Management Transition Framework provided a way to consider the sub-systems that comprise the social-ecological system. The separate management of these sub-systems should be considered as a whole when addressing the overall ecological function of the system being considered. The MTF is a useful diagnostic tool for teasing out these management areas. However, it is most useful for identifying the current state of the resource system and the management transitions that have led up to it. This framework also guides researchers to consider where the current state may be within the policy process. Establishing the current state of the resource system and its sub-systems allows a common place to begin creating shared desired outcomes across actor groups. Understanding previous human-environment relationships can also provide lessons for policymaking and inspiration for future caretaking endeavors.

The SES Framework and MTF provide diagnostic tools for examining a social-ecological system using history. Resolution is gained chronologically, socially, and ecologically. Having this granular yet wide perspective is pertinent for all common pool resource units in the system. The fundamental consideration of the SES framework (Ostrom 2009) is the broad consideration of how social and ecological variables interact. It is not an exact science, but these tools can be used to provide perspective and a minimum standard for what should be considered when creating policy that affects human and environmental interactions. This broad understanding of the system allowed for creation of important and system-specific time-series variables based on qualitative information.

CHAPTER 3

TRACING RELATIONSHIPS

3.1 Introduction

This chapter will describe the conceptual model used to answer the second research question, what social and ecological relationships in *Hāʻena* are statistically related over time? An agreed understanding of past events is required in order to trace the historical interactions within a social-ecological system. Sometimes this understanding comes in the form of time series data, but most of it must be inferred from the synthesis of qualitative data. Chapter 2 discusses why a shared understanding of a social-ecological system must be based on the study of past events for a localized region. This foundation of a shared understanding allows for conceptualization of important historical events within this unit of analysis into statistical models. The models described in this chapter will uncover statistical relationships between social and ecological variables previously never compared.

Established frameworks for studying social-ecological systems (Ostrom 2009, Pahl-Wostl et al. 2010) were operationalized to create indicator variables for a quantitative analysis of time series variables. This case study combines a correlational analysis with a case study of historical events specifically related to the *ahupuaʻa* of *Hāʻena*. This combination of correlational analysis and case study is known as an embedded case study (Cox 2015). The relationships between social and ecological time series variables will be analyzed to formulate future science-based resource management investigations and caretaking activities.

3.2 Research Design

The foundation for examining linked historical events was inspired by the concept of 'nested focal action situations' for a social-ecological system (McGinnis 2011) and the Management Transition Framework (MTF) (Pahl-Wostl et al. 2010). These frameworks were outlined and operationalized in Chapter 2 for this case study of *Hāʻena*. These theoretical frameworks can describe the current state of a social-ecological system at any scale. Agreement of the current state of a system across all stakeholders clarifies shifting baselines (Knowlton and Jackson 2008), and provides an equitable starting point for actors involved in the future governance of shared natural resources. This starting point was created from time series variables based on available information.

This research is observational since it is based upon a collection of historical information. This research does not employ an experimental test to change or manipulate variables in order to test their effects. Instead it is synthetic because it relies on existing information versus primary data collection. This is a case study meta-analysis (Cox 2015) since it is a literature review systemized to allow for formal analysis. This case study uses many data sources to draw inferences about the social-ecological system as a unit of analysis. Observations from historical events about this specific social-ecological system are clustered to answer the first research question stated and answered in Chapter 2; how has the social-ecological system of Hāʻena changed over time? The sampling method to collect observations and the mixed methods for creating variables were described in Chapter 2. Chapter 3 will conclude with a definition of the three models created from available variables and a description of how the models will be analyzed. Chapter 4 will explain the results of the statistical models and provide a direction for future research and management investigations.

3.3 Measurement Protocols

3.3.1 Operationalization of concepts into variables

3.3.1.1 Historical Grounding

Variables were created from multiple stages of clustering the historical information. The desired end products were time series variables that represent germane occurrences within the social and ecological system. Data gathering was purposely inclusive of any documentation to overcome limitation of data availability. The conceptual models to correlate time series variables were limited by the data that overlaps chronologically. Before important concepts could be chosen to create variables a thorough understanding of the order and duration of pivotal events was necessary.

Any information that could be chronologically noted from previous documents and academic studies was recorded on a single timeline. An index of quantitative variables along with their time span and reliability characteristics was recorded. All data was then divided into lenses based upon topical similarities. This initial stage of information clustering was done to understand the type of information collected. The non-quantitative data scattered throughout the timeline had to be re-conceptualized into something meaningful about the interaction of the social and ecological systems. The full list of quantitative data points can be found in Appendix

B.

Once this information was chronologically laid out and categorized, important events also referred to as ‘focal action situations’ (McGinnis 2010) were chosen. This clustering focused on the time period between the *Māhele* in 1848 and the current effort to establish a thriving community based subsistence fishery (See **Table 5**). Important events happened about every decade starting in the 1940s, which marks the 1946 Aleutian Tsunami. The 1946 Tsunami is the oldest extreme climate event within the living memory of *kamaʻāina* during the time of this research.

3.3.1.2 Regime Shifts

The collected observations were chronologically ordered and grouped by similar topical lenses important. After these major events were identified and time periods were generalized to identify noticeable and persistent changes to the ecosystem and how residents interacted with it. Social and ecological factors can cause large, persistent changes in the structure and function of systems known as regime shifts (Folke et al. 2004). Looking at the history of change allows for recognition of longer-term regime shifts, and helps to signal the direction or possibility of a future shift. Examining the resource system over time outlines distinct social eras and the introduction of new actors to the system (See Table 4).

Historical observations were clustered and examined in many different ways in order to arrive at an understanding of the actors and how they benefited from the ecosystem. Inferences were drawn from a convenience sample of qualitative and quantitative sources. Aerial photographs and photo collections were examined to understand the physical state through time. Decadal censuses older than 50 years provided the occupations of residents from the area. Important singular events as well as subtle changes were noted and considered as possible indicator variables in the model.

An indicator variable is used in statistics, specifically regression analyses, to show the presence or absence of something to be tested for correlation with other variables. A zero is used to indicate absence, while a one is used to indicate presence. Some variables gradually increased or decreased, but no exact quantified measurements were documented to show the change. Varying degrees can be represented using values between zero and one to represent approximate change over time. An example that will be described later is the revival of previously used

ʻauwai (ditch systems) and *loʻi* (agricultural wetlands). Indicator variables also allow for inclusion of major climatic events such as hurricanes. Cultural practices and caretaking efforts such as removal of invasive species and the revival of culturally important areas can also be represented with indicator variables. Inclusion of such variables allows for this novel testing of social and ecological relationships over time. The selection and creation process for these variables are described later under the ‘Measurement of Variables to Create Data’ section. Variables could not be chosen without this historical wide-angle view of the social-ecological system and how it changed.

3.3.1.3 Management Areas

An understanding of historical social patterns of tenure, governance, and management is necessary to understand physical alterations to the land and current policy issues. The historical observations were clustered in many different ways. The Management Transition Framework inspired a clustering that linked related events. Linkages are limited by the set of historical observations collected. Once each collected observation was linked to subsequent outcomes creating a ‘sub-plot’ from the collected historical observations resource management areas within the system were revealed. Each resource management area ‘sub-plot’ ends with the most current issues of concern for natural resources that are important to the overall physical character of the social-ecological system. For instance, the removal of cattle from *Limahuli* Valley led to the creation of *Limahuli* Garden and Preserve, and the eventual ungulate fencing on the ridgeline. Another example is that the Community Based Subsistence Fishery Area, established in 2006, was preceded by a number of marine biology studies starting in the 1990s. However, in the 1970s subsistence fishing was completely overlooked in a residential survey about marine protected areas (Takeuchi 1975). Once sub-plots were teased out the preceding human-environmental interactions were linked. This understanding of the system was mostly based upon transcriptions from historical oral interviews (Maly and Maly 2003), archeological accounts (Earle 1978, Dye 2005a, Dye 2005b, Dye 2002, Riley 1979), and historical documentation from a book that captured the lifestyle of the people within the specific social-ecological system of *Hāʻena* (Andrade 2008). Not every social-ecological system has this type of dense documentation with qualitative descriptions of ecological characteristics and how people interacted with their natural surroundings. Understanding these changes in interactions and management were important to identify practices that preserve social and ecological relationships. This granular view of the observations was also necessary to identify important variables for the social-ecological system.

The process tracing that was conducted through qualitative comparative analysis of regime shifts and management areas (**Table 5**) was required to choose variables that could represent the unit of analysis at many levels. The methods for identifying regime shifts and management areas was organically manifested, but inspired by the SES (Ostrom 2009) and Management Transition (Pahl-Wostl et al. 2010) theoretical frameworks. Historical concepts could not be operationalized into variables for statistical correlation testing without three previous operations. First, the wide-angle gathering of observations was necessary to capture an objective view of the past. Second, these observations needed to be clustered and re-clustered within the SES frameworks to gain a holistic view of the social-ecological system. Finally, these observations needed to be put in the context of the lives of real people who lived there by reading interviews, talking to their descendants, and being in the place.

3.3.2 Measurement of variables to create data

3.3.2.1 Qualitative Time Series Variables

Qualitative data pointed to major events or changes in the use of shared natural resources. Major events became apparent after laying out the singular timeline and identifying the important 'focal action situations' (McGinnis 2011) for the social-ecological system that were defined in Chapter 2. The Management Transition Framework (Pahl-Wostl et al. 2010) inspired a granular scale of observing changes in the use of shared natural resources . This granular understanding along with systematic analysis of historical oral interviews illuminated important cultural practices involving natural resources and caretaking measures that preserve the natural functions of the land (Appendix A). In order to turn these changes in resource use into time series variables 5 steps were taken:

1. Systematic review of sources, especially oral interview transcriptions, for references to natural resource use
2. Note every documentation of a cultural or caretaking practice, the associated species and the associated practitioner
3. Research birth and death dates of associated practitioner
4. Estimate presence or absence of each natural resource cultural practice based on the

birth and death dates of notable practitioners

5. Verify with community of caretakers and *kāma'aina* the practices, practitioners and current or last remembered time of practice

Three Cultural/Caretaking indicator variables were used in the conceptual model: ungulate fencing (Figure 17), overgrowth of *hau* (*Hibiscus tillieacious*) in *Limahuli* Stream (Figure 18), and the revival of *'auwai* and *lo'i* in the *ahupua'a* (Figure 19). The economic impact of two extreme climatic events, Hurricane *'Iwa* (Figure 20), and Hurricane *'Iniki* (Figure 21), were represented using ramped down indicator variables. Information from a report estimating the amount of time it took for *Kaua'i*'s economy to recover from Hurricane *'Iniki* in 1992 (Coffman and Noy 2012) was used to decrease value between one and zero. The economic damages for *'Iniki* were sized relative to the calculated economic damages for Hurricane *'Iwa* in 1982, and the ramped down variables were created based on number of years for economic recovery.

Figure 17. Ungulate Fencing

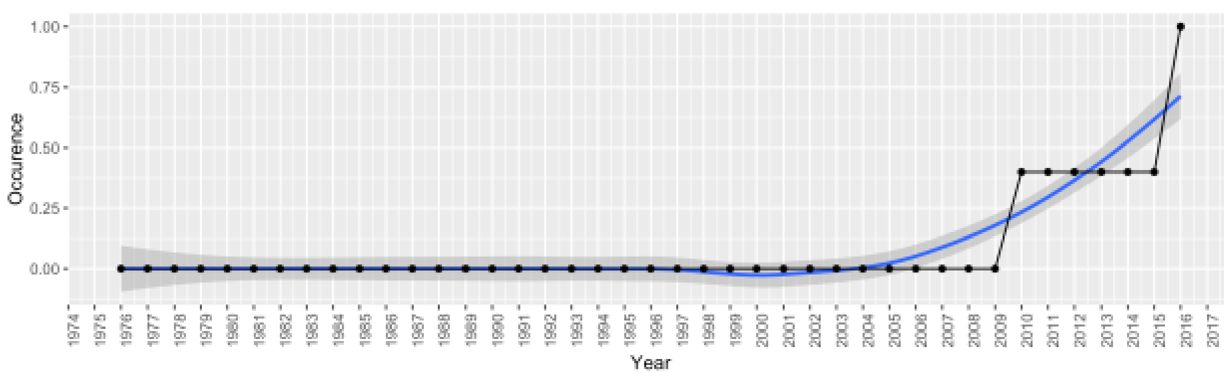


Figure 18. Overgrowth of *Hau* (*Hibiscus tillieacious*) in *Limahuli* Stream

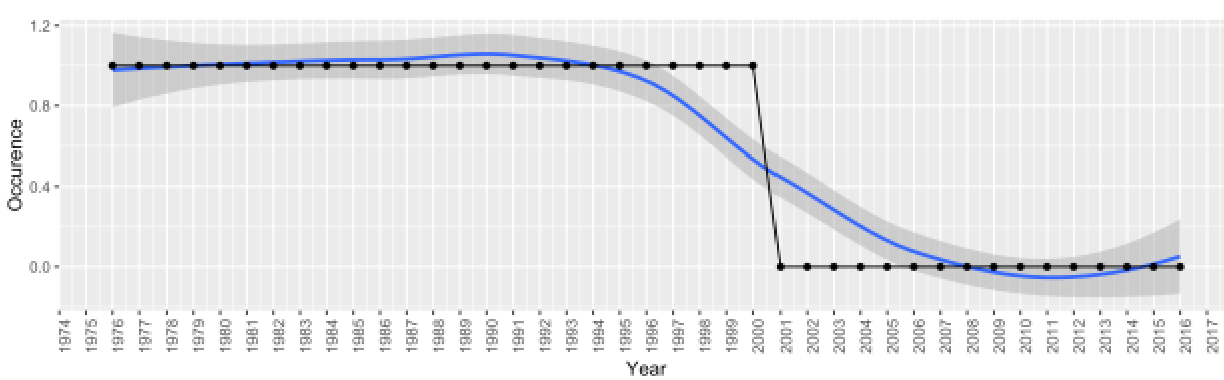


Figure 19. Revival of *'Auwai* and *Lo'i* in the *Ahupua'a*

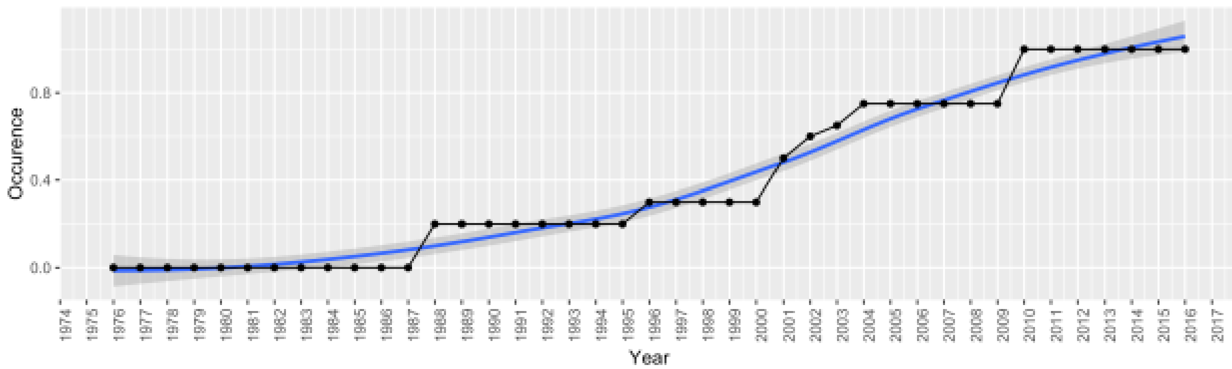


Figure 20. Economic Impact of Hurricane *ʻIwa*

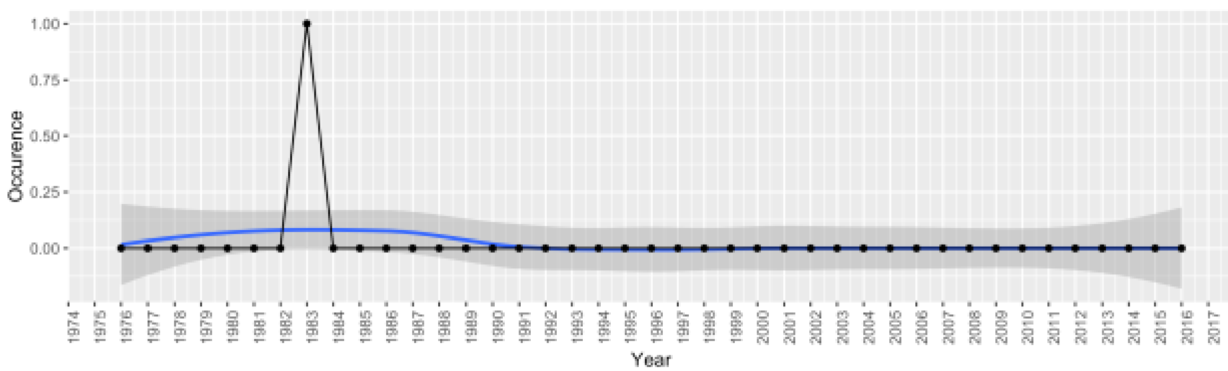
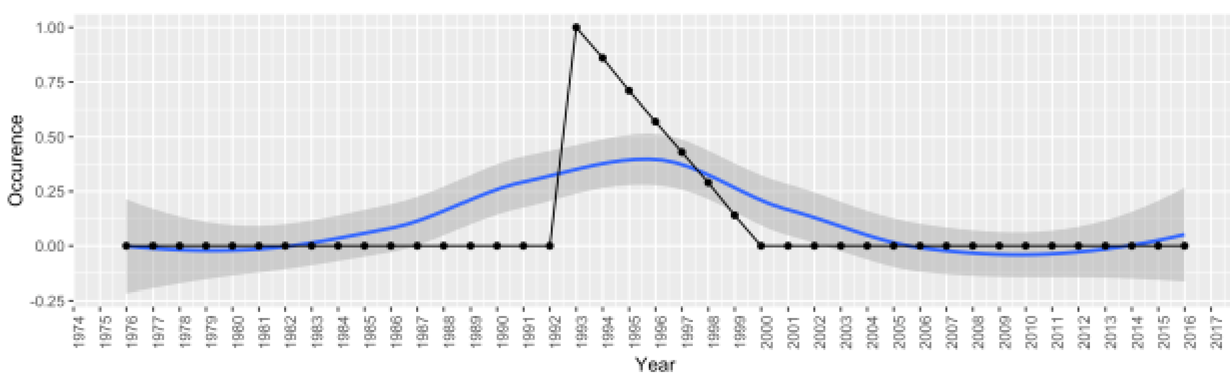


Figure 21. Economic Impact of Hurricane *ʻIniki*



The 1946 and 1957 Aleutian tsunamis were notable extreme climatic events that affected the *ahupuaʻa* of *Hāʻena*, but they could not be included in this conceptual model because they occurred before the bulk of collected quantitative data. Other important cultural/caretaking practices were identified within the social-ecological system, but they could not be included in the conceptual models because each variable had leveled off at zero or one for each period of analysis and therefore could not be tested within a statistical model. The desired practices to be tested were use of inland fishponds, large-scale cattle ranching, consumption of *ʻoʻopu* (Gobildae family) from *Limahuli* or *Mānoa* Stream, and steady *hukilau* within the boundaries of *Hāʻena*.

3.3.2.2 Chronological Alignment of Concepts

The analysis for the conceptual model described in this chapter begins in 1975, which marks the beginning of the visitor arrivals data set (DBEDT 2015). The precipitation data (NCDC 2015) began in 1949. The living area (County of Kauai 2015) and on-site disposal system (SHDOH 2015) records began in 1969. The groundwater level data (USGS 2015) began in 1972. These data sets were updated at the time of this research allowing for the longest analysis to stretch from 1975 to 2015. This stretch of analysis also included ungulate fencing, *hau* removal in *Limahuli* Stream, *ʻauwai* and *loʻi* revival, Hurricane *ʻIwa* and Hurricane *ʻIniki*, which were all represented using indicator variables. Separate regression analyses were created to include shorter important data sets such as well pumpage (1988 to 2015), coastal salinity (1990 to 2015), *Limahuli* Stream flow (1994 to 2005), and well chlorides (1975 to 2002). The shortest stretch of analysis considered included the combination of well pumpage and well chlorides (1988 to 2002). One important set of quantitative data excluded from the analysis was the Native Stream Species Index (Kido 2013). Because of the pristine state of *Limahuli* Stream it is considered one of the reference streams for this statewide index created to measure the native stream habitat for Hawaiian streams. This research was noted as the current state of the *Limahuli* Stream management area, but the data set only lasted from 1998 to 2003. There were not enough sample observations for a reliable historical correlation analysis.

3.3.2.3 Quantitative Time Series Variables

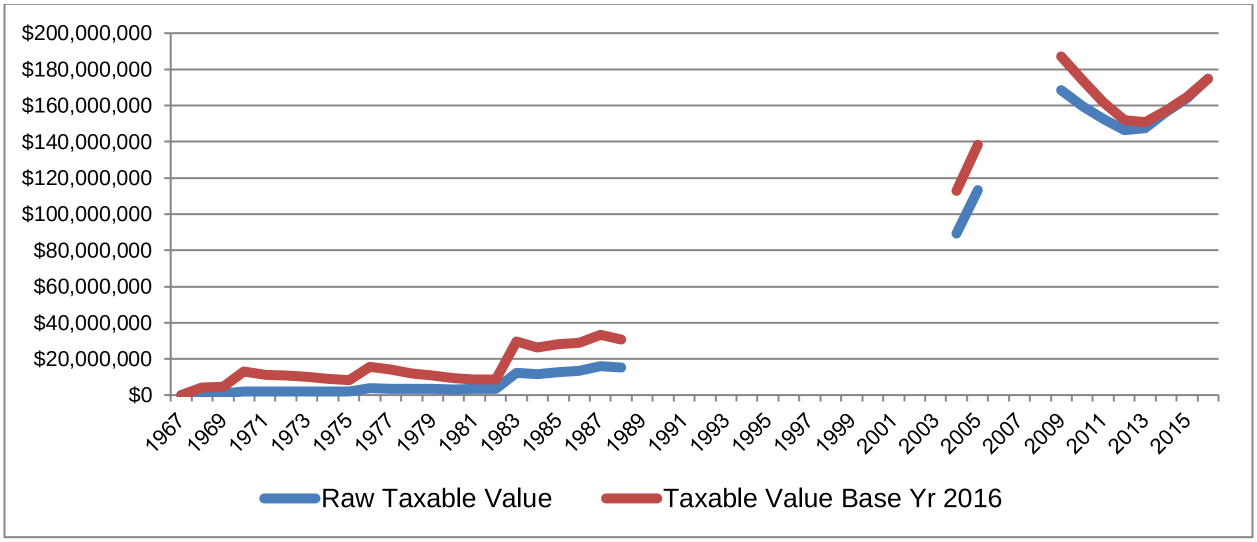
A search for as many publically available quantitative data sets that included *Hāʻena resulted in* 297 data sets (Appendix B). Many found to be either too short, erratic, or had wide gaps. A keen understanding of historical regime shifts and caretaking transitions was important to select quantitative variables. This was also the case with variables collected from qualitative data.

Data created from real property data required collation of annual data points from multiple land plots. Market value, assessed value, living area, on-site disposal system installations, tax, tax exemptions and tax classifications were available in *Hāʻena*, but separately for each of the 232 historic and existing Tax Map Key (TMK) plots. Data points from each TMK plot were scraped from the County of Kauai Real Property Tax web site using DataMiner[2]. Data from each plot had to be scraped page by page because of the way the web page was formatted.

[2] DataMiner is a web browser application that assists is scraping data from web sites.

To limit the number of scraped pages to 78, all TMKs on or bordering a wetland were included in the aggregated data set for each real estate variable. A map of wetland areas identified by the FWS (2009) was combined with the tax map key plot to find intersections. Cesspool, septic tank and aerobic unit installations were obtained from (SHDOH 2015). These were given as individual paper records. Installation dates were re-recorded into a database by TMK plot and aggregated to create a variable that represent the SES. All TMK parcels jumped up in price in 1970, 1976 and 1983 (see Figure 22). Property values from 1989 to 2009 were unable to be located at the County of Kauai Real Property Tax Office and the Honolulu Real Property Tax Office where the values were stored prior to 2001.

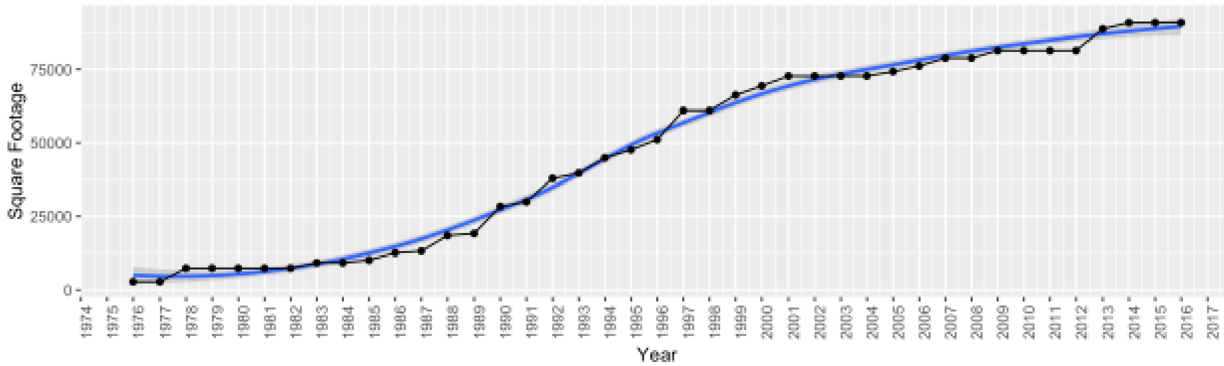
Figure 22. Aggregate Taxable Property Value of all Parcels on Wetlands



The aggregate taxable property value of tax map key parcels on wetlands. The gaps are explained by data that cannot be accounted for by the State of Hawaii and the County of Kauai Real Property Tax Office.

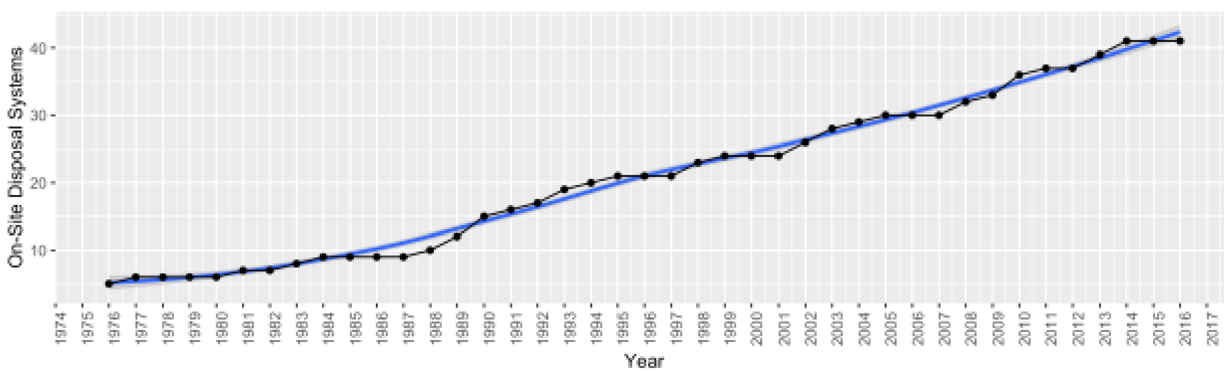
The two decades of missing property value data marks a time when building square footage started to increase as can be seen from the steep increases in area built on wetlands during the 1990s (Figure 23). Honolulu or Kauai County Real Property Tax Offices could not supply the data, nor did they know where it could be retrieved. In lieu of missing assessed value, market value and taxes (Figure 23), the increase in living area by year on wetlands represents development in the conservation district. To create this variable the year and living area built for each tax plot on or bordering a wetland area was noted. Cumulative area built on wetlands is the time series variable used in this model.

Figure 23. Cumulative Living Area on Wetland Tax Plots



The other development variable constructed from separate tax map key plot records was installation of on-site disposal systems (Figure 24). This includes the number of cesspools, septic tanks, or aerobic units installed each year. Each type of system was weighted by possible effluent leakage. Cesspools were weighted a '2', septic tanks were weighted '1,' and aerobic units '.5' (Siegrist et al. 2000).

Figure 24. Cumulative On-Site Disposal Systems



The remaining variables within the 1975 to 2015 time range included: visitor arrivals (Figure 25), precipitation (Figure 26), groundwater level (Figure 27), well pumpage (Figure 28), and *Limahuli* Stream flow (Figure 29). Even though this data had sufficient length, data was not always consistently recorded. The frequency of all quantitative variables needed to be considered in order to decide the time-step at which the multivariable regression analysis would be conducted. The most appropriate time-step was annual, so all variables needed to be standardized at this scale. For some quantitative data sets, records were taken at inconsistent times throughout the year. This can be an issue for data such as precipitation or well pumpage that might have different seasonal patterns throughout the year.

For the data sets that had recorded values at inconsistent intervals, the data was deseasonalized before it was aggregated at an annual time step. Data averaged within a single year to get the annual value can contain bias. For instance, if precipitation was mostly recorded during winter months, the annual values would be biased upward. To remove this bias by deseasonalizing the data, the number of records taken in each month of the year was counted. Taking the count for each month and dividing that by the average for all records in the time series obtained a seasonal factor. Then each record was divided by the seasonal factor for that month to create a deseasonalized value. These deseasonalized values were then used to find the average for each year.

Figure 25. Visitor Arrivals

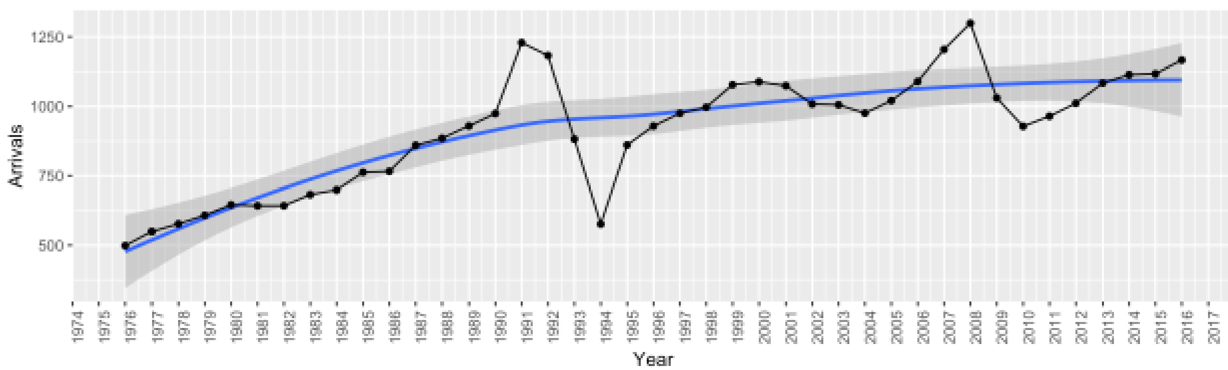


Figure 26. Precipitation

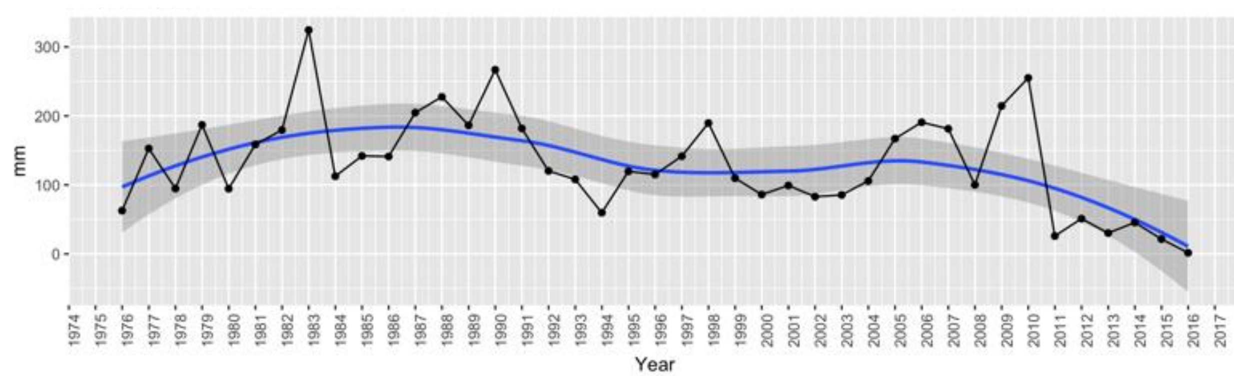


Figure 27. Groundwater Level

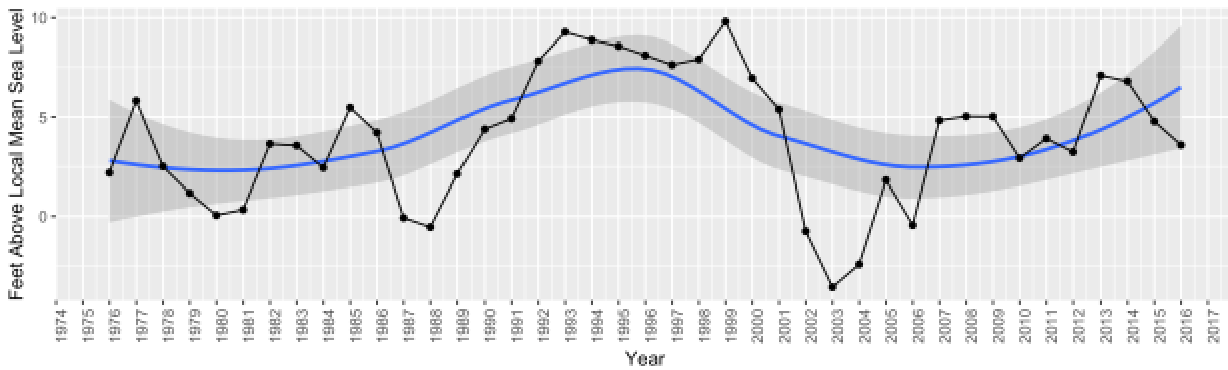


Figure 28. Well Pumpage

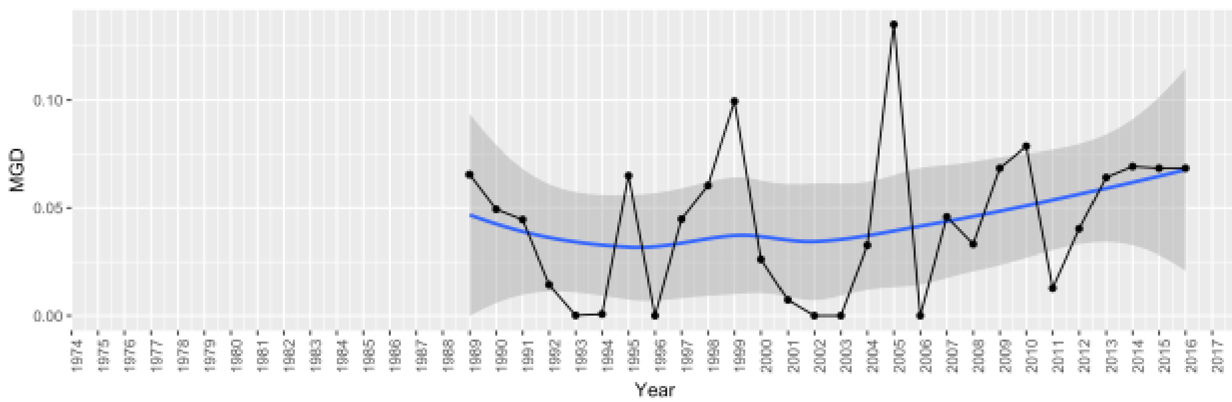
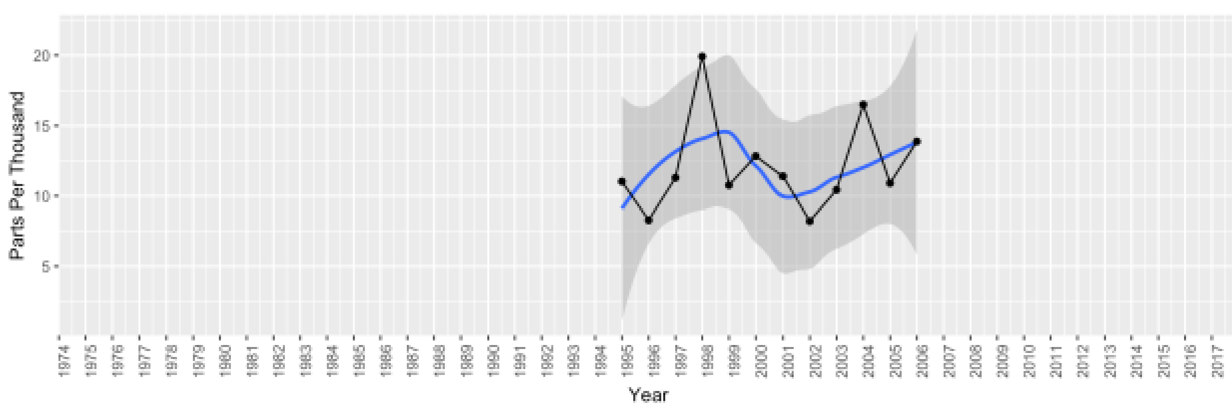


Figure 29. *Limahuli* Stream Flow



3.4 Model Creation Criteria

3.4.1 Dependent Variables

Dependent variables were chosen from the possible pool of time series variables. Out of all the available time series from 1975 to 2015, groundwater level appeared to have had the most significant impact on both the social and ecological systems. Other water quality variables shorter than the 1975 to 2015 time period were considered. Coastal Salinity (1990 to 2015)

(Figure 30) and Well Chlorides (1975 to 2002) (Figure 31) are the other available water quality data that have importance for coastal habitats and natural resource users of this *ahupua'a*.

Figure 30. Coastal Salinity

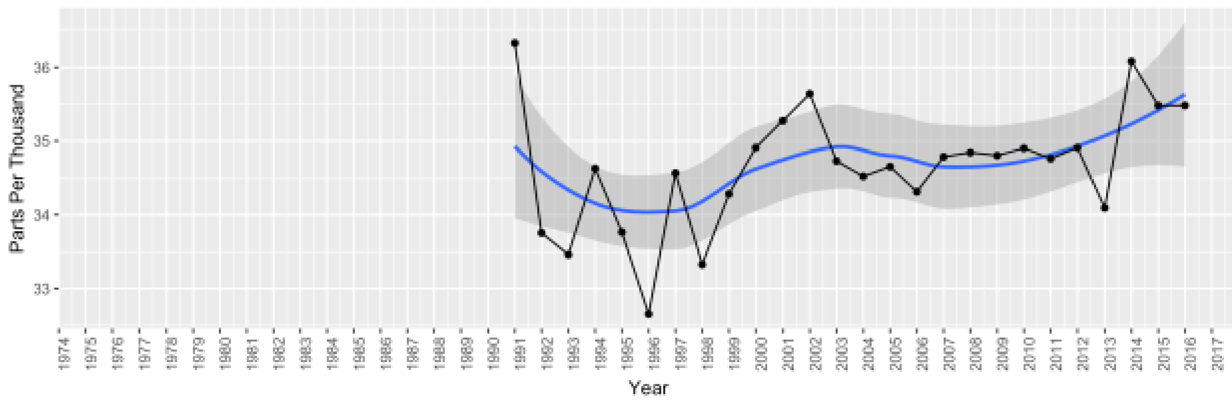
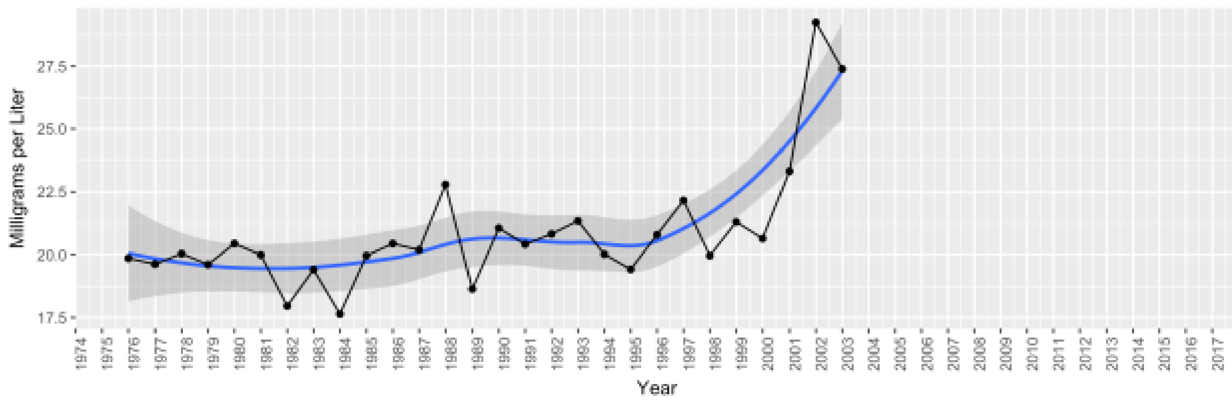


Figure 31. Well Chlorides



3.4.2 Independent Variables

The remaining independent variables were hypothesized to have a relationship to one or more dependent variables. With the exception of Figure 22, Figure 17 through Figure 31 comprises the pool of possible variables that were standardized for analysis.

Figure 32 **through**

Figure 34 are the independent variables considered for each dependent variable along with the hypothesized direction of their relationship. A visual diagram of the conceptualized social-ecological interactions is displayed to the right of each list. Beneath each figure describing the social-ecological interactions a list of models tested for each of the three dependent variables is given along with the corresponding years of analysis. The hypothesized interactions will also be explained.

A correlation matrix for each independent variable and all hypothetically related variables was created in order to arrive at possible independent variable combinations. This was done for all variable combinations for each time period (1975 to 2015, 1990 to 2015, 1975 to 2002, 1994 to 2005 and 1988 to 2002). A correlation of 70 percent or higher was the threshold at which two variables were not included in the same model. Separate models were created to avoid multicollinearity.

Multicollinearity is the condition where two explanatory variables provide similar information, and the redundancy creates statistical noise. The ecological variables had low correlation with the other variables, so instead of creating separate models for them, their significance was tested across models. For data sets with less years, such as well pumpage or Limahuli Stream flow, models were created by first comparing the models with the longest set of years. The model with the lowest Baysian Information Criteria (BIC) and Akaike Information Criteria (AIC) scores was chosen and a similar model was created for the shortened set of years including the focus variable with the shorter set of data. For instance, among the groundwater models with data from 1975 to 2015, the *ʻauwai* and *loʻi* model had the lowest criterion scores. When creating a model to include well pumpage which only had data from 1988 to 2002, the variables for the *ʻauwai* and *loʻi* model were used for the shortened set of years, the well pumpage data was added and the model was regressed against groundwater levels for the same set of years.

All regressions were performed using the lm() function in R and plotted to observe annual patterns using the ggplot package. Consistently significant variables across models were noted. Further research questions were created based on the statistical relationships consistently found across models (Chapter 4).

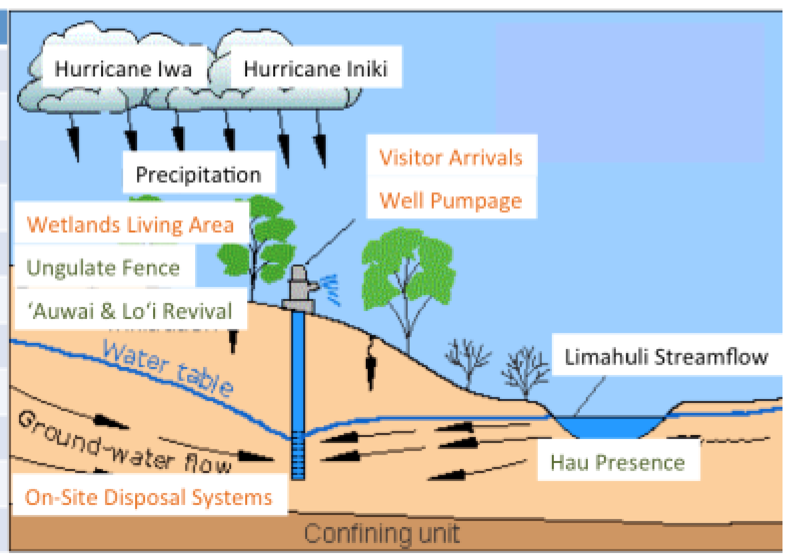
3.5 Statistical Models

3.5.1 Groundwater Level Models

Increased visitor arrivals, living area built on wetlands, and well pumpage were hypothesized to draw down groundwater levels. As luxury homes are built and visitors use park facilities water well pumpage increases, which also decreases groundwater levels. When impervious surfaces such as homes and driveways are built on wetlands, there is less area for water to recharge the aquifer. On the other hand, on-site disposal systems were thought to add water to groundwater level through effluent discharge. Ungulate fencing was hypothesized to add water to the aquifer. As ungulates browse and trample native flora and fauna they compact the soil, which increases runoff and sediment transport (Dunkell et al. 2011, Strauch et al. 2016) (see Figure 32). The presence of *hau* was thought to have a positive effect on groundwater levels because it diverts away from in-channel stream flow. This causes overbank flow which increases groundwater residence time because surface water is stored in the floodplain (Helton et al. 2014). The *hau* essentially creates a dam similar to a beaver dam, which has been shown to divert stream flow to naturally drier riparian areas that are not connected to groundwater flow (Westbrook, Cooper, and Baker 2006). The hypothesis that the presence of *hau* diverts stream flow also supports the case that increased stream flow would allow more groundwater to flow out of the aquifer.

Figure 32. Groundwater Level Hypothesized Relationships to Independent Variables

	Independent Variables	Hypothesis
SOCIAL	Visitor Arrivals (S1)	-
	Wetlands Living Area (RS8)	-
	Well Pumpage (RS4)	-
	On-Site Disposal System (RS4)	+
	Ungulate Fencing (I5)	+
	Hau in Limahuli Stream (I10)	+
	'Auwai & Lo'i Revival (I1)	-
ECOLOGICAL	Hurricane Iwa (ECO1)	+
	Hurricane Iniki (ECO1)	+
	Precipitation (ECO1)	+
	Limahuli Streamflow (RS6)	-



Model 1 - *Wetlands Living Area* – 1975 to 2015

Groundwater Level = fn (Wetlands Living Area, Ungulate Fencing, Hurricane *'Iwa*, Hurricane *'Iniki*, Precipitation)

Model 2 – *On-Site Disposal Systems* – 1975 to 2015

Groundwater Level = fn (On-Site Disposal Systems, Ungulate Fencing, Hurricane *'Iwa*, Hurricane *'Iniki*, Precipitation)

Model 3 – *Visitors & Hau Presence* – 1975 to 2015

Groundwater Level = fn (Visitor Arrivals, Ungulate Fencing, *Hau* Presence, Hurricane *ʻIwa*, Hurricane *ʻIniki*, Precipitation)

Model 4 – *Visitors & Loʻi* – 1975 to 2015

Groundwater Level = fn (Visitor Arrivals, Ungulate Fencing, *ʻAuwai* & *Loʻi*, Hurricane *ʻIwa*, Hurricane *ʻIniki*, Precipitation)

Model 5 – *Well Pumpage* – 1988 to 2015

Groundwater Level = fn (Visitor Arrivals, Well Pumpage, Ungulate Fencing, Hau Presence, Hurricane *ʻIniki*, Precipitation)

Model 6 – *Limahuli Streamflow* – 1994 to 2005

Groundwater Level = fn (Visitor Arrivals, Well Pumpage, *Hau* Presence, Hurricane *ʻIniki*, Precipitation, *Limahuli* Stream Flow)

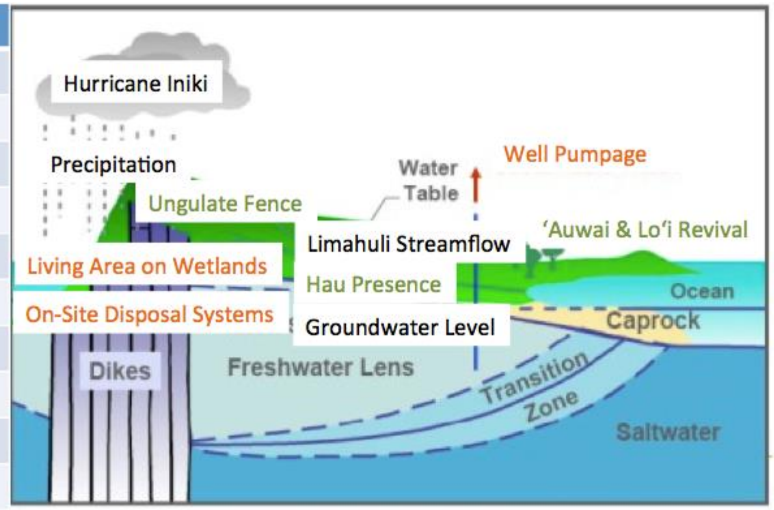
3.5.2 Coastal Salinity Models

A physically dynamic coastal salinity model would include stream flow, precipitation, rainfall-runoff, wind field, air temperature, evaporation, and measured tides (Teh et al. 2008). Stream flow and precipitation were the only available time series variables relevant to coastal salinity and available for this social-ecological system. Hurricane *ʻIniki* and groundwater levels were also included since increased fresh water should decrease coastal salinity.

All three cultural/care-taking variables were tested. The ungulate fence would contribute to aquifer recharge and thus decrease coastal salinity. The presence of *hau* in the stream would also decrease coastal salinity as it is hypothesized that the *hau* is preventing groundwater outflow. This increases the volume of the freshwater lens. Increased groundwater is believed to decrease coastal salinity. It is also hypothesized that *ʻauwai* and *loʻi* revival would increase coastal salinity because there would be outflow to wetland agricultural patches. The outflow would decrease the volume of the freshwater lens, which would increase coastal salinity (see Figure 33).

Figure 33. Coastal Salinity Hypothesized Relationships to Independent Variables

	Independent Variables	Hypothesis
SOCIAL	Well Pumpage (RS4)	+
	Living Area on Wetlands (RS8)	+
	On-Side Disposal Systems (RS4)	+
	Ungulate Fence (I5)	-
	Hau Presence (I1)	-
	ʻAuwai & Loʻi Revival (I1)	+
ECOLOGICAL	Groundwater Level (O2)	-
	Precipitation (ECO1)	-
	Hurricane Iniki (ECO1)	-
	Limahuli Streamflow (RS6)	-



Model 7 - *Wetlands Living Area* – 1990 to 2015

Coastal Salinity = fn (Wetlands Living Area, Well Pumpage, Ungulate Fence, Hurricane *ʻIniki*, Precipitation, Groundwater Level)

Model 8 – *On-Site Disposal Systems* – 1990 to 2015

Coastal Salinity = fn (Well Pumpage, On-Site Disposal Systems, Hurricane *ʻIniki*, Precipitation, Groundwater Level)

Model 9 – *ʻAuwai & Loʻi Revival* – 1990 to 2015

Coastal Salinity = fn (Well Pumpage, Visitor Arrivals, ʻAuwai & Loʻi Revival, Hurricane *ʻIniki*, Precipitation, Groundwater Level)

Model 10 – *Hau & Ungulate* – 1990 to 2015

Coastal Salinity = fn (Well Pumpage, Ungulate Fencing, *Hau* Presence, Hurricane *ʻIniki*, Precipitation)

Model 11 – *Streamflow* – 1990 to 2015

Coastal Salinity = fn (Well Pumpage, Hurricane *ʻIniki*, Precipitation)

3.5.3 Well Chlorides Models

Well chlorides are an indicator of saltwater intrusion in the fresh water lens. Paine (2003) recognizes well chlorides as an indicator for saltwater intrusion on coastal aquifers.

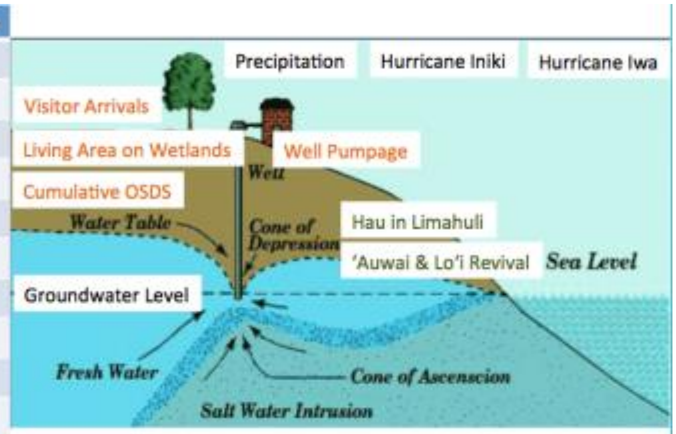
Figure 34 depicts the cone of depression, which is dependent on well placement and aquifer structure. These factors need to be considered, and data collection needs to be revived in order to monitor the future usefulness of the well.

All development variables, except for on-site disposal systems, are hypothesized to add chlorides to the well because they are removing water from storage, thus increasing the concentration of well chlorides. On-site disposal systems are hypothesized to add chlorides to well water via the effluent water they add to groundwater. *Hau* removal in *Limahuli* Valley may be too far to have an effect on the well in *Mānoa* Valley, but this variable was still included because both places sit on the same aquifer. The hypothesis is that there is a negative relationship because the presence of the overgrown *hau* diverts stream flow away from the streambed. This decrease in stream flow prohibits groundwater from outflowing through the stream. This causes fresh water to stay in the aquifer, which dilutes well chlorides. It is also hypothesized that *'auwai* and *lo'i* revival will have a positive relationship with well chlorides because these areas discharge water. If areas of discharge like *Limahuli* Stream are not overflowing onto the flood plain groundwater will increase residence time in the aquifer (Helton et al. 2014). However, if these areas of recharge are full the hypothesis is that freshwater will outflow decreasing groundwater levels. All ecological variables (groundwater level, precipitation, Hurricane *'Iniki,* and *Limahuli* Stream flow) will decrease well chlorides because they are hypothesized to add fresh water to the aquifer, once again diluting well chlorides.

Measurements for well chlorides from the County of Kauai were available until the year 2002. Another set of well chloride data from USGS was found for the years 2006 to 2011. It closely aligned with the upward trajectory of the Kauai County data. However, to combine both datasets without controlling for sampling method would be incorrect. If the trend between these sets of data is accurate, then steps should be taken to monitor the steep increase in chlorides, especially in relationship to the downward trend in groundwater levels.

Figure 34. Well Chlorides Hypothesized Relationships to Independent Variables

	Independent Variables	Hypothesis
SOCIAL	Visitor Arrivals (S1)	+
	Wetlands Living Area (RS8)	+
	Well Pumpage (RS4)	+
	On-Site Disposal System (RS4)	+
	Hau in Limahuli Stream (I10)	-
	‘Auwai & Lo‘i Revival (I1)	+
ECOLOGICAL	Hurricane Iwa (ECO1)	-
	Hurricane Iniki (ECO1)	-
	Precipitation (ECO1)	-
	Groundwater Level (ECO3)	-



Model 12 - *Wetlands Living Area* – 1975 to 2002

Well Chlorides = fn (Wetlands Living Area, Hau Presence in *Limahuli* Stream, Hurricane *‘Iwa*, Hurricane *‘Iniki*, Precipitation, Groundwater Level)

Model 13 – *On-Site Disposal Systems* – 1975 to 2002

Well Chlorides = fn (On-Site Disposal Systems, *Hau* Presence in *Limahuli* Stream, Hurricane *‘Iwa*, Hurricane *‘Iniki*, Precipitation, Groundwater Level)

Model 14 – *Visitor Arrivals*– 1975 to 2002

Well Chlorides = fn (Visitor Arrivals, Hau Presence in Limahuli Stream, Hurricane *‘Iwa*, Hurricane *‘Iniki*, Precipitation, Groundwater Level)

Model 15 – *‘Auwai & Lo‘i Revival* – 1975 to 2002

Well Chlorides = fn (*‘Auwai & Lo‘i* Revival, *Hau* Presence in *Limahuli* Stream, Hurricane *‘Iwa*, Hurricane *‘Iniki*, Precipitation, Groundwater Level)

Model 16 – *Well Pumpage* – 1988 to 2002

Well Chlorides = fn (Well Pumpage, *‘Auwai & Lo‘i* Revival, *Hau* Presence in *Limahuli* Stream, Hurricane *‘Iniki*, Precipitation, Groundwater Level)

3.6 Limitations of Statistical Models

As mentioned earlier this entire analysis is limited by available historical data. There were desirable variables that were sought such as invasive canopy cover over time and assessed value of land, but the data simply was not available. Along the way unexpected data was found or proxies were created. Finding many datasets at the same geographic scale is almost impossible unless that data was purposely recorded for another purpose. Some older datasets were found for monitoring stations throughout *Limahuli* Valley, but the data was found to be too inconsistent to use. Water quality measurements were taken at different locations and therefore may not have a direct impact on each other. This is why all relationships found through these analyses are correlational and not at all meant to imply causation. The internal, external, deductive, ecological, measurement, and statistical validity of relationships across these models will be evaluated in the next chapter.

The regression technique used in the analysis required the creation of separate models to test variables that were highly correlated. This took away from testing system interactions within the system. Structured equation modeling is another statistical methodology that accounts for the system interactions. However, for this analysis historical perspective of the system was more important to capture than social-ecological system interactions. Social-ecological relationships over time were discovered through the seven stages of analysis described below.

3.7 Analytical Technique

The analysis of the collected sample of historical observations underwent seven stages of analysis each resulting in research outputs that subsequently built upon each other. The stages are listed below with the research outputs in **bold** font.

1. Create **singular timeline**
2. Cluster collected data by **topical lenses** (seven timelines)
3. Identify **pivotal events** (Focal Action Situations)
4. Create (decadal) time periods to identify **regime shifts and introduced actor groups**
5. Link observations to uncover **management transition sub-plots and areas**
6. Create models of possible social and ecological variables to test for **social and ecological relationships over time** with consideration of data availability and multicollinearity
7. Use correlation results from models to formulate **questions for future research**

investigations and caretaking projects

Stages 1 through 5 were described and exemplified for this case study of *Hāʻena* in Chapter 2. This chapter described the sixth stage of analysis listed above. Chapter 4 will describe the correlation results that point to future research investigations and caretaking projects. In the concluding chapter support for the notion that **future management could improve with a shared understanding of the social-ecological system** will be revisited to see if this case study can be used for caretaking of social-ecological systems.

3.8 Conclusion

This longitudinal analysis of events operationalized the SES and Management Transition Frameworks to describe the current state of the social-ecological system. This environmental history approach (Diamond 1997, Cronon and Demos 2003) creates thick descriptions (Geertz 1963, Geertz 1973) to give the context of important events. These events point to triggers that initiated actions and trace the evolution of the current state for different fresh water resources within the resource system. Qualitative comparative analyses (Ragin 2014) were conducted of collected historical observations that revealed regime shifts based on the introduction of new actors and changes in natural resource use. This can be used to identify sources of social-ecological traps where the system moves to such an undesirable state that people become complacent and choose to live in a poorer-quality habitat (Boonstra and de Boer 2014, Cinner 2011, Steneck 2009). The results gathered through this analysis give co-management actors a broader sense of the resource system as a whole and other resource units and stakeholders in the system that may have aligned interests. A systematic account of historical events based upon available documentation is a potential way/means for community members to come to a shared understanding of the current situation and identify specific goals on which to collectively move forward. Identifying actors over time highlights which have the most experience and knowledge of the resource system. Identifying fresh water management areas within the system can prioritize and motivate policy for key resource units in the system. The process-tracing analysis used aided in the creation of variables and conceptual models for groundwater level, coastal salinity, and well chlorides that are comprised of the time series variables from available data. The correlations offer future scientifically-based research considerations and possible caretaking projects.

CHAPTER 4

CHARTING A COURSE BACKWARDS

4.1 Introduction

In Chapter 2, the most up-to-date SES framework including the concept of the 'nested focal action situation' and the Management Transition Framework, were operationalized to gain a systems understanding of the *ahapuaʻa* of *Hāʻena*. These frameworks aided in creating a physical, social, and historical perspective of the SES. These methods allow actors interested in co-management of natural resources to gain a shared understanding of the current state of the system and the important events that have influenced the positions of other actors. Specifically, it allows for identification of stakeholders to be included in management and rulemaking. Additionally, understanding the history of related resource management units can bolster co-management efforts for the entire resource system. For instance, past terrestrial management of the valley or the historical management of the stream can have implications for coastal and fresh water management. Aligning actors and goals across the resource system can have both social and ecological benefits. A shared understanding of historical social-ecological action situation outcomes can help inspire future human-environment relationships. The Hawaiian term for future is *ka wā ma hope*. It translates to "the time in back."

> "It is as if the Hawaiian stands firmly in the present, with his back to the future, and his eyes fixed upon the past, seeking historical answers for present-day dilemmas." (Kameʻeleihiwa, 1992, 22-23)

The methodologies presented in this research hinge future management recommendations on a meticulous study of a social-ecological system's history. This Hawaiian epistemological lens is employed to chart a course backwards into the unforeseen future.

In Chapter 3, the collection of historical observations and the steps taken to gain an even finer resolution view of the resource system by creating time series variables. Social and ecological variables that have never been considered together over the same set of years are quantitatively compared. The models used to relate independent variables over time to groundwater level, coastal salinity, and well chlorides were described as well as the hypothesized relationship between the dependent and independent variables.

This chapter goes on to highlight significant relationships found between independent variables and the three dependent variables for which models were created. The internal, external, deductive, ecological, measurement, and statistical validity of these relationships (Cox 2015) will be examined to identify relationships worth investigating further. Investigations can take the form of closer monitoring through qualitative and quantitative data collection. Data collection can be used to enforce sanctions or measure overall progress toward co-management goals. Any further investigation will lead to a greater understanding of how the resource system functions as a whole. Stakeholders in co-management and other resource users can collectively act on this information to reach shared goals for the social-ecological system.

Before the significant relationships are uncovered, the six types of validity that will be considered for each relationship will be defined (Cox 2015). For this research relationships are considered significant when an independent variable shows significance in one or more of the multi-regression models designed to test ground water levels, coastal salinity, or well chlorides. The integrity of how each relationship was derived will be discussed for each significant relationship between an independent and dependent variable.

4.2 Variable Relationship Validity Types

The definitions laid out in this section come from Cox (2015). They are reiterated here for ease of understanding how relationships were evaluated. The validity of relationships is examined to help evaluate which ones should be investigated further. In some cases, understanding the validity of how relationships were derived can inform how to monitor the system and point to future caretaking efforts.

Inferences of a relationship can violate internal validity in two ways. The first way is when an alternate story explains the relationship between a dependent and independent variable, and the second way is when there is not enough data to tell the whole story. An alternate story may arise from the fact that the dependent variable actually explains the independent variable, or the independent variable is related to the error term in the dependent variable model. An alternate explanation could include the omission of a variable in the model, measurement error in the independent variable, and when the independent variable is jointly determined with the dependent variable, also known as simultaneity. An alternate explanation for a correlational relationship may be that the relationship is spurious and doesn’t actually exist. This is known as a Type 1 Error. It may also be the case that a relationship between variables was completely overlooked. This is a Type 2 Error.

The second way an inference of a relationship can violate internal validity is if the spillover effects from other causal relationships are not fully taken into account. Both positive and negative effects can be overlooked. An example of a positive effect is diffusion of a beneficial technology that is not accounted for, and a negative effect would be the implementation of a policy in one area may encourage negative behavior in another. Ultimately there is a relationship between the two variables, but it is not so direct that the addition of an omitted or instrumental variable could improve the explanation. In the case of a relationship caused by spillover effects, there is not enough data or understanding to proximately model the relationship. However, the relationship is not spurious, but created through a series of relationships that are hard to observe.

External validity refers to when the finding from a relationship can be generalized from a sample to the larger population or from one population to another. If valid, the types of relationships inferred from the statistical multiple-regression models identified in Chapter 3 could be applied to other *ahupuaʻa* in Hawaiʻi or in similar social-ecological systems where groups of actors are coming together to collectively co-manage resource units within a resource system.

Deductive validity occurs when a relationship is internally valid and also externally valid to the point that the general explanation of the relationship can be applied to this and other specific cases. For this analysis, the combination of the internal and external validity of the relationship was used as criteria to determine deductive validity. Deductive validity was considered possible if either internal or external of validity was confirmed.

Ecological validity refers to when the relationships that have been isolated in the dependent variable models outlined in Chapter 3 hold within the uncontrolled circumstances of the actual ecosystem. A significant relationship may have been inferred through these models, but after consideration of biophysical principles it may be identified as ecologically insufficient.

An invalid relationship can arise when the creation of the variable resulted in distorted information. This can happen through the data collection method or the instrument through which the data was collected created biases. An in-depth explanation for how concepts were operationalized into time series variables was given in Chapter 3. Weak characteristics of the measurements chosen or how they were derived will be discussed if they can point to ways to improve validation of the relationship.

Statistical validity means that the assumptions used to create these models are true. The justification for the statistical validity of these models was given in Chapter 3. Therefore, the statistical validity of significant relationships found in these models will be considered sound, and thus not discussed in this chapter.

Table 6 provides a summary table of the validity of the significant relationships found for the ground water level, coastal salinity, and well chlorides models. The following section will explain in more depth the overall validity of the relationships found, and a hypothesized explanation of the mechanics behind the relationship.

Table 6 Summary of Significant Relationships and Validity Assessment of Relationships

		RELATIONSHIP VALIDITY					
	Relationship	Internal	External	Deductive	Ecological	Measurement	Statistical
GROUNDWATER							
Kaua'i Island Visitor Arrivals	+	Spillover	Place specific	No	Test further	Visitor data too broad	Yes
Hau Presence in Limahuli Stream	+	Test further	Possible	Possible	Test (Maly & Maly 2003)	Aquifer/Groundwater flow not factored	Yes
'Auwai & Lo'i Revival	-	Test further	Possible	Possible	Test (Helton et al. 2014 & Whittier et al. 2014)	Aquifer/Groundwater flow not factored	Yes
Economic Impact of Hurricane Iniki	+	Spillover	Place specific	No	Test further	Possible relationship to unemployment	Yes
Well Pumpage	+	Omit Var	Possible	No	Test (USGS 2005)	Well dynamics in dike aquifer	Yes
Precipitation	-	Omit Var	Possible	No	Test further	Good quality	Yes
COASTAL SALINITY							
Economic Impact of Hurricane Iniki	-	Spillover	Place specific	No	Test further	Possible relationship to unemployment	Yes
WELL CHLORIDES							
Kaua'i Visitor Arrivals	+	Spillover	Place specific	No	Test further	Visitor data too broad	Yes
Living Square Footage on Wetlands	+	Test further	Possible	Possible	Test further	Proxy for impervious surface/Permitted only	Yes
Cumulative On-site Disposal Systems	+	Test further	Possible	Possible	Test further	Permitted only	Yes
Hau Presence in Limahuli	-	Test further	Possible	Possible	Test (Maly & Maly 2003)	Aquifer/Groundwater flow not factored	Yes
'Auwai and Lo'i Revival	+	Test further	Possible	Possible	Test (Helton et al. 2014 & Whittier et al. 2014)	Aquifer/Groundwater flow not factored	Yes
Groundwater Levels	-	Test further	Possible	Possible	Test, saltwater intrusion of aquifer (Paine 2003)	Well dynamics in dike aquifer	Yes

Significant relationships that are opposite the hypothesis are highlighted in orange.

4.3 Statistical Model Results

4.3.1 Groundwater Level Model

Six multiple-regression models were created for the dependent variable of groundwater levels (see Table 7). Four models were created that span the longest set of years from 1975 to 2015. Each model has one or two focal variables around which the model was created. Variables were included in some and excluded in others because they were too highly correlated. Highly correlated variables are a condition for multicollinearity, which adds noise to the model. Groundwater level models spanning from 1975 to 2015 focused on Cumulative Living Area on Wetlands, Cumulative On-Site Disposal Systems, Visitor Arrivals & Presence of *Hau* in *Limahuli* Stream and Visitor Arrivals & Revival of *'Auwai and Lo'i*. A model including data from 1988 to 2015 was created to focus on Well Pumpage. A final model that spanned from 1994 to 2005 was created to consider the stream flow from *Limahuli* Stream. Five out of eleven variables showed significance for one or more of the models in which they were included. The validity of the relationships between these independent variables and Groundwater Level will be discussed one at a time in reference to the graphic comparison of the two time-series variables.

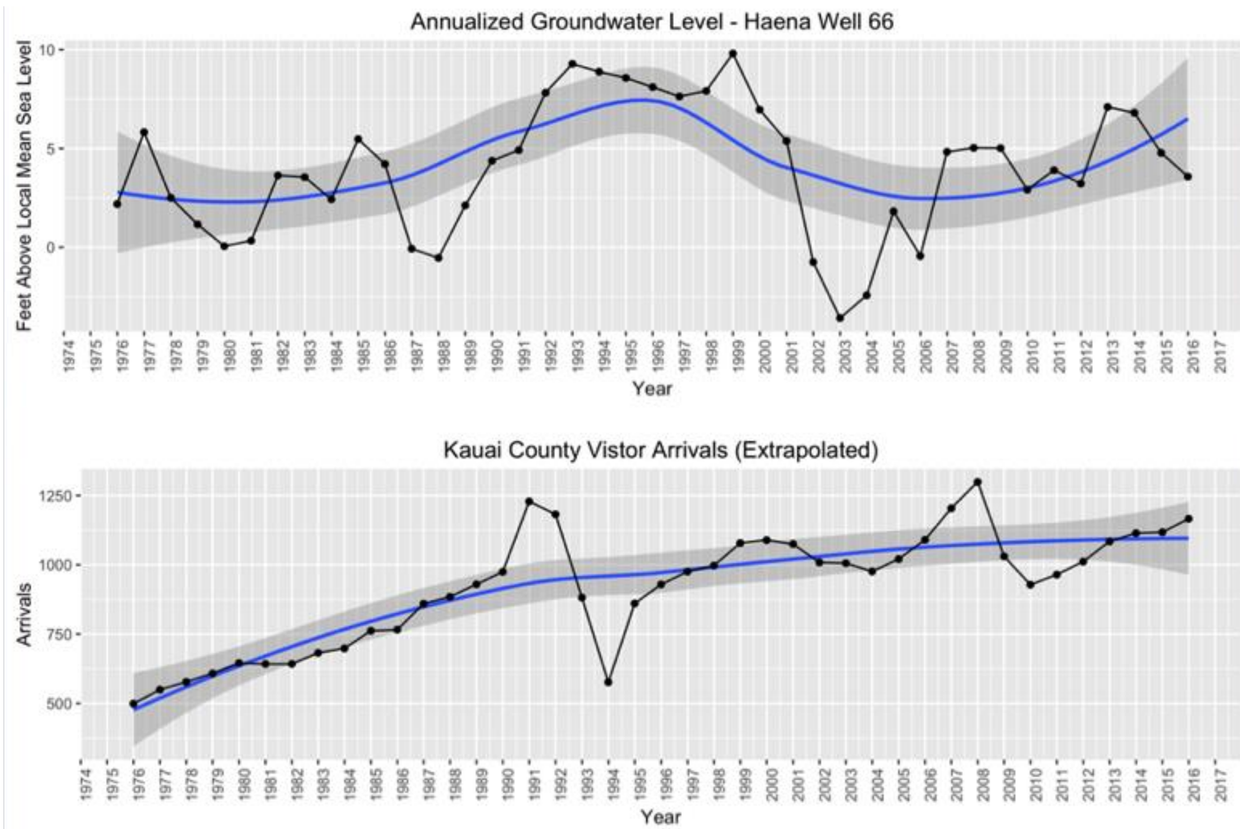
Table 7. Groundwater Level Models and Variable Significance

	Independent Variables	Wetlands Living Area	OSDS	Visitors & Hau	Visitors & Lo'i	Well Pumpage	Limahuli Streamflow
SOCIAL	Visitor Arrivals			0.0077**	0.0081**	0.010.	0.079*
				0.0023	0.0029	0.0049	0.025
	Wetlands Living Area	0.000012					
		0.000017					
	Well Pumpage					27.16	38.89.
						16.30	15.89
	On-Site Disposal System		0.03				
			0.05				
	Ungulate Fencing	1.25	0.92	2.91	4.37	0.74	
		2.89	3.17	2.47	3.01	2.76	
	Hau Presence in Limahuli Strm			3.47**		2.93.	0.063
				1.14		1.43	3.03
	'Auwai & Lo'i Revival				-4.30*		
					2.02		
ECOLOGICAL	Hurricane Iwa	1.15	1.15	2.30	1.82		
		3.27	3.28	2.87	3.04		
	Hurricane Iniki	7.66***	7.66***	6.46***	7.82***	7.79*	29.85*
		1.90	1.90	1.73	1.75	3.00	10.17
	Precipitation	-0.0015	0.00	-0.0072	-0.0048	-0.010	-0.05
		0.0083	0.01	0.0073	0.0077	0.009	0.03
	Limahuli Streamflow						0.32
							0.27
	Intercept	2.76.	2.66	-5.11.	-2.19	-7.97	-79.98*
		1.57	1.68	2.66	2.42	5.66	25.59
	F-Statistic	3.772 | 5/35 DF	3.76 | 5/35 DF	6.282 | 6/34 DF	4.984 | 6/34 DF	5.181 | 6/21 DF	12.64 | 6/5 DF
	P-Value	0.0078	0.0079	0.00016	0.00093	0.0021	0.0068
	Adj R2/Variance Exp.	0.26	0.26	0.44	0.37	0.48	0.86
	AIC	209.82	209.87	198.91	203.62	139.40	53.40
	BIC	221.82	221.86	212.62	217.33	150.05	57.28
	Years of Observations	1975 to 2015	1975 to 2015	1975 to 2015	1975 to 2015	1988 to 2015	1994 to 2005

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Of the six multiple-regression models created to represent groundwater levels, four included visitor arrivals. This variable was significant each time it was included. However, the relationship between visitor arrivals and groundwater levels is positive rather than negative. It was hypothesized that more visitors would contribute to the drawdown of groundwater levels. Rather than dismiss this relationship as spurious it is believed that a relationship exists as a symptom of spillover effects from the way tourism affects a specific place. This model does not capture the intricacies of the spillover effects, and therefore the direction of the relationship is counter to what was hypothesized. Figure 35 shows the slight upward trend that both variables have, but the relatively abrupt increases and decreases in each variable have not been accounted for. It is possible that this relationship could be applied to other social-ecological systems once the place specific implications of the tourism industry on groundwater levels are fully understood. The measurement validity of the relationship between groundwater levels for this local well and the tourism industry could be improved if the island wide Visitor Arrivals variable were replaced with something more granular and specific to the visitor patterns of the resource system such as visitors to *Hāʻena* State park, lifeguard counts at the beaches or cars parked in the area per day. This replacement data would have to be continuously monitored with other measurements over a similarly long period of 40 years to conduct this type of analysis.

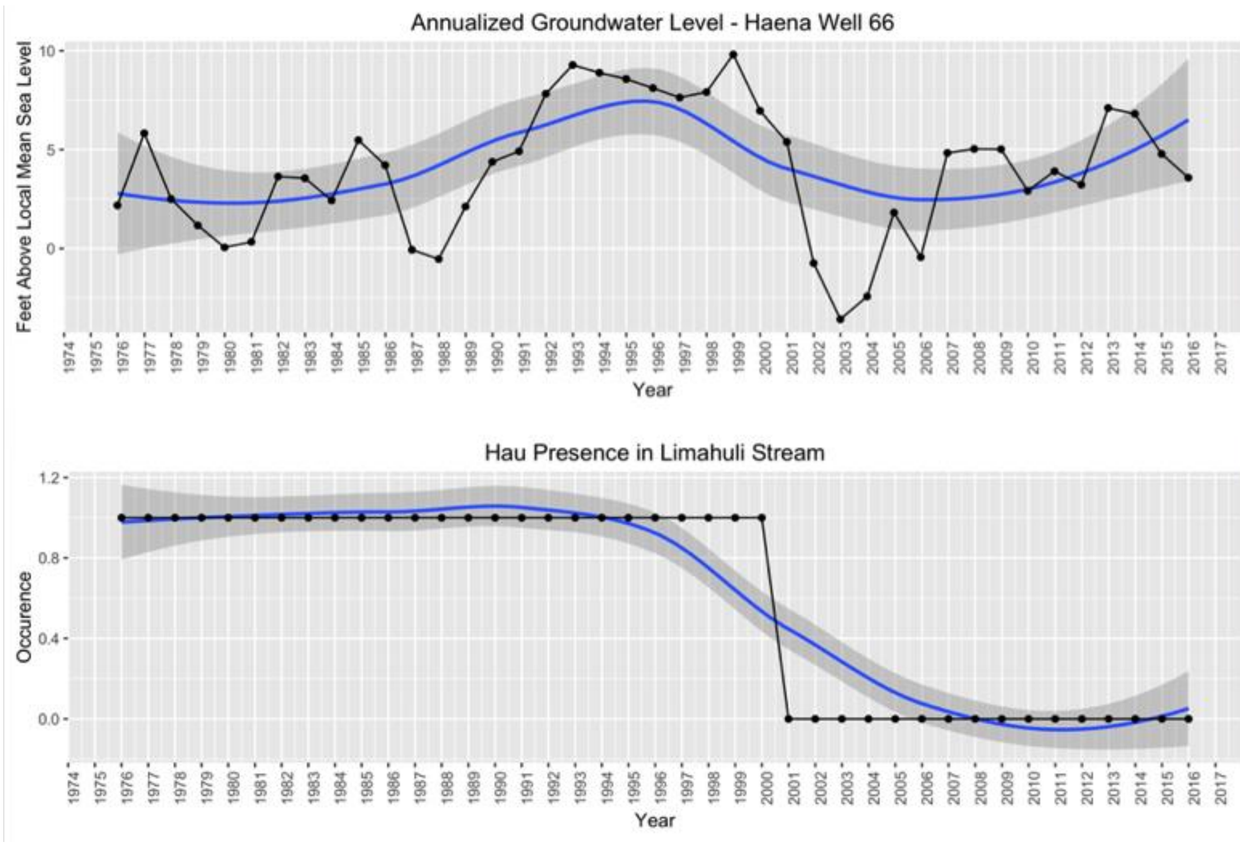
Figure 35. Groundwater versus *Kauaʻi* Island Visitor Arrivals



The relationship between groundwater levels and presence of *hau* trees clogging *Limahuli* Stream is especially interesting if you see the concurrently steep drops around the year 2000 (see Figure 36). This relationship between groundwater levels and presence of *hau* was tested on the longest sets of data, 1975 to 2015, and it was found to be significant. The relationship was slightly less significant when tested from 1988 to 2015 to include well pumpage. When the set of years was reduced from 1994 to 2005 the relationship was no longer significant. The groundwater level from 10 feet above mean sea level in 1999 to almost -3 feet below mean sea level, correlates with the removal of half an acre of thick *hau* grove that was impeding movement of native stream species to complete their life cycle upstream (Cabin 2011). It may be the case that this relationship suffers from a Type 1 error where a relationship is inferred, but none exists. However, there is not a clear explanation for the dramatic drop in groundwater levels.

Streams can be an area of groundwater recharge and an area of discharge if the in-channel flow is full enough for surface water and ground water exchange. There is strong evidence that groundwater recharge is greater when surface water is diverted away from the stream channel and stored in riparian areas or alluvial aquifers versus either entering the aquifer through the stream bed or through extreme precipitation events (Stanford and Ward 1988; Workman and Serrano 1999).This could have wide-impact for many neglected and overgrown streams and forests in *Hawai'i*. The external validity has not been confirmed. However, proving the external and ecological validity could be straightforward if groundwater levels were monitored after an equally large natural obstruction is removed from a pristine stream with similar native species diversity. Proving internal, external, and ecological validity would necessitate the deductive validity of the relationship between groundwater levels and obstructive *hau* removal. It would be interesting to concurrently track the data required to measure a native species-based index of biological integrity for Hawaiian stream environments (Kido 2013). The removal of overgrown stream barriers could dramatically decrease groundwater levels, but it will definitely allow for growth of native stream algae (Sherwood and Kido 2002) and full maturation of amphidromous species that end their life-cycle upstream (Cabin 2011, Kido 2008, Kido 1999).

Figure 36. Groundwater Levels versus *Hau* Presence in *Limahuli* Stream

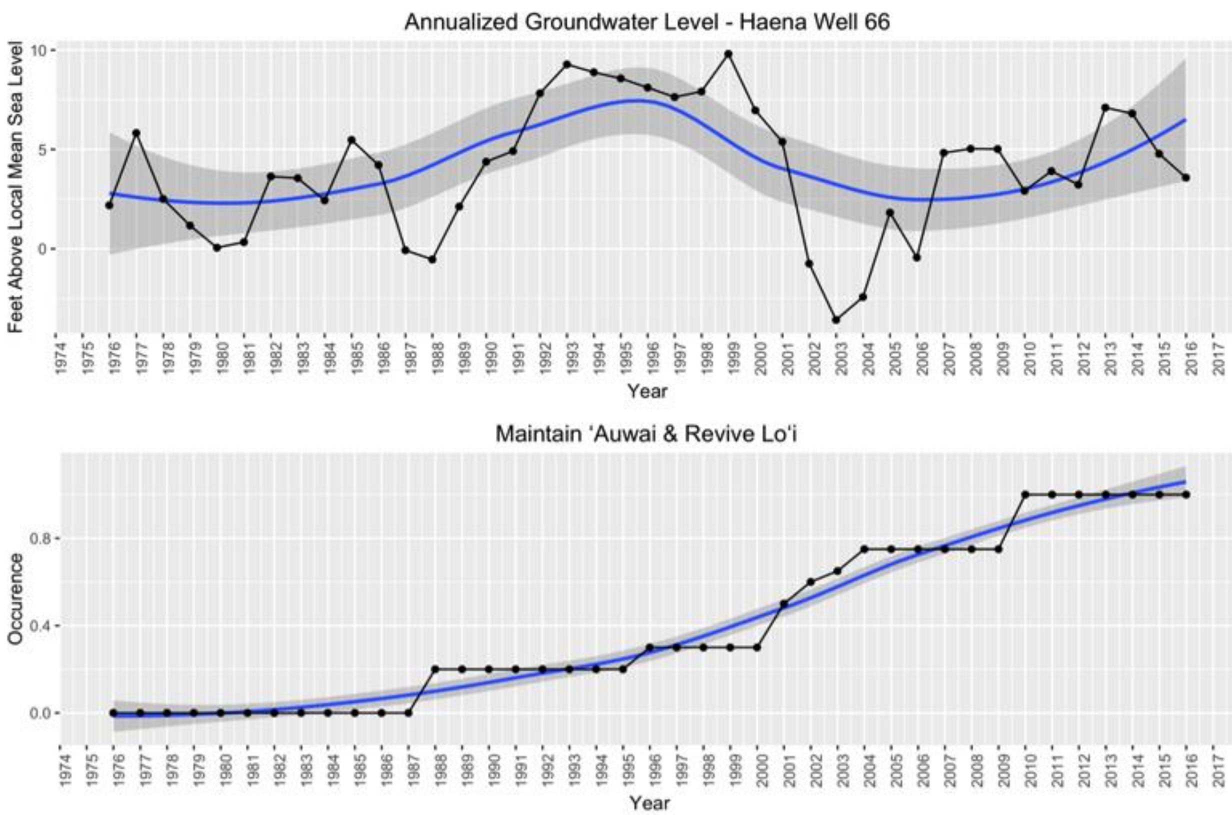


The revival of flooded agricultural areas known as *lo'i* and the irrigation provided by natural contours was operationalized into a variable by estimating the current area of restored agricultural land and plotting when different patches were revived. An indicator variable was created, but the measurement validity could be improved if exact square area revived was plotted over time. This variable was only tested in one groundwater level model, but a significant negative relationship with groundwater level can be inferred from this model results. Figure 37 shows the consistently increasing nature of the *'auwai* and *lo'i* revival variable. Conversely, groundwater levels had peaks and troughs during the 1975 to 2015 time period. This lack of co-movement of the variables could explain the negative relationship.

The previous section explained that a *hau* dam diverted surface flow away from contact with ground water stream channel discharge, which hypothetically explains the relationship between high groundwater levels and the presence of hau. In the case of *'auwai* & *lo'i* revival these ditches and patches provide flooded areas that allow for ground flow to escape, therefore decreasing groundwater levels. The *hau* removal in 1999 potentially influenced a large drop in ground water because surface water was no longer being stored in riparian areas. After the removal, an increase in in-channel flow potentially contributed to the dramatic decline in groundwater levels. Shortly prior to this, in 1998, the slow process of *lo'i* revival was occurring in the coastal flood plain of the State park. This continued restoration effort may be creating ponded areas for groundwater storage once discharge increased after *hau* removal.

If in fact a relationship does exist between *'auwai* & *lo'i* revival variables explaining the hydrology of the aquifer could be considered for omitted or instrumental variables. The validity of the relationship between *'auwai* & *lo'i* revival and groundwater levels could also have wide impact across the Hawaiian Islands. Ultimately, the dynamics of the underexplored island aquifer system should be considered to understand the impact of obstructed streams and increased seepage of groundwater flow from flooded areas.

Figure 37. Groundwater Levels versus *'Auwai & Lo'i* Revival

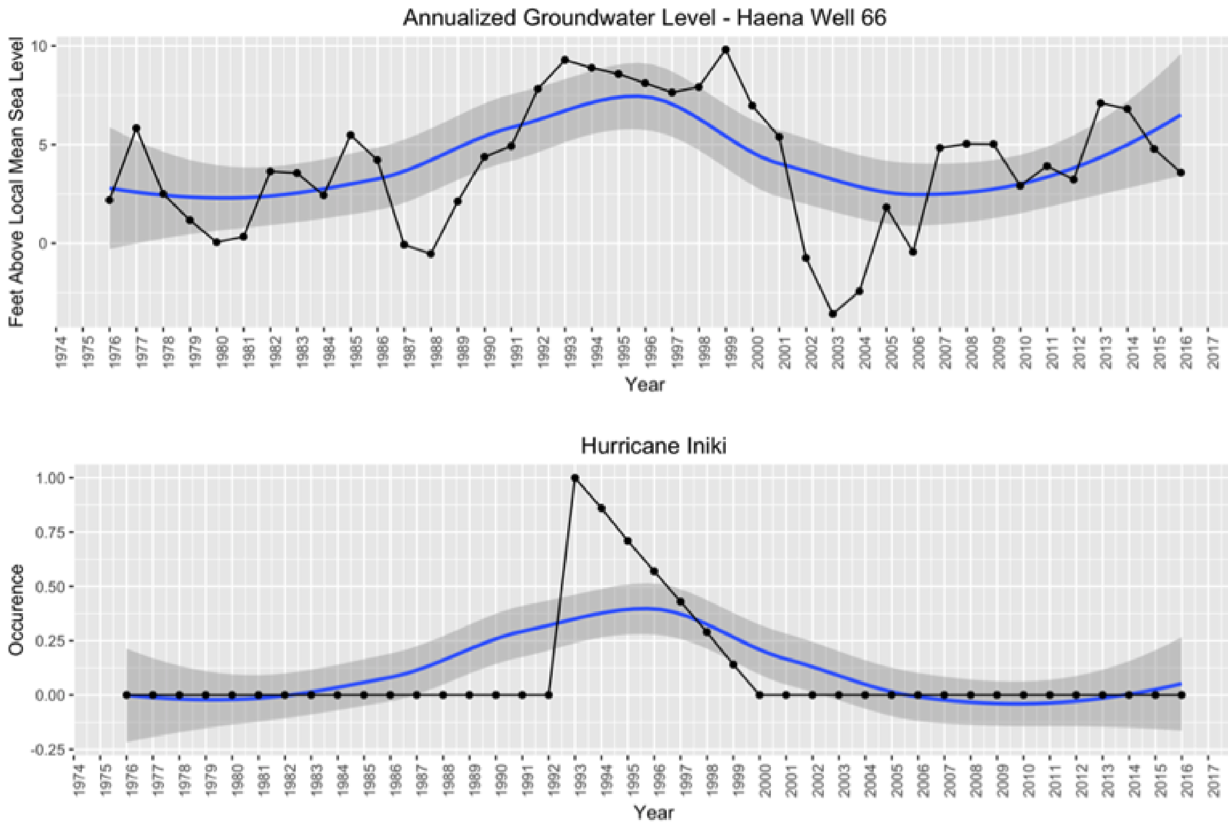


The relationship between a social variable such as the economic impact of Hurricane *'Iniki* and the ecological variable of groundwater levels may seem spurious. However, when looking at Figure 38 it is visible that the 1992 impact of Hurricane *'Iniki* correlates with a peak reached by groundwater levels in the same year. These levels sustained themselves and make a steep drop from 1999 to 2003 mentioned earlier when discussing the relationship between groundwater levels and the removal of *hau* in *Limahuli* Stream. The economic impact of Hurricane *ʻIniki* also tapers off around this time. It was tested in all six models for groundwater levels, and was significant in each one.

One hypothesis is that omitted or instrumental variables can explain the relationship between the removal of *hau* and groundwater levels. In the case of the economic impact of Hurricane *ʻIniki* the relationship is a part of a much larger series of social and ecological spillover effects. The estimate of seven years for economic recovery after Hurricane *ʻIniki* (Coffman and Noy 2012) heavily factored in unemployment rates which may be an important social and ecological link. Since hurricanes impact geographic locations in dramatically different ways, the relationship between economic impact and local groundwater levels would be place specific. To improve measurement validity more granular socio-economic data would have to be compared to local groundwater levels.

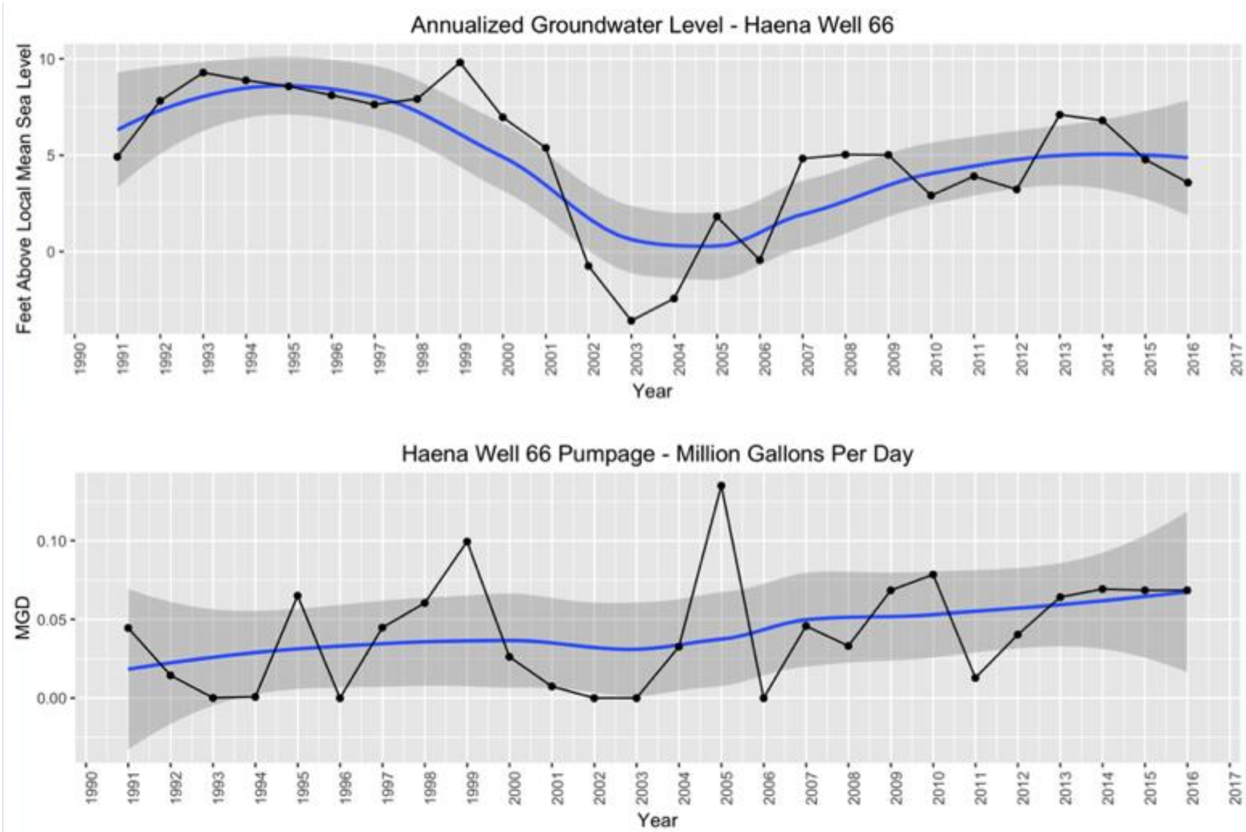
It may also be the case that the seven-year ramped down indicator variable represents something else besides economic recovery. *Hāʻena* was the last stop for Hurricane *ʻIniki* as it whipped through the center of *Kauaʻi* in a north-northeasterly direction. In its path, it uprooted a lot of native vegetation in the forested valleys of *Hāʻena*. A decrease in absorption and fog intercept from native species could explain the slight decline in groundwater after 1992 (Figure 38). Then additional removal of the *hau* dam between 1999 and 2000 could explain the dramatic drop in ground water levels after 2000 (Figure 4.2).

Figure 38. Groundwater Levels versus Economic Impact of Hurricane *ʻIniki*



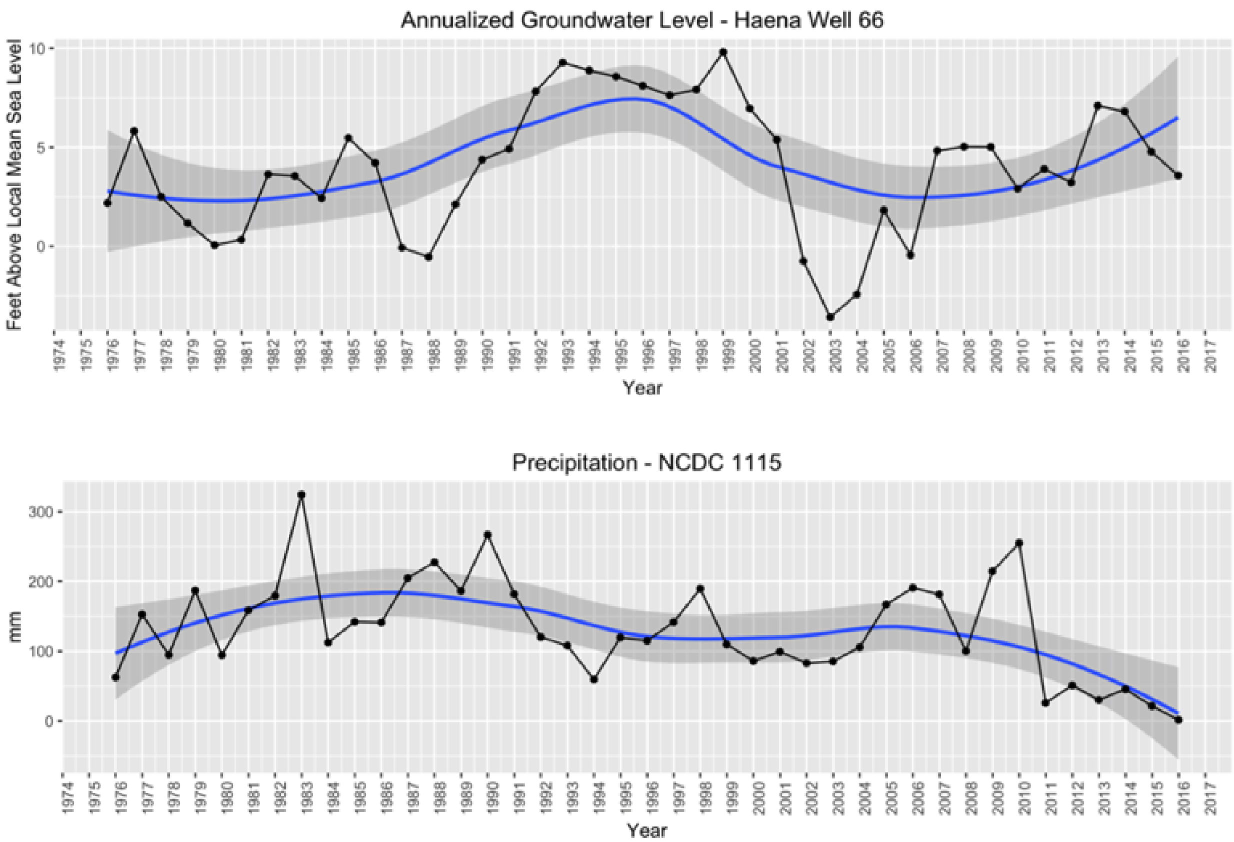
Well pumpage was included in a model that spanned from 1988 to 2015 and another from 1994 to 2005. It was only slightly significant in the model from 1994 to 2005. This is surprising considering the similar trough from 1999 to 2005 (see Figure 39). This model may suffer from a deficiency in observations, which decreases its measurement validity. This appears to be a Type 2 error where the model infers there is a weak or no relationship between groundwater levels and pumpage, when in fact there is one. Understanding the relationship between groundwater levels and well pumpage could have wide application for water distribution and pricing throughout *Hawai'i*. Longer sets of data and omitted variables may improve the internal and external validity of this relationship. This would create deductive validity and the opportunity to confirm ecological validity in wells and aquifers across *Hawai'i*. According to a map of aquifer structures (DLNR 2010) it appears that the *Hā'ena* well from which measurements were taken sits on or near a dike aquifer which may affect the hydraulic dynamics of groundwater levels (USGS 2015).

Figure 39. Groundwater Levels versus Well Pumpage



Precipitation was tested in all six of the models and was not found to have a significant relationship with groundwater levels in any of them. The lack of co-movement can be seen in Figure 40. Given the role that both of these variables play in the water cycle, this lack of inference appears to be a Type 2 error. Omitted variables such as run-off, recharge, ocean capture, reservoir storage, and evapotranspiration rates could better account for the relationship between precipitation and groundwater levels. This is reported as a result of the model because it points to the role that the landscape plays on groundwater level recharge. The ecological validity of the relationship between precipitation and groundwater levels could be widely tested.

Figure 40. Groundwater Levels versus Precipitation



4.3.2 Coastal Salinity Model

The overall measurement validity for these variables is weak given the short sets of data with observations from 1990 to 2015 and 1990 to 2005. Five models were created focusing on each of these variables or variable combinations: Cumulative Living Area on Wetlands, On-Site Disposal Systems, *ʻAuwai* & *Loʻi* Revival, *Hau* Presence in *Limahuli* Stream & Ungulate Fencing and Streamflow (see Table 8). Precipitation and the economic impact of Hurricane *ʻIniki* were used as independent variable in all five models. Only the economic impact of Hurricane *ʻIniki* was found to be significant.

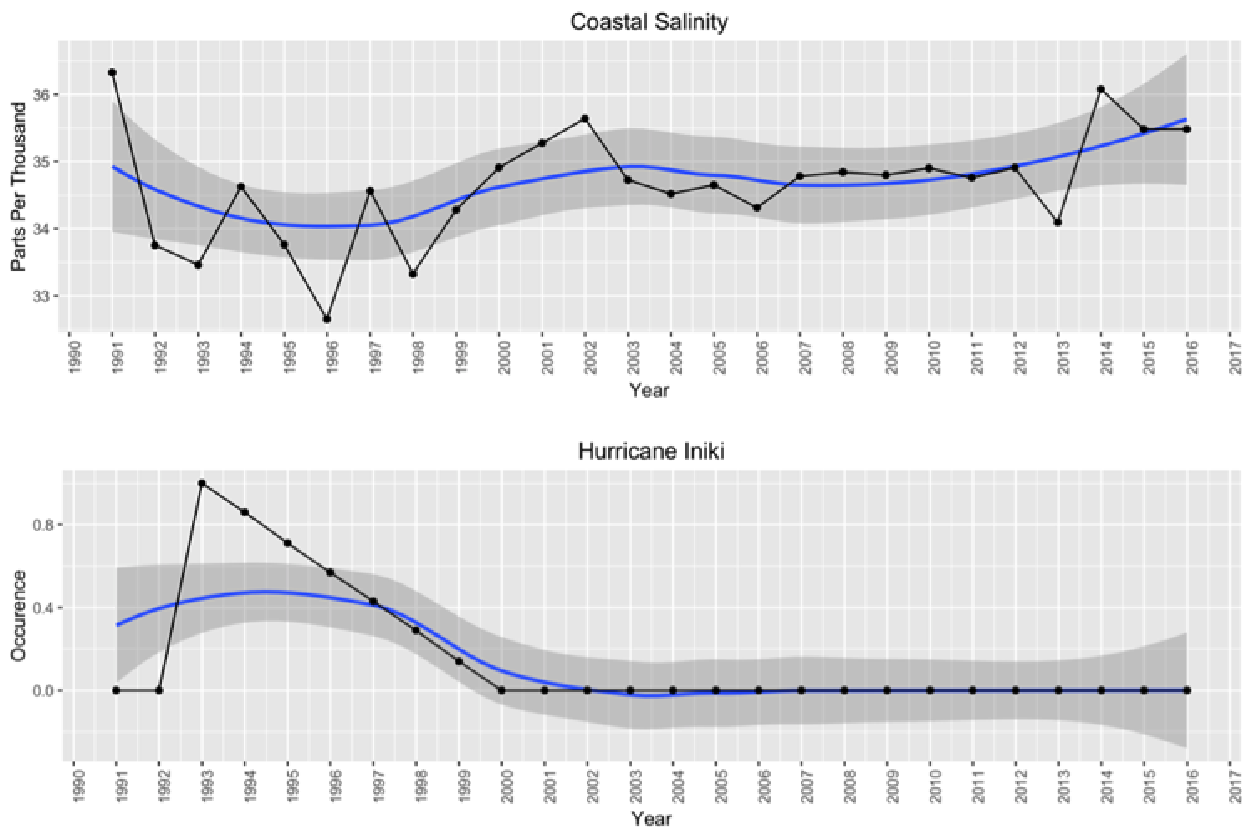
Table 8. Coastal Salinity Models and Variable Significance

	Independent Variables	Wetlands Living Area	OSDS	‘Auwai & Lo‘i	Hau & Ungulate	Streamflow
SOCIAL	Living Area on Wetlands	-0.0000096				
		0.000014				
	Well Pumpage	2.72	2.97	2.93	0.81	1.58
		5.43	5.45	5.21	4.82	4.33
	On-Site Disposal System		-0.0045			
			0.029			
	Ungulate Fence	0.57			0.30	
		0.87			0.84	
	Hau Presence				-0.18	
					0.43	
	‘Auwai & Lo‘i Revival			-0.13		
				0.73		
ECOLOGICAL	Hurricane Iniki	-1.40.	-1.28.	-1.29.	-1.25.	-2.14*
		0.73	0.69	0.70	0.68	0.69
	Precipitation	-0.0026	-0.0031	0.00	-0.0018	-0.0075
		0.0031	0.0029	0.00	0.0029	0.0049
	Limahuli Streamflow					
	Groundwater Level	-0.042	-0.035	-0.04		
		0.056	0.056	0.06		
	Intercept	35.83***	35.38***	35.33***	35.04***	35.65***
		1.15	1.07	0.76	0.43	0.59
	F-Statistic	1.98 on 6 and 19 DF	2.28 on 5 and 20 DF	2.29 on 5 and 20 DF	2.29 on 5 and 20 DF	4.48 on 3 and 8 DF
	p-value	0.12	0.085	0.085	0.084	0.040
	Adj R2/Variance Exp.	0.19	0.20	0.20	0.21	0.49
	AIC	66.45	65.34	65.33	65.29	26.42
	BIC	76.52	74.14	74.14	74.10	28.85
	Years of Observations	1990 to 2015	1990 to 2015	1990 to 2015	1990 to 2015	1990 to 2005

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Similar to the relationship between the economic impact of Hurricane *‘Iniki* and groundwater levels, the economic impact of Hurricane *‘Iniki* and coastal salinity is explained by a series of social and ecological spillover effects. However, coastal salinity involves more unpredictable marine factors than groundwater level, so the relationship between the social aspects of economic recovery and ecological factors involved with coastal salinity are more complicated to link. The negative relationship between these variables can be seen in Figure 41. During the 1992 to 1999 period when the indicator variable for the economic impact of Hurricane *‘Iniki* is greater than zero, coastal salinity is experiencing a relative dip in values. This infers that the coastline was relatively less salty during these years. Overall coastal salinity had a short range between a high just over 36 parts per thousand to a low just under 33 parts per thousand, but the trend line is shaped in a trough during these years. Precipitation did not have a large increase after the 1992 hurricane, so it is hard to attribute this decrease in salinity directly to increased fresh water from the hurricane. Similar to groundwater, it would be interesting to understand if a social factor such as unemployment or decreased earnings has an impact on coastal salinity. The measurement used to describe the economic impact of Hurricane *‘Iniki* is island wide and this analysis attempts to make a correlation with the measurements from a specific location. This discrepancy in measurement scale may be causing this spurious relationship. The relationship between a location specific measurement of coastal salinity and the social factors contributing to economic impact seem so place-based that the external validity seems unlikely. The seven-year period from 1992 to 1999 marks a relatively low period for both groundwater levels and coastal salinity. The same spillover effects are likely to explain the relative dip for both measures, which are linked to freshwater storage and distribution.

Figure 41. Coastal Salinity versus Hurricane *'Iniki*



4.3.3 Well Chlorides Model

The well chloride models test the same development-related independent variables as the groundwater level model*: Kaua'i* island visitor arrivals, cumulative living area on wetlands, well pumpage, and cumulative on-site disposal systems (see Table 9). The development variables related to construction in the area, cumulative living area on wetlands, and cumulative on-site disposal systems, had significant relationships with well chlorides, but not groundwater levels.

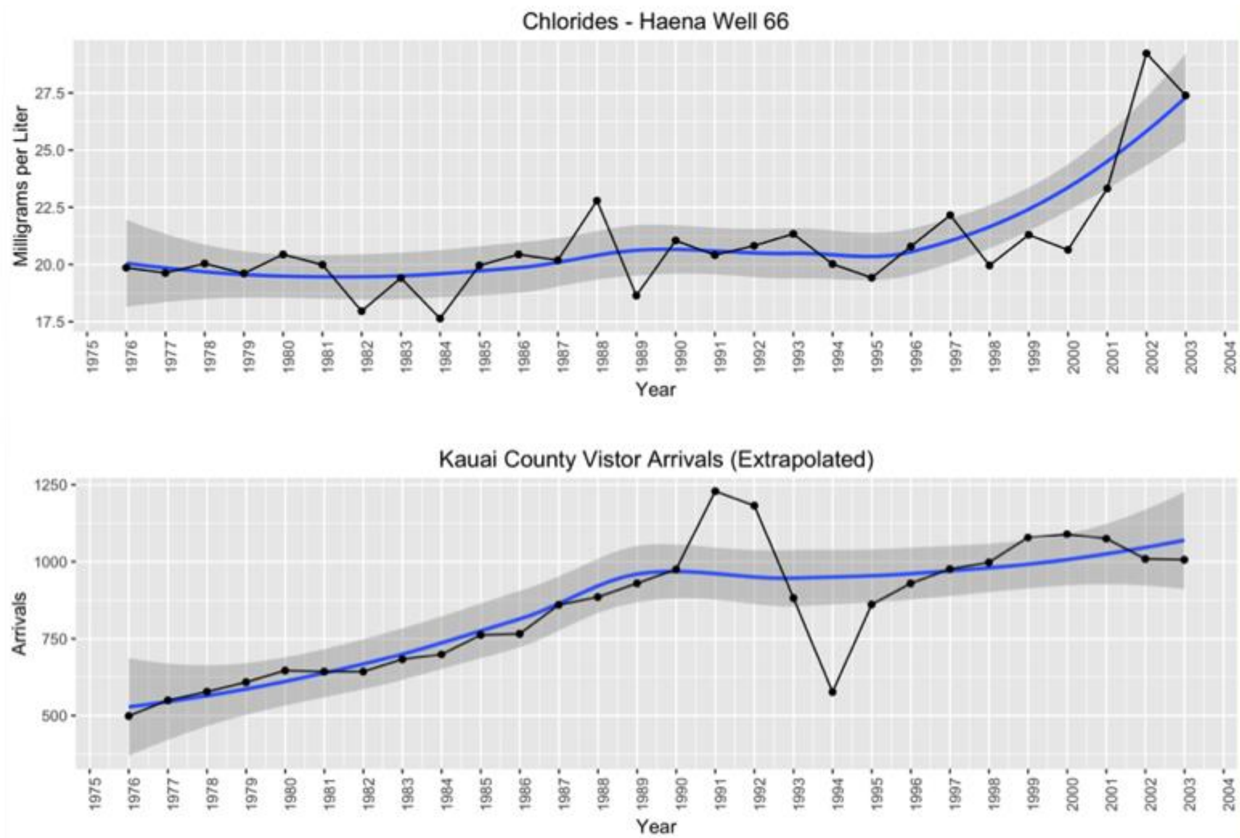
Well chlorides may be more tied to construction than groundwater levels. These models test a shorter set of data from 1975 to 2002 for four models, and 1988 to 2002 for the model that focuses on well pumpage. The County of Kauai stopped collecting well chloride data in 2002. Presence of *hau* in *Limahuli* Stream, *'auwai* and *lo'i* revival, and *Kaua'i* island visitor arrivals are significantly related to both well chlorides and groundwater levels. Groundwater level was a significant independent variable in the well chlorides models. A better hydrological understanding of *Hā'ena* could explain the relationship of these freshwater storage and distribution variables.

Table 9. Well Chlorides Models and Variable Significance

	Independent Variables	Wetlands Living Area	OSDS	Visitor Arrivals	'Auwai & Lo'i	Well Pumpage
SOCIAL	Visitor Arrivals			0.0040*		
				0.0017		
	Wetlands Living Area	0.000049*				
		0.000017				
	Well Pumpage					-11.04
						15.16
	On-Site Disposal System		0.16*			
			0.061			
	Hau Presence in Limahuli Strm	-3.21*	-3.348*	-4.69***		
		1.49	1.51	1.21		
	'Auwai & Lo'i Revival				10.32***	14.99**
					1.30	4.60
ECOLOGICAL	Hurricane Iwa	-0.25	-0.15	0.54	1.12	
		1.63	1.66	1.79	1.50	
	Hurricane Iniki	0.96	0.58	2.14.	0.33	0.56
		1.12	1.18	1.17	1.06	1.46
	Precipitation	0.00092	-0.000054	0.00	-0.0049	0.0013
		0.01	0.0057	0.01	0.0048	0.010
	Groundwater Level	-0.28*	-0.27*	-0.25*	-0.27**	-0.12
		0.12	0.12	0.12	0.083	0.17
	Intercept	23.13***	22.60***	22.94***	20.87***	17.85***
		1.48	1.71	1.71	0.86	3.20
	F-Statistic	13.44 on 6 and 21 DF	12.94 on 6 and 21 DF	12.32 on 6 and 21 DF	17.93 on 5 and 22 DF	10.62 on 5 and 9 DF
	p-value	0.0000031	0.0000041	0.0000060	0.00000042	0.0014
	Adj R2/Variance Exp.	0.73	0.73	0.72	0.76	0.77
	AIC	100.36	101.19	102.26	97.02	58.45
	BIC	111.02	111.84	112.92	106.35	63.41
	Years of Observations	1975 to 2002	1975 to 2002	1975 to 2002	1975 to 2002	1988 to 2002

Figure 42 shows that both the well chlorides variable and *Kaua'i* island visitor arrivals both have an overall upward trend. However, there is no co-movement in well chlorides to suggest the dip in visitors after Hurricane *'Iniki* had any influence. The lack of significance of the economic impact of Hurricane *'Iniki* also points to this fact. The relationship between increased visitor arrivals and well chlorides is something that could be measured better if the visitor data were more location specific. Location specific visitor data would improve external and ecological validation of this relationship. Isolating these place specific relationships could improve understanding of the spillover impacts of tourism on fresh water resources. Once this place-specific correlation is better understood, the ecological validity can be tested in other resource systems.

Figure 42. Well Chlorides versus *Kaua'i* Visitor Arrivals



Cumulative living square footage on wetlands has an upward trend like the visitor data, but slightly steeper (Figure 43 and Figure 44). Cumulative living square footage on wetlands is a proxy for impervious surfaces that impede recharge. This measurement could be improved if aerial image capture over the years was available to calculate increase of impervious surface area, including roads and ungulate trails. Building plans submitted for permit are available, but this would be a very time-consuming task to calculate for all parcels. Additionally, not everything that gets built is necessarily permitted. The on-site disposal systems were calculated from submitted permits. However, for many parcels with known homes no type of on-site disposal system such as a cesspool, septic tank, or aerobic unit was recorded. Only about a third had a reasonable number of bathrooms recorded for the number of bedrooms. Inclusion of this missing data would greatly improve the measurement validity of this relationship. Research on groundwater and effluent flow has been conducted statewide to correct for the underestimate of on-site disposal systems and consider aquifer structure (Whittier and El-Kadi 2014). However, data was not available to test relationships over a long period of time.

The cumulative on-site disposal systems were used to represent amount of effluent discharge entering the well or groundwater over the years. Omitted variables could explain the relationship between effluent discharge and well chlorides as well as the relationship of impervious surfaces and well chlorides. Given the weakness of the current measurement validity the external validity of these relationships is still questionable, but once confirmed the external and ecological validity could be widely relevant to other social-ecological systems.

Figure 43. Well Chlorides versus Living Square Footage on Wetlands

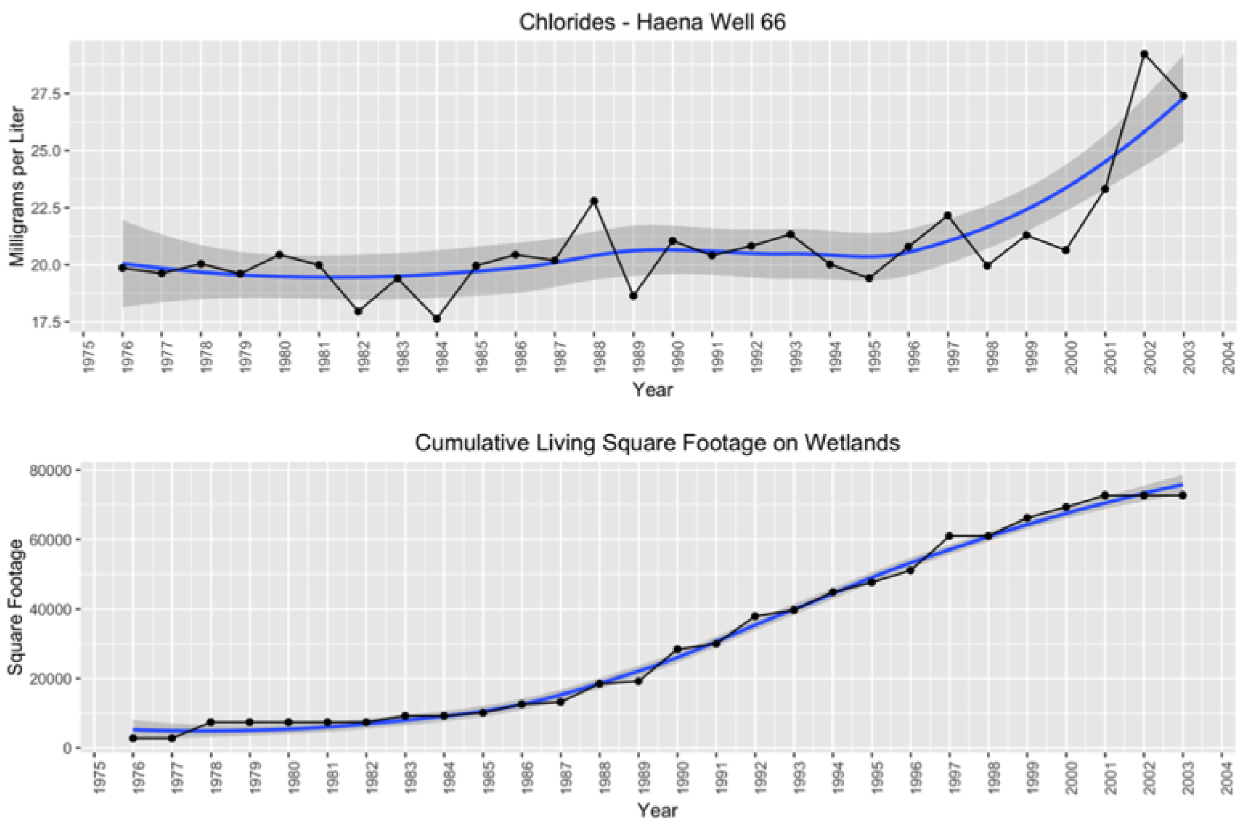
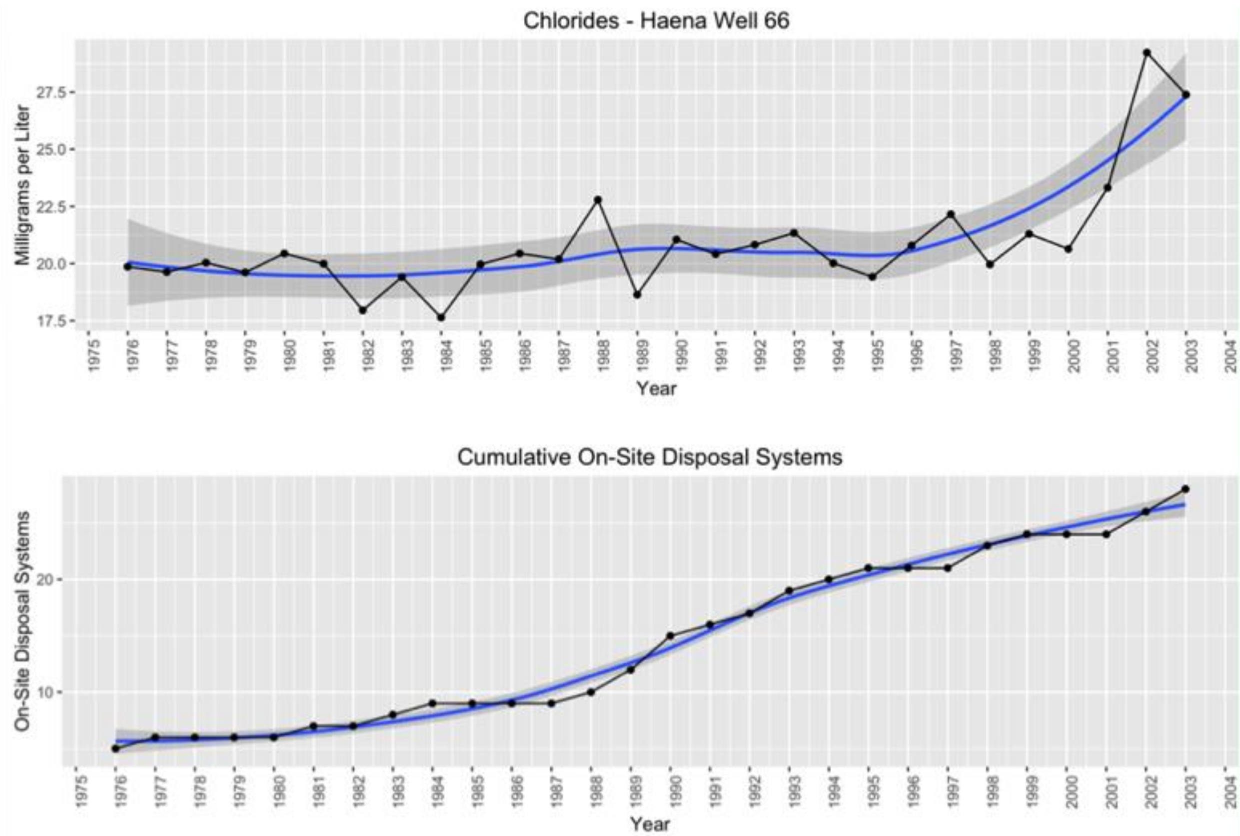
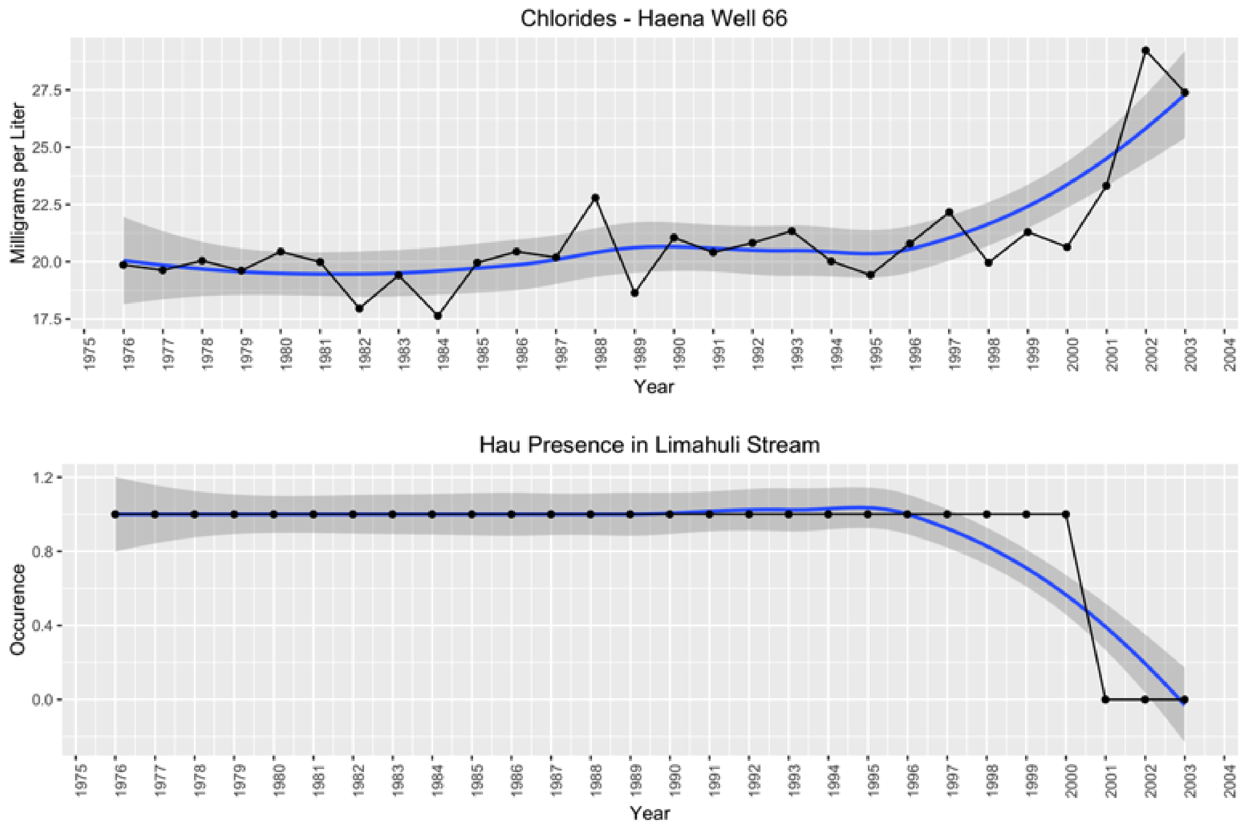


Figure 44. Well Chlorides versus Cumulative On-site Disposal Systems



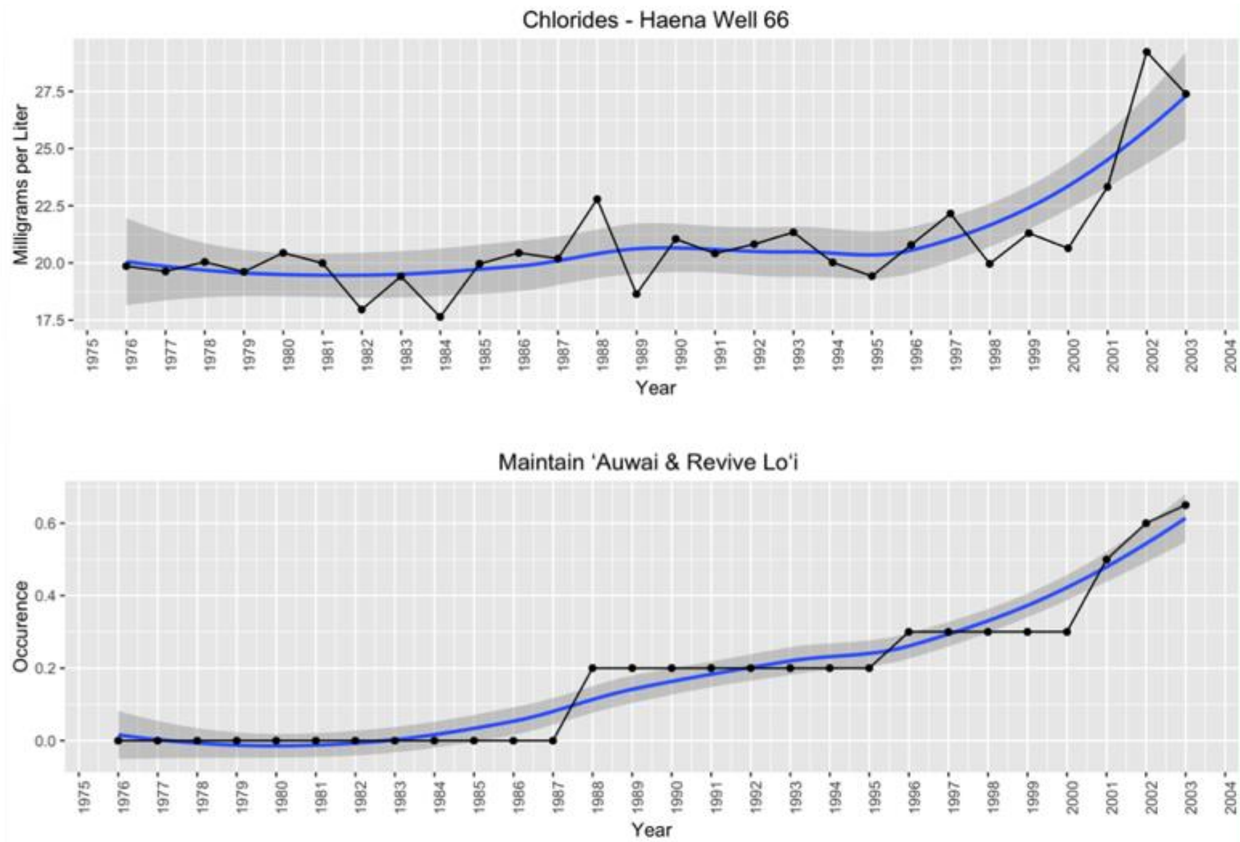
Three of five well chlorides models include *hau* presence in *Limahuli* Stream, and it tested to be significant in all of them. The negative relationship is apparent in Figure 45 as the trend line for the *hau* presence indicator variable takes a downward turn just as the well chlorides took a steep upward turn in 1996. Well chlorides take a dramatic upward jump from a little over 22.5 milligrams per liter to almost 28 milligrams per liter in 2001, just after the *hau* is removed from 1999 to 2000. Given that *Limahuli* Stream and the well sit relatively far from each other in different catchment basins this relationship may seem spurious. However, these locations do sit on the same aquifer, and likely have some omitted variable to explain their hydraulic connection. Any external validity for the relationship of *hau* removal to groundwater levels or well chlorides could have impactful management implications in other *ahupuaʻa* with obstructed streams. The ecological validity could be tested in steams where natural barriers obstruct the upward movement of native stream species using groundwater levels and a native species index for stream biological integrity (Kido 2013).

Figure 45. Well Chlorides versus *Hau* Presence in *Limahuli* Stream



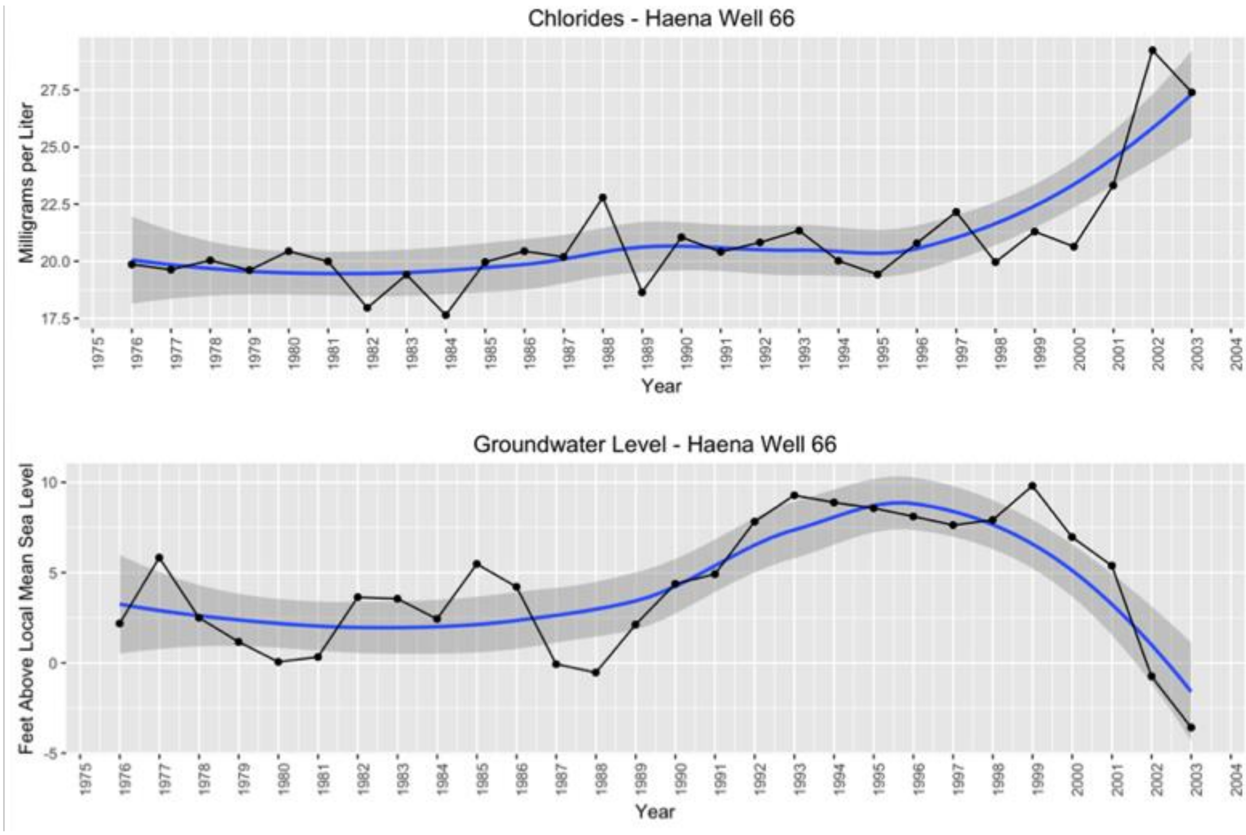
ʻAuwai and *loʻi* revival was tested in two models for well chlorides, and it was significant in each one. One model spanned from 1975 to 2002 that focused on *ʻauwai* and *loʻi* revival and the other from 1988 to 2002 that included well pumpage. The trend line has a similar upward run as cumulative living area built on wetlands and on-site disposal system installations (Figure 46). As mentioned earlier, the measurement for *ʻauwai* and *loʻi* revival could be improved if timing of actual square footage was used. A large area of *loʻi* was revived around 1998, which also coincides with a spike in well chlorides. The relationship between well chlorides and *ʻauwai and loʻi* revival may be spurious, but greater understanding of aquifer and groundwater flow hydraulics may be able to explain the cause for this correlation. It is possible that these revived flooded areas provide points for freshwater to escape the aquifer, which would increase the concentration of well chlorides (Westbrook, Cooper, and Baker 2006). It may also be the case that the ponded areas allow for increased residence time of groundwater, holding in certain chlorides (Helton et al. 2014).

Figure 46. Well Chlorides versus *ʻAuwai* and *Loʻi* Revival



Concurrently opposing inflection points between well chlorides and groundwater levels around 1996 is apparent in Figure 47. If this relationship has true internal validity the implications for *Hā'ena* is possible saltwater intrusion of their fresh water source (Paine 2003). A confounding factor could be that the well sits on a dike aquifer (DLNR 2010), which may affect the dynamics of groundwater levels and thus well chlorides. Understanding the relationship of newer USGS well chlorides measurements from 2006 to 2011 to the County of Kauai measurements from 1975 to 2002 could help prove the internal validity of this relationship. This would allow the Kauai County Board of Water Supply to notify possibly affected parties and prepare for alternate delivery of freshwater. Confirming the external and ecological validity of the relationship between groundwater levels, well pumpage, and well chlorides could greatly improve freshwater management across the state.

Figure 47. Well Chlorides versus Groundwater Levels



4.4 Implications for Social and Ecological Outcomes

Creating quantitative time series variables and conceptual models discussed in Chapters 3 helped to answer the second research second research question: what statistical social-ecological relationships have occurred over time in *Hāʻena*? This chapter answers the third research question: how can this research improve social and ecological outcomes?

This overall research was conducted to set a foundation for a shared understanding of the social-ecological system. To create this foundation a wide range of existing qualitative and quantitative information was collected. Existing information was used to spread awareness about what has already been discovered about a place. Retelling and reanalyzing previous lessons in a current context encourages the continuation of knowledge sharing. When this researched information is presented back to the community of people who interact with the system and make decisions for it, the information can be further enhanced and given context with feedback from actual stakeholders.

The inferred relationships found from the statistical models discussed in Chapters 3 and 4, are merely correlations based on available data. This is opposed to measuring relationships based on deliberately collected data that answer specific questions. A wide spectrum of data must be collected in order to find useful social and ecological indicators. Common pool natural resources are often not monitored, but it becomes a requirement in cases where government and community stakeholders agree to co-manage. The creation of long term monitoring programs is essential to gauge the impact of co-management efforts. Setting success measures and the appropriate indicators to monitor must also have some degree of stakeholder consensus to ensure desired outcomes are aligned. Looking to existing data is a good way to begin structuring a monitoring program since there is already protocol around collecting data and a history of observations. Data not currently collected for monitoring can be pinpointed based on the goals and outcomes shared by stakeholders.

Commonly desired social and ecological outcomes across resource system actors are often missing when pursuing public policy regarding shared natural resources. Agreement to co-manage is a big barrier to overcome, since it forces stakeholders to state their requirements for desired outcomes. A shared platform for future caretaking can start with a shared understanding of the current state based on prior transitions. Further substantiating history with quantitative data can only improve agreed understanding across stakeholders. There are two main reasons why this historical research used a wide range of sources for historical observations. The first was to make up for a dearth of available social and ecological system data. The second was to look for relationships that have not been previously discovered or considered.

After examining relationships found to be significant through these statistical models, more granular visitor information can be found to test internal validity of the place-specific relationship between tourism, groundwater, and well chlorides. Testing the impact of removing natural stream barriers, especially *hau*, on groundwater and chloride levels in other resource systems can help inform what happened in *Limahuli*. It would also help explain the dramatic drop in groundwater levels from 1999 to 2003. Additionally, understanding the relationship between flooded areas such as *loʻi* and *ʻauwai* with decreased groundwater levels and increased chlorides would be helpful to other communities looking to reclaim cultural caretaking of their coastline. An overall model for understanding the dynamics between well pumpage, groundwater flow, and aquifer storage can lead to information on how to manage the health of shared natural resources throughout the system. Further validating the relationship between impervious surfaces and effluent discharge on well chlorides could have important implications for permitting and zoning guidelines that impact the health of the resource system. Finally, of all the relationships found in this research, it is most important to test the validity of the relationship between well chlorides and groundwater levels in *Hāʻena*. If confirmed these results point to potential saltwater intrusion of the aquifer. If internal and external validity are confirmed, wells throughout *Hawaiʻi* should be tested to find other aquifers with possible saltwater intrusion.

4.5 Future Research and Management Investigations

Examining the validity of existing data sources provides a benchmark from which to build a monitoring program to measure co-management goals. The goal is not to maximize each type of validity, since there are trade-offs between them. Rather, the goal is to evaluate if the relationship between the independent and dependent variable is real. Understanding why the relationship is not valid can help explain the broader mechanics of the situation. Confirming the validity of a relationship indicates the information can be acted on, and if not evaluation of validity can point to better measurements. This research can lead to data collection and monitoring approaches that are more purposeful and account for finer scale seasonal changes that are important for understanding the health of the ecological system. Such subtle seasonal changes is knowledge held by the most experienced resource system users such as subsistence gatherers and cultural practitioners. Some of this information has been passed on for generations, and it can be useful to sustain and monitor a healthy social-ecological system.

Hui Makaʻāinana o Makana and the staff at *Limahuli* Garden and Preserve, have been observing subtle seasonal change from within the soil and underwater upwards to the sky and everything in between. Records are qualitatively and quantitatively recorded until patterns reveal themselves or match up with information passed down from earlier generations (Cadiz 2017). These types of observations should be used in conjunction with quantitative analysis to confirm the overall validity of monitoring and co-management. The knowledge gained from general seasonal observations can be shared for generations to come.

CHAPTER 5

CONCLUSION

5.1 Applications for Systematically Examining History of a Place

Stakeholders with longstanding generational ties to *Hāʻena* have negotiated ways to co-manage the area with the State of Hawaii. They have persevered through early stages of co-management negotiations, and have created rules for the near shore area (Vaughan et al. 2017). Operationalizing of established social-ecological system frameworks provide a way to methodically establish the history of a place for all parties engaged in collective caretaking and rulemaking. Operationalizing the ‘nested focal action situation’ concept (McGinnis 2011b) in this research uncovered actors groups within the resource system that should be considered or included when creating rules and taking care of shared natural resources. This systematic historical examination points to which actor groups have the most experience with the natural functions of the local ecosystem, and how all possible actor groups should be considered when making rules. A list of diagnostic questions (Hinkel et al. 2015) can be used to tease out how each actor group interacts with the system. Operationalizing the Management Transition Framework (Pahl-Wostl et al. 2010) provided a more detailed examination that links related historical events and outcomes leading to the current state of resource management units within the system. Recognizing these sub-systems enhances understanding of how a resource system functions ecologically while recognizing the management and governance forces that affect the system. This social and ecological perspective is important when aligning goals for overall management of the system. This system-wide thinking can also help achieve goals for specific resource units affected by the surrounding ecosystem. Looking at past management transitions also forces consideration of previous human-environment interactions that provided abundantly for resource system actors. Lessons can be learned from these interactions that can sustain a healthy SES for future generations.

Examining an SES can help diagnose the characteristics of failed and successful human-natural resource interactions. Researchers study social-ecological systems to understand conflicts within a system and sometimes to offer principles that foster abundance in certain types of systems. Ostrom (2009) established a lexicon for SES research that has been employed and adapted for case studies all over the world. This research operationalizes the most recent evolution of Ostrom's seminal work (McGinnis 2011b). Generally, social-ecological system case studies compare different places or examine a single place in a static way. Focusing on particular points in time these studies seek to diagnose issues by isolating resources of interest to understand the current actors, governance system, and external forces. In contrast, this study takes an in depth and nuanced look, using a wide-breadth of data sources focused on a single system as it has evolved dynamically over two centuries. This research builds upon two social-ecological system frameworks, which stress scrutiny of history and tracing related events over time. A handful of other case studies have looked at transitions over time, especially to understand the role of successful governance (Barnett and Anderies 2014, Bernstein 2013).

Tracing related events over time can also offer insights into the processes that explain the current state of the system as well as reveal previous human-environmental interactions that maintained its system health. Case studies rarely employ such a systematic approach to examining history. The reliance on historical information and quantitative evidence was meant to strengthen a shared understanding of the system across diverse stakeholders. This systematic approach was designed with the intention to create substantiated common ground so policy can move forward faster. This analysis can also be used to share knowledge with future generations, and to help establish monitoring programs focused on goals agreed upon by all stakeholders.

It can moreover be a way of uncovering documented knowledge that can be reapplied to care for the system. The next extension of this research would be to dig further into history for the knowledge documented in Hawaiian language newspaper. Examining history further can expose a wider variation in cultural practices that can explain how the natural function of the system has changed. It may provide a better blueprint for taking care of shared common pool resources such as fresh water.

5.2 Elucidation of Social-Ecological System Components

The main take away from operationalizing the two SES frameworks is that a good understanding of a social-ecological system can be built from understanding when new actors were introduced to the system, and how they interact with it. Secondly, looking for different areas of fresh water management with separate governance provides an overall understanding of the full ecological system, while understanding the management transitions that have led to the current state. Someone who has had extensive experience in the system can approximate these system characteristics. However, an outside researcher can provide objectivity by ensuring information is corroborated and balanced by other perspectives. An initial estimation of actor groups and fresh water management areas by various stakeholder groups may help minimize the reinforced literature review process. However, when looking to understand and describe a social-ecological system, it is useful to know that actor groups and management transitions over time are useful descriptors for a system. Statistically comparing time series variables over time uncovered possible unforeseen social and ecological relationships that point to future investigations or long-term monitoring indicators.

5.2.1 Actors

Identifying time periods around important historical events uncovered which groups of actors have had the most experience with the social-ecological system. Actors experience is justified by how long they have been benefiting from the system through activities such as owning land, gathering from the forest, surfing, or fishing. This can be useful for other communities who would like to co-manage shared natural resources with the government and other resource system users. All stakeholder groups should be accounted for when embarking on creating new policy. Identifying all actor groups and their positions is especially important to avoid surprise opposition that may thwart years of collective effort. Identifying all the relevant stakeholders in a given resource system makes it more likely that newly created rules will pass the scrutiny by all affected parties (Vaughan and Caldwell 2015).

5.2.2 Resource Management Areas

The Management Transition Framework (MTF) more closely links historical outcomes to their subsequent action situations. Rather than just chronologically order historical observations, related events were threaded together, and six historical subplots for smaller resource management units in the overall system were exposed: coastline, streams, alluvial plain (State park), *Limahuli* Valley, *Mānoa* Valley, and the public fresh water transport and storage system. The uncovering of these sub-systems creates a better understanding of the ecology and physical functions within the resource system. It also points to important actors that control resource management areas, which impact other resource units in the system. Aligning goals of actors in related management areas can improve caretaking efforts and build social capital that promotes future coordination of collective efforts to improve the entire social-ecological system.

5.2.3 Social-Ecological Correlations & Possible Relationships

Once agreement is made to collectively manage shared natural resources, rules must be established and a monitoring program set up to measure the success of caretaking efforts. A plethora of unexplored research and quantitative measurements exist that have not been previously shared or incorporated into decision-making or monitoring. This methodology attempts to bring forward buried knowledge about a place to look at related historical events as part of the current system as a whole. With this comprehensive understanding of publically available information important qualitative information was turned into quantitative measures to be statistically compared over time to other existing quantitative data. This approach was taken to broaden understanding of past knowledge and never considered social and ecological system interactions. The results from the statistical comparison of time series variables pointed to the importance of place-based interactions between tourism and groundwater as well as well chlorides. These relationships require more data collection to understand social and ecological interactions. These results also point to a large unexplained drop in groundwater levels from 1999 to 2003 that coincides with the removal of *hau* obstructing upstream movement of native stream species. The potential impact of *hau* removal, the negative relationship between *loʻi* revival to groundwater level and positive relationship to well chlorides beg a better understanding of surface and ground water dynamics. The surface movement of freshwater becomes especially interesting with the unexpected insignificant relationship between precipitation and groundwater. Additionally, well pumpage had an unexpected positive relationship with groundwater levels that seems counterintuitive without a better structural understanding of the underlying aquifer. The negative relationship between groundwater levels and well chlorides should be investigated and monitored closely if in fact the relationship is internally valid. Data monitoring already indicates that the well in *Hāʻena* has a thin freshwater lens (Gingerich and Oki 2000).

The statistical models created in this research were built to look for co-movement between previously disparate social and ecological systems data. The validity of statistical relationships was examined because it was known that the models were built from data sets not intended for the purpose of understanding statistical social and ecological relationships. This means that proxy data was used to represent desired variables or the only available data was sparse or inconsistent. The significant relationships found in the models are purely correlational.

Examination of the validity helped to consider overall social and ecological systems interactions while scrutinizing methods for improved future measurement. The purely correlational nature of statistical model results, allows for consideration of measurement improvement while pointing to future caretaking investigations with potentially important unforeseen impacts.

5.3 New Perspective of the Social-Ecological System from Never-Previously Compared Data

5.3.1 Ecological + Ecological Data

The negative statistical relationship between well chlorides and groundwater levels points to existing ecological data that has never been analyzed for monitoring purposes. The unexpected lack of relationship between groundwater levels and precipitation is another example of important ecological data that has not been fully explored. While these are interesting results this study originally aimed to understand the integrality of the system by comparing social and ecological data.

5.3.2 Social + Ecological

The increasing visitor arrivals, economic impact of Hurricane *ʻIniki*, cumulative living area on wetlands, cumulative on-site disposal systems, *hau* presence in *Limahuli* Stream and *ʻauwai* and *loʻi* revival are variables driven by human interactions with the ecosystem. All of them had a statistical relationship with one or more of the modeled dependent variables. The relationships are not easily explained, as they are probably the result of a series of spillover effects that are not easily measured. The study of social-ecological systems is predicated on the fact that there are no panaceas (Ostrom 2007, Ostrom and Cox 2010, Anderies et al. 2007, Brock and Carpenter 2007). This means that a relationship found in a specific location does not necessitate it should be true everywhere. The dynamics are unique in every social-ecological system.

5.3.3 Quantitative + Qualitative

Quantitative measures are perceived to more objective because patterns can be accounted for and easily explained. Qualitative measures on the other hand are more subjective because patterns must be inferred from unquantified descriptions. However, both quantitative and qualitative measures are open for interpretation. Both types of measures add to the breadth of available information. In order to compare the two types, they must be standardized. The use of indicator variables made standardization of qualitative information possible. It was only possible after gaining a thorough understanding of the system's history. Indicator variables can be employed to answer questions about other specific events. The choice of standardizing data in quantitative form does necessarily mean that this type of data is superior. Some qualitative measures such as the color of the sky, temperament of the sea, and quality of relationships are equally as important for understanding the social-ecological system.

5.3.4 Breadth and Depth of Social-Ecological Systems

This research brought resolution to social-ecological system components such as actors, resource management areas, and statistical social-ecological relationships over time by coalescing a wide breadth of information representative of the historical depth of a single place. This type of whole system thinking required the delineation of boundaries and the definition of variables that focused on human and ecosystem interactions. This breadth is necessary to consider not only all the actors that have entered the system over time, but the ecological system as an actor in itself. The living nature of the social-ecological system makes it the most fundamental actor in the system. It is dependent upon all the SES variables identified by Ostrom (2009), and therefore policy creation and rulemaking should also consider the ideal outcomes for the ecosystem itself. Chapter 2 identified the connection different actor groups had with the ecosystem and the benefits they reap. The inclusion of ecological variables in Chapter 3 attempts to give a voice to the ecosystem by letting the data show the impacts of human interactions on the environment. Chapter 4 attempts to make sense of possible relationships found. The discovered statistical relationships give stakeholders a foundation from which to agree upon future actions that can sustain ecosystem health and the benefits provided through caretaking of shared natural resources.

The cobbling of available data sources for one place was an exercise in itself to see what is available. Any historical times series data provided information about regime shifts and transitions. It also gave a sense of what data is available for long term monitoring, and what data is required to measure and meet stakeholder requirements.

This method, further turned available data into statistical models for understanding bivariate relationships over time. Rule makers cannot immediately benefit from results, but caretakers can propose projects to improve natural geologic and ecologic functions. This type of analysis can also be useful for (prospective) landowners who are interested in long term returns to the health of the overall ecosystem, and not solely market value for opportunistic sale.

5.4 Shared Understanding of the Social-Ecological System

This research aimed to support the notion that a shared understanding of a social-ecological system's history can help clarify possible social-ecological outcomes and how they should be prioritized. Established social-ecological system frameworks and concepts were operationalized to create a methodical way of creating a shared understanding of the social-ecological system. This method used any publically available English language data to synthesize and chronologically order a wide breadth of qualitative and quantitative historical observations. This publically available information was then shared with caretakers of the place who have been connected to the system their whole life and interact with it often. This was done to bring forward the researched knowledge, but also to add context from their perspective. Anecdotal data from discussions with a community of people who frequently interact with the system combined with transcribed oral interviews from previous system users gave clarity to the collected historical observations rather than merely corroborate it. Another benefit of this knowledge exchange was the intergenerational transfer of information. Younger community members were present to hear information and stories they never knew. This increases the chance that they will pass this information on to the next generation of caretakers so there is continuity and a shared understanding of how the ecosystem functions and the lessons learned from previous management regimes.

Marrying researched data with the lived experience of people who have a long history of interacting with the system can help to create a shared understanding of the social-ecological system. This provides a platform upon which to create shared desired outcomes for the system. This platform also allows for prioritization of policies and programs that will achieve these outcomes. A shared understanding also creates social capital across user groups that will promote collective action toward common goals. Creating a shared understanding is similar to the way the *konohiki* created social capital by gathering information and coordinating resources for everyone's benefit. Central and representative institutions can play a modern role in adapting and passing on knowledge about ecosystem function that has been tested by previous generations. Future goals require monitoring that goes beyond mere data collection and incorporates monitoring that includes observations from being in the place that may or may not need to be recorded. Prior to Western contact such observations were not recorded in Hawaiʻi, but shared from generation to generation creating a continuous relationship between people and place.

Within this system experts passed on their knowledge to apprentices and younger generations as a way of constantly monitoring the place and sanctioning this method for future generations. This sharing sustained families, abundance of resources, and reciprocal caretaking across a social-ecological system.

Identifying all actor groups and their benefits helps in creating rules that are congruent for each actor and would lead to a collective-choice arrangement (Ostrom 1990). Including important actors in the early stages of rulemaking allows all parties to be represented in the process of creating institutions and policies (Vaughan and Caldwell 2015). Appropriate monitors can be defined based on who needs to know the information for provisioning purposes and who is benefitting. Knowing benefits allows for effective setting of sanctions that can be graduated as actors break rules multiple times. Also, providing a low-cost dispute resolution mechanism becomes easier when the network of actors and their relationship to the governance system is understood. Additionally, recognition by the governance system of all appropriators and their right to self-organize is in itself a design principle for successful common pool resource management (Ostrom 1990). Lastly, sustainable management for common-pool resources requires nested enterprises meaning responsibilities regarding appropriation, provisioning, monitoring, enforcement, conflict resolution and governance is organized in multiple layers across entities with jurisdiction over various scales.

Agreement on the current situation among all possible stakeholders is an ideal state to achieve. The methods offered in this research are aimed to do so, but are quite intensive. A wide breadth of information had to be collected to draw these conclusions together. The process used to operationalize the ‘nested focal action situation’ and Management Transition Framework was intensive because of the data collection process. This effort could be minimized if actors with more system experience helped to lay the guideposts for pivotal events, actor introductions and interactions, and fresh water management areas and transitions. The input of an independent researcher is still useful for problem framing, facilitation, and to search sources that may not be considered by actors involved in the system. The efforts of a Hawaiian language researcher could also be employed to uncover more human-environment relations that were never translated to English. Hawaiian language descriptions of the ecological system and people’s interactions can expose practices congruent for the people and the place.

The methodical linking of historical observations that was required for the Management

Transition Framework may not be necessary. The results of the methodology employed exposed fresh water management areas. The relationship between the historical sub-plots discovered when operationalizing the MTF and fresh water was an unintentional discovery. However, the methodical linking could be bypassed, and delineation of fresh water management areas could be made without the effort required to arrive at the sub-plots. Once these areas have been identified, past management transitions can be analyzed based upon discussions with system actors. The most important output from the MTF is the agreement of a current state. However, equally as important are the transitional action situations that led to the current state. Lessons from these situations as well as from periods of sustained congruent human-environment relations should be important input for future policy. A researcher's independent perspective is helpful once input has been given by a diverse set of key stakeholders. The researcher can then scour sources to confirm and add to this initial groundwork. These conclusions can only have been made in hindsight since the outputs of what would come of operationalizing these frameworks was unknown.

The initial intention was to find time-series information from qualitative sources that could be compared to existing time series data. However, the quantitative time series data was sparser than expected. Many desired data sets required a lot of collation such as canopy cover or land surface changes over time. Proxies needed to be devised. Data such as aggregate cumulative square footage required intensive data collection that was only possible via computer-aided gathering. Another barrier to conducting this type of research is that the data is not collected in the format required to answer the questions in which people are interested. One way to avoid this is to be intentional about what is monitored. With a shared vision of the social and ecological system across stakeholders, goals can be set and the proper metrics to monitor progress can be collected on a long-term basis. This vision needs to adapt to new actors and external drivers, but the value of important social-ecological relationships must be passed on if they are to sustain. The ultimate beneficiary of this approach is the land. Human activities impact the environment. Without intentionally monitoring our impacts and maintaining relationships with our natural surroundings, the requirements of the environment get put aside. In the end, our future generations pay by no longer having the same access to natural resources such as fish and fresh water that enhance and sustain humanity.

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This is a list of cultural practices that began with mentions from Maly and Maly (2003) that was then shown to intergenerational members of *Hui Maka'āinana o Makana*. In that presentation (Feb 2016) practices were clarified and added

LAWAI'A

'Upena (Net)

Sew net

- Sew net: soak for dye or to harden
- Sew net: string
- Sew net: fishing line

Surround net

- Surround net: free dive
- Surround net: boat

Hukilau

- *Hukilau: māhele*
- *Hukilau: ho'oku'u*
- *Hukilau: kilo*
    - *Hukilau: kilo: Hale Pōhaku*
    - *Hukilau: kilo: above Maniniholo*
- *Hukilau: sell*

Ho'olei (Throw net)

Bag net

- Bag net: skin dive
- Bag net: SCUBA

Bang-bang net

- Bang-bang net: Chase fish off edge of reef to shoreline (*easy catch for everyone*)

'Upena ho'omoe (lay net)

- *'Upena ho'omoe:* fish
- *'Upena ho'omoe: ula (lobster)*
- *'Upena ho'omoe:* turtle

'Upena for *hinana*

'Upena ho'opae (cluster, made from guava)

Spear

Spearfish

- Spearfish: harpoon
- Spearfish: sharpened fence wire, bamboo & tube rubber
- Spearfish: long handle, kind of fat, 2 to 3 inches in diameter

Spearfish: Hawaiian sling
Spearfish: Speargun
Spearfish: SCUBA and spear
Spearfish: heʻe
Spearfish: ula

Trap

Fish *imu*
Paniwai (o ʻīao)
Kahe

Pole

Kāʻili (drift fishing in traditional canoe)
Kāmākoi
Kākā (two iron poles on the reef with line across)
Deep sea longline
Casting
Dunking

Other

Stick (heʻe)
Bare-handed
Bare-handed: manini
Bare-handed: 'o'opu (hāhā)
Bare-handed: ʻōpihi
Bare-handed: ula (lobster)
Bare-handed: wana
Bare-handed: loli
honu
Slip noose (honu)
Fish poison
Fish Poison: natural plants
Fish poison: Bleach the reef
Dynamite

Customs

Hoʻomaha (seasonal fishing kapu)
Kūʻula: (Call fish with stick)
See under water
See under water: glass box
See under water: coconut or kukui (natural) oil
See under water: cooking oil
Torch fishing
Night fishing: bamboo & kukui nuts

Night fishing: kerosene/burlap
Night fishing: flashlight
Feed *mana* stone
Feed *ko‘a*
Beliefs
Beliefs: no ‘*ōpe‘a kua* (crossing hands behind back)
Beliefs: don't bring bananas
Beliefs: bad omens (*‘alalauwā*)
Beliefs: swear/lie to throw off *kepalō*
From Place
From *‘auwai*
From *kahawai*
Loko Kē‘ē

MAHI‘AI
Poi preparation
Poi: pounder
Poi: mill in *Hā‘ena*
Poi: mill outside *Hā‘ena*
Lo‘i
Lo‘i: everyday maintenance
Lo‘i: fed by ditch and stream
Loi: kūpa‘a (pack) *kipikipi* (trimmings) after *lomi* (mix) back into soil for fertilizer
Loi: for home consumption
Loi: plow
Pu‘e (mound)
Maintain *‘auwai*
Taro cook house (*Hale kuke‘ai)*
Hale
Hale: Thatch houses
Hale: Wood

PANIOLO
‘āhiu (feral) livestock (cows, horses & goats)
‘āhiu: cows
‘āhiu: horses
‘āhiu: goats
Wrangle and break-in
Seasonal round-up

OTHER CULTURAL PRACTICES

Burials

- Burials: *Puʻuone*
- Burials: On your plot
- *Konohiki*

Hula hālau at *Kēʻē*

Moʻolelo

ʻOahi

Oli

Weaving

- Weaving: *Moena* (mat)
- Weaving: *Ulana Papale*

Use moon for fishing and planting

Orange indicates different materials used for that practice
Red indicates a method or style for that practice
Green indicates a species associated with that practice

APPENDIX B Ecological Time Series Data

Data Set	Unit	Start Date	Last Date	Frequency	Source
Monthly Mean minimum temperature		10/1/49	5/1/14	Monthly	NOAA-NCDC
Total precipitation	mm	10/1/49	5/1/14	Monthly	NOAA-NCDC
Monthly Mean maximum temperature		10/1/49	5/1/14	Monthly	NOAA-NCDC
Discharge	cfs	10/2/98	9/2/05	Monthly	USGS
Gage Height	ft	9/30/94	10/6/05	Random	USGS
Streamflow/Discharge	cfs	9/30/94	10/6/05	Random	USGS
Species diversity per site	1/d, Berger-Parker Index	Jan-98	Feb-04	monthly/bi-monthly	Kido
Sig correlated species abundances		Jan-98	Feb-04	monthly/bi-monthly	Kido
Monthly Pumpage Data	Mg	Dec-87	Sep-13	monthly/bi-monthly, incrd freq	Kauaʻi County Board of Wtr
Monthly Pumpage Data	Mgd	Dec-87	Sep-13	monthly/bi-monthly, incrd freq	Kauaʻi County Board of Wtr
Monthly Pumpage Data	Chlorides (PPM)	Jan-06	Mar-11	monthly/bi-monthly, incrd freq	Kauaʻi County Board of Wtr
H20 lvl - ft above spec vert datum	Feet above Local Mean Sea Level	6/7/73	10/30/13	Random	USGS
Temperature	Degrees Celcius	10/4/72	8/21/02	Random	USGS
Specific Conductance, unfiltered	microsiemens per centimeter at 25 deg C	10/4/72	8/21/02	Random	USGS
Chloride, water, filtered	milligrams per liter	10/4/72	10/15/93	Random	USGS
Chloride, water, unfiltered	milligrams per liter	11/5/73	8/21/02	Random	USGS
Clostridium perfringens	#/100ml (before 2005) - cfu/100ml (after 2005)	8/2/93	3/19/14	Random	EPA-STORET
Dissolved oxygen (DO)	mg/l	3/2/92	3/19/14	Random	EPA-STORET
Dissolved oxygen saturation	%	8/4/05	3/19/14	Random	EPA-STORET
Enterococcus	cfu/100ml	6/4/90	3/19/14	Random	EPA-STORET
Fecal Coliform	MPN (before 1991) - #/100ml (after	6/4/73	9/7/93	Random	EPA-STORET

	1991)				
pH	pH level	3/2/92	3/19/14	Random	EPA-STORET
Salinity	ppth (Before 200	6/4/90	3/19/14	Random	EPA-STORET
Temperature, water	Degrees Celsius	12/2/91	3/19/14	Random	EPA-STORET
Turbidity	NTU	8/7/02	3/19/14	Random	EPA-STORET
Clostridium perfringens	#/100ml (before 2005) - cfu/100ml (after 2005)	4/12/93	3/19/14	Random	EPA-STORET
Dissolved oxygen (DO)	mg/l	3/2/92	3/19/14	Random	EPA-STORET
Dissolved oxygen saturation	%	8/4/05	3/19/14	Random	EPA-STORET
Enterococcus	cfu/100ml	6/4/90	3/19/14	Random	EPA-STORET
Fecal Coliform	MPN (before 1991) - #/100ml (after 1991)	6/4/90	9/7/93	Random	EPA-STORET
pH	pH level	3/2/92	3/19/14	Random	EPA-STORET
Salinity	ppth (Before 200	6/4/90	3/19/14	Random	EPA-STORET
Temperature, water	Degrees Celsius	12/2/91	3/19/14	Random	EPA-STORET
Turbidity	NTU	9/14/99	3/19/14	Random	EPA-STORET
Coral 1m benethic, by species		1999	2004	1999, 2000, 2002, 2004	Winward Commnity College-CRAMP
Coral 10m benethic, by species		1999	2009	1999, 2000, 2002, 2004, 2008, 2009	Winward Commnity College-CRAMP
Handpick- No. of licenses		1972	2000	Annual	Friedlander
Handpick- No. of trips		1972	2000	Annual	Friedlander
Handpick- No. Caught		1972	2000	Annual	Friedlander
Inshore handline- No. of licenses		1972	2013	Annual	Friedlander
Inshore handline- No. of trips		1972	2013	Annual	Friedlander
Inshore handline- No. Caught		1972	2013	Annual	Friedlander
Inshore handline- lbs caught		1972	2013	Annual	
Net- No. of licenses		1967	2013	Annual	
Net- No. of trips		1967	2013	Annual	
Net- No. Caught		1967	2013	Annual	
Net- lbs caught		1967	2013	Annual	

Spear/dive- No. of licenses		1974	2014	Annual	
Spear/dive- No. of trips		1974	2014	Annual	
Spear/dive- No. Caught		1974	2014	Annual	
Spear/dive- lbs caught		1974	2014	Annual	
(Tax) Year				Annual	
Tax				Annual	
Tax Classification				Annual	
Total Market Value				Annual	
TotalAssessedValue				Annual	
Mrkt/Assessed				Annual	
Unemployment Rate					
Employment		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Total Nonfarm Jobs		1972	2014	Monthly, but can get Annual	Census- Fact Finder
Construction & Mining		1972	2014	Monthly, but can get Annual	Census- Fact Finder
Manufacturing		1972	2014	Monthly, but can get Annual	Census- Fact Finder
Trade, Transport & Utility		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Information Jobs		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Financial Activities		1972	2014	Monthly, but can get Annual	Census- Fact Finder
Professional & Business Services		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Educational & Health Services		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Leisure & Hospitality		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Other Service Jobs		1990	2014	Monthly, but can get Annual	Census- Fact Finder
Total Government Jobs		1972	2014	Monthly, but can get Annual	Census- Fact Finder
Visitor Expenditures		2003	2015	Monthly, but can get Annual	DBEDT
Visitor Days		1992	2015	Monthly, but can get Annual	DBEDT
K. County Total Expenditures		1979	2015	Monthly, but can get Annual	DBEDT
K. County Total Revenue		1979	2015	Monthly, but can get Annual	DBEDT
K. County Highway & Streets Expenditures		1979	2015	Monthly, but can get Annual	DBEDT
K. County Tax Revenue		1979	2015	Monthly, but can get Annual	DBEDT