# Land Use Planning in Maui, Hawaii to Prevent Sedimentation of Fringing Coral Reefs

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# Abstract

One of the greatest threats to coral reefs of the Hawaiian Islands is sedimentation from land-based sources. Sedimentation occurs when runoff from storm events carries terrigenous sediments into the marine environment. Once in the marine environment it increases turbidity and eventually settles onto the coral, effectively smothering it. The severity of sedimentation depends on the type of sediment, the sediment load, and the residence time of the sediment.

Land use that results in exposed soil, such as development, causes an increase in sedimentation. Because sedimentation begins on land, the policies addressing it must also be focused on the land. Current land use policy in Maui does not effectively address sedimentation, as it only tries to minimize the total sediment load. Land use policy does not address residence time of the sediment. Residence time is limited by wave exposure. Where wave exposure is higher, sediment is removed faster, thus having less impact on the coral. In order to effectively limit the impact of sedimentation, there must be spatially explicit land use regulations that require sediment filtration, density restriction, increased limits to total exposed soil, impervious surface restrictions, while encouraging habitat restoration and open space preservation, in areas where wave exposure is low.

To better understand spatial and temporal variations in wave exposure in Maui, I created a GIS-based model of nearshore wave exposure. Using a model such as the one described here to identify critical areas that are more susceptible to sedimentation could result in more effective management of Maui's reefs.

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# Introduction

The nearshore waters around the island of Maui, Hawaii are home to extensive fringing coral reef ecosystems. Like coral reefs throughout the world, these reefs are experiencing an overall decline in health and abundance that can be attributed to a variety of anthropogenic disturbances. Some of these disturbances include coral bleaching caused by increased ocean temperatures, nutrient loading and freshwater input from injection wells, destructive overfishing, ocean acidification, uncontrolled snorkeling and dive tourism, and sedimentation from land-based sources (Riegel et al. 2009; Richmond et al. 2007).

There have been attempts to manage the human behaviors that affect Maui's reefs and mitigate these disturbances in the recent past. Marine Life Conservation Districts (MLCDs) have been established to address overfishing and the impacts of excessive tourism (National Marine Protected Areas 2009). There have been efforts to treat more wastewater to re-useable levels, thereby reducing the volume injected in the substrate. This reduces both freshwater input and nutrient loading to marine waters (West Maui Watershed Management Project 1996). Fishing regulations have been established that limit the amount of herbivorous fish taken from the ecosystem. Herbivorous fish limit algal growth that can outcompete coral (DAR 2010). Threats that originate outside of the coral reef ecosystem, however, are more difficult to manage. Sedimentation of Maui's reefs is one such threat.

While some efforts have been taken to address the issue of sedimentation, little significant improvement has been made (Jokiel et al. 2004). Managing sediment input to the nearshore waters and reefs is difficult, as it requires managing human activities on land, such as development. Management becomes even more difficult when the tools and data needed to predict the effects of a changing landscape are not available.

In Maui, current land management policies are not effectively addressing sedimentation of the reefs, as seen by their continued degradation. In order to prevent further destruction to Maui's reefs from sediment input, developers and policy makers must first understand the process of sedimentation and the environmental factors that contribute to it.

The lack of large sets of long term data and accessible environmental models prevents successful policy actions from being taken. There has been significant research regarding site-specific sedimentation events, but the small spatial scale of the research has left much to be desired in terms of predicting the impacts of sedimentation given certain environmental variables (Grigg 1995; Storlazzi et al. 2005).

This paper will explore the environmental factors that impact sedimentation, and using those factors, present a GIS based model to analyze the land use planning process on Maui as it affects sedimentation of its fringing coral reefs.

## The Study Area: Maui

The Island of Maui is the second largest island of the Hawaiian Island chain. The chain includes the Northwestern Hawaiian Islands, a series of coral atolls, and the 8 Main Hawaiian Islands: Kauai, Ni'ihau, Oahu, Molokai, Kooholawe, Maui, Lanai, and Hawaii. The entire archipelago ranges from latitudes 18º 55' to 28º 25' North and from 154º 40' to 178º 20' West (Figure 1). The volcanically formed islands decrease in age from

Northwest to Southeast, with Kure Atoll as the oldest and the big island of Hawaii as the youngest.

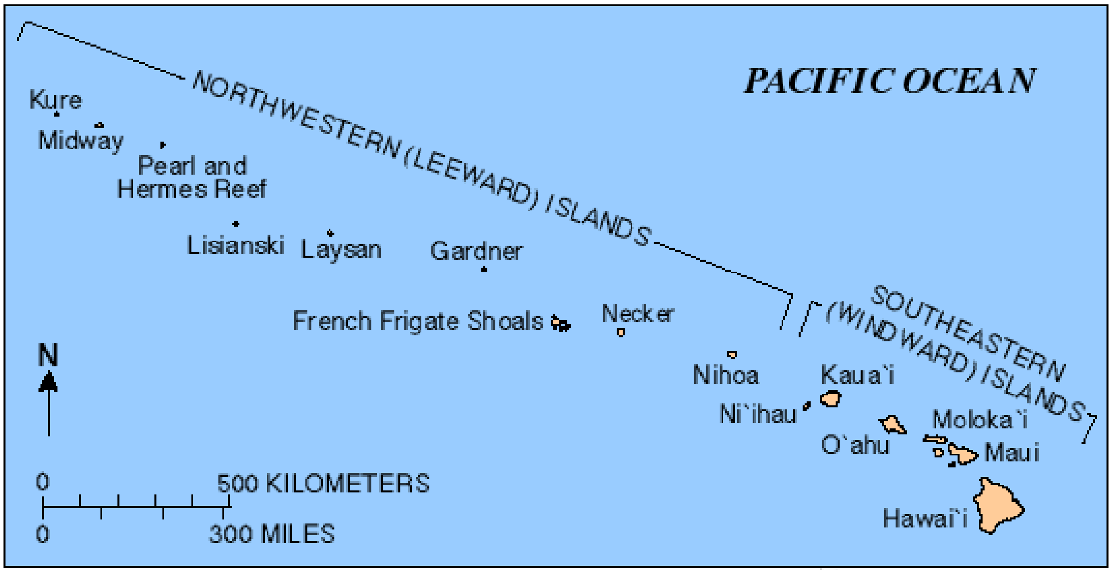


**Figure 1: Map of the Hawaiian Island chain, including the Main and Northwestern Hawaiian Islands (USGS 2011).**

Maui is the second youngest island, formed around 1.3 million years ago (SOEST 2011). It is made of two large volcanic cones connected by a large low-lying valley, giving it the nickname “The Valley Isle” (Figure 2). The island of Maui, and the neighboring islands Molokai, Kahoolawe, and Lanai, make up the county of Maui. These islands together are often referred to as Maui Nui, which in Hawaiian means “Greater Maui.” Maui’s tropical climate and warm waters make its nearshore waters an ideal habitat for reef building corals and the ecosystems that they support.

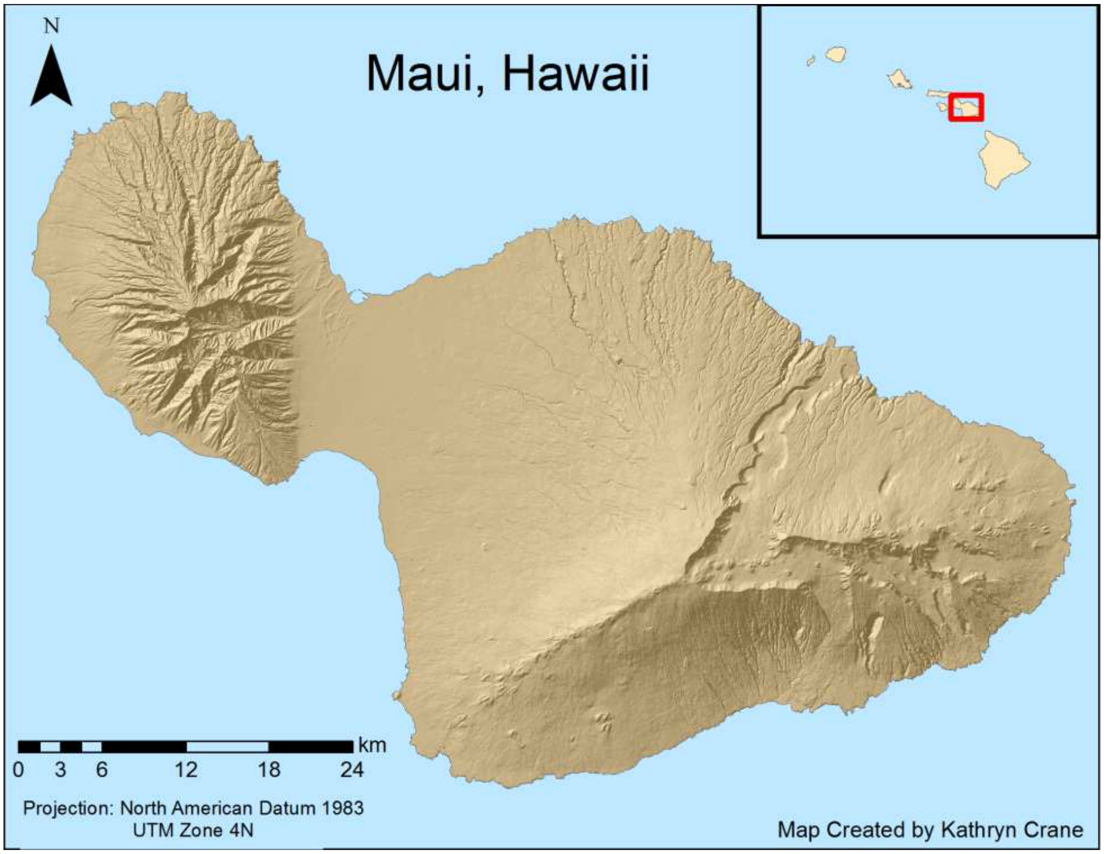


**Figure 2: The island of Maui and its location in the Main Hawaiian Islands. Data from Hawaii Statewide GIS Program (2010).**

# CORAL REEFS

Corals are a taxonomic group of Anthozoans that contain over 6000 species. The stony corals, or Schleractinian corals, are responsible for building the majority of reef structure, like the reefs fringing the island of Maui. Coral reefs are some of the oldest extant ecosystems on the planet, existing for over 500 million years (Riegel et al 2009). However, due to anthropogenic modifications of their biological, chemical and physical environments, they have been identified as endangered ecosystems. It is estimated that

24% of coral reefs worldwide are under impending risk of complete ecosystem collapse and 26% are in danger of irreversible damage (Riegel et al 2009).

Corals live in a delicate balance between ideal and completely inhospitable habitats. For example, they thrive at 28º C but temperatures over 30º C can cause bleaching and mortality. Calm waters are preferable to rough waters in terms of coral breakage, but without adequate flushing from waves, sediment can build up on the coral causing sedimentation and mortality. It is this delicate balance that makes them so vulnerable to anthropogenic disturbances.

## Reef Biology

Reefs are composed of thousands of tiny coral polyps that secrete skeletons of calcium carbonate. While individual coral polyps are very small (1-3 mm in diameter) coral reef colonies are very large and can weigh over several tons (Barnes and Hughes 1999).

Schleractinian corals rely on symbiotic algae called zooxanthellae that reside intracellularly and supply necessary compounds to the coral through photosynthesis (Barnes and Hughes 1999). As much as 90% of the material produced by the algae is used directly by the coral (Sumich 1996). This extreme efficiency allows for the conservation of nutrients in the otherwise nutrient poor environment of tropical oceans (Richmond 1993). Because of their reliance on photosynthesis, corals are restricted to the photic zone, which extends to roughly 70 meters in depth, depending on water turbidity. Coral reefs thrive in shallow tropical marine environments. They require oligotrophic waters where nutrient levels are low and the water is clear (Richmond 1993).

They thrive in waters between 23º and 29º C (Veron 2000). Corals require water with salinity ranging between 32-42 psu, and are thus restricted to the marine environment (Lalli and Parson 1995).

## Distribution

Because of their structural complexity and biophysical requirements, coral reefs are restricted in their potential habitat and are present in only 0.25% of the global marine environment (McKeown 2010). Barring any anthropogenic disturbance, corals thrive in calm, tropical waters. There is a negative correlation between maximum wave height and coral cover, diversity, and species richness (Storlazzi et al. 2005). Without human disturbance, calm waters tend to be clear, proving ample light for photosynthesis. Because they require warm waters, corals range in latitude from 30º N to 30º S, spanning the tropics. Since they require high levels of salinity, they are restricted to the marine environment.

## Economic, cultural, and ecological value

Coral reefs provide both intrinsic and economic value for both the people of Maui and for people of the world. Coral reefs provide sand for white sandy beaches in the tropics. They also protect the shoreline from excessive erosion (Richmond 1993). The economic value includes the tourism dollars from beach and dive tourism, fisheries they support, and natural products they produce. Estimates suggest that coral reef tourism potentially contributes over $9.6 billion per year to the global economy (Reigel 2009). It has been estimated that the reefs around Maui contribute over $264,000/acre to the total economy each year (Cesar et al. 2002).

The cultural importance of reefs is significant, especially in the Hawaiian Islands. Coral plays an integral role in the Hawaiian creation story. In the Creation chant, “Kumulipo,” the tiny coral polyp is the primary organism described after the creation of humans (CRAMP 2008). There is also intrinsic value to reefs and their protection (Richmond 1993). Even those who have never and will never see a coral reef first hand can appreciate their beauty and value.

Corals have ecological value as well. Reefs act as a nursery for juvenile fish, as their structural complexity provides protection from predators as well as from large waves and ocean currents. Although coral reefs are restricted in their potential habitat to only 0.25% of the global marine environment, they support 25% of all marine life (McKeown 2010). The total biodiversity found in coral reefs is comparable to tropical forests.

## Threats

Both anthropogenic and natural disturbances impact coral reef community distribution, structure, and overall health. Disturbances such as typhoons and tropical storms limit the distribution of reefs to relatively calm waters. These events usually crop the reef, but do not cause widespread coral mortality (Richmond 1993). Coral disease occurs in the absence of human disturbance, and can cause widespread or localized mortality (Vargas-Angel 2009). When these natural disturbances are paired with anthropogenic disturbances, the conditions for recovery are greatly impaired (Richmond 1993).

Human induced changes in the environment, both global and local, have threatened coral reef ecosystems. Global threats are difficult to mitigate, as the catalysts exist across both political and biophysical boundaries. Climate change is a global phenomenon that increases the temperature of the oceans. Because corals can only survive within a limited temperature range, even small changes in temperature can cause bleaching and eventual mortality. Increased levels of $CO_2$ in the atmosphere change the ocean chemistry, making the water more acidic. Acids dissolve the calcium carbonate excreted by the polyps. This change, known as ocean acidification, threatens the structure of reef building corals. While coral disease occurs naturally, it is thought that changes in the marine environment have led to increased outbreaks of disease (Vargas-Angel 2009). Invasive species, especially those that compete with or prey on coral, pose a threat to the ecosystem as a whole (Riegel et al 2009).

Local threats can be just as damaging to reefs as global threats. Runoff brings pollution, sediments, and nutrients to the marine environment. All three of these inputs can damage coral reefs. Overfishing removes fish from the ecosystem that control algal species that compete with coral. Destructive fishing practices can physically harm the coral (Riegel at al 2009; Richmond 1993).

The National Oceanic and Atmospheric Administration (NOAA) has recently narrowed the focus of its coral reef conservation program in order to maximize efficiency of both limited time and limited funds. The program has chosen to focus on what they perceive to be the top three global threats to coral reefs: fishing, land-based sources of pollution, and climate change (NOAA 2008).

Land-based sources of pollution encompass many things, such as nutrient runoff from agricultural fields, animal and human waste, toxins, and sediment. When terrigenous sediments run off of the land and into the marine environment, this process is known as sedimentation. While there are many threats to coral reefs on Maui, sedimentation is one that is significant and has yet to be effectively addressed in management. For these reasons the focus of this report is sedimentation from land-based sources.

## Sedimentation

Sedimentation of coral reefs is a process that occurs when runoff from coastal land enters the marine environment. Although this is a naturally occurring process, poor land use practices and anthropogenic disturbances have increased the intensity and frequency of these events. In Hawaii, total sediment runoff from land-based sources exceeds 1 million tons per year (Gulko et al. 2000). Excessive anthropogenic sedimentation is one the greatest threats to coral reef communities, especially on tropical islands with high elevations and steep slopes (Phillips and Fabricus 2003; Piniak 2004). Sedimentation has been identified as the most significant threat to Hawaiian coral reefs (Friedlander et al. 2008).

When runoff is produced from a large storm with heavy rains, it often carries with it sediment. When soil is exposed, even more sediment is eroded. The sediment enters the marine environment by streams or sometimes in shears coming from hillsides and cliffs. The amount of runoff that a given storm produces depends on the size and slope of the watershed, the volume and intensity of the rainfall, soil condition, and land use (Roger 1990). From steeply sloping watersheds, runoff moves more quickly, giving it less time to percolate into the soil, thus increasing the total volume. More rainfall or rainfall at higher intensities produces more runoff. When land is disturbed and soil is exposed, more soil is eroded and transported by the runoff into the marine environment. Floods resulting from drought-breaking storms tend to have extremely high sediment concentrations, as the lack of precipitation results in a buildup of sediments over time (McCulloch et al 2003).

## Impacts

The impacts of sedimentation range from widespread mortality to more subtle changes in community characteristics, structure, and distribution (Richmond 1993). Sediment affects the coral in two major ways: by reducing light availability while suspended in the water column, and by settling out of the water column and onto the coral.

When sediment is suspended in the water column, it reduces the light available to the coral and their photosynthetic symbiotes. This decreases the photosynthetic capability of zooxanthellae and enhances coral respiration and mucus production (Phillips and Fabricus 2003; Piniak 2004). Because corals rely on photosynthetic symbiotes for most of their nutritional requirements, reduction in available light negatively affects their nutrition. An increase in turbidity also can limit the depth range at which corals can survive (Richmond 1993).

Once the sediment settles out of the water column, it settles on to the coral itself. This effectively smothers the coral. With enough sediment, this can cause coral mortality in short periods of time (Rogers 1990). Sediment on the coral also prevents feeding, spawning, and recruitment, as polyps need a solid surface on which to attach. Some coral species are able to cope with higher than normal levels of sedimentation by exhibiting both active and passive sediment removal (Rogers 1990). This is, however, extremely energy intensive, and results in a decrease in coral growth and reproduction because the majority of energy is used in the production of a viscous mucus layer used to slough off sediments.

Although sediment discharge onto coral reefs is the most visible impact of runoff, it is not the only one. Runoff also carries pesticides, fertilizers, nutrients, animal and human waste, and toxic chemicals (Jokeil 2006). While these inputs also have an impact of the coral reef ecosystem and the marine environment as a whole, this paper will focus solely on the affects of the sediment itself.

In areas where sedimentation is common or frequent, the reef is dominated by sediment resistant species. If the reef had historically higher than normal sedimentation levels, this may not result in a change in community structure. However, where anthropogenic disturbance has drastically increased the frequency and severity of sedimentation, there is often a change in coral community structure to more sediment tolerant and branching species (McClanahan and Obura 1996).

As threats to reefs are often coupled, it is difficult to observe a coral reef that is experiencing degradation caused solely by sedimentation (Grigg 1995). However, through many case studies, laboratory experiments, and in situ experiments, the effects of sedimentation can be understood. Sedimentation is associated with less coral species richness, decreases in live coral, slower coral growth, increase in abundance of branching corals, reduced recruitment, decreased calcification, decreased net primary productivity, slower reef accretion, decreased zooxanthellae density, and increased coral disease (Rogers 1990; Fabricus 2005; Phillips and Fabricus 2003).

## Environmental Factors Impacting Sedimentation

The severity of a sedimentation event depends on three factors: the type of sediment running off the land, sediment load, and the residence time of the sediment in the system.

### Type of Sediment

Sedimentation impacts vary greatly among sediment types (Fabricus 2005). Several studies, both in situ and in the laboratory, have shown that terrigenous red clay soils have more detrimental effects on coral than do similar amounts of carbonate sand (Piniak 2004; Richmond 1993). Smaller grained sediments stay suspended in the water column longer, thus increasing turbidity for a longer period of time. Once the sediment does settle on the coral, the cohesive properties of clays make them difficult to re-suspend and flush from the system.

### Sediment Load

Holding all else constant, increasing the total sediment load will result in increased coral reef degradation. This makes sense intuitively, in that more sediment causes more damage. However, this is only true when holding the other two factors (type of sediment and residence time) constant. Because of this, it is important to attempt to minimize the amount of sediment running off the land, but doing so is not enough to prevent the mortality. Land use, precipitation, slope of the watershed, and location of streams impact total sediment load.

When more soil is exposed through various types of land use, this soil becomes vulnerable to erosion following precipitation. High or intense precipitation can result in higher levels of runoff and erosion. Steeper watersheds result in faster moving water, which does not allow as much sediment to settle out of the water before entering the ocean. The location of a reef with respect to river mouths or exposed soil impacts the amount of sediment entering the system. Sediment input is generally highest at river mouths and lowest at exposed headlands (Nugues and Roberts 2003).

## Sediment Residence Time

The final factor that determines the severity of sedimentation is the retention of sediments, or residence time. Once input to the system, removal of sediments depends of hydrodynamic processes (Fabricus 2005). When strong currents and waves are present that are able to re-suspend and flush sediments from the reef, sediments are less likely to cause a problem (Rogers 1990). When wave energy is low, suspended sediment settles out of the water column quickly, and is not easily re-suspended and flushed from the system (Phillips and Fabricus 2003). While high wave energy can cause coral breakage, these same waves clear sediments from the reef, and thus can be beneficial to the coral communities (Jokiel 2006). In more wave-exposed areas, a wider range of species are able to survive even at moderate levels of sedimentation (Fabricus 2005). Studies have shown that sedimentation stress of corals exposed to large amount of sediment for a short time is similar to corals exposed to less sediment for a longer amount of time (Phillip and Fabricus 2003).

This relationship between sediment flushing waves and sedimentation recovery has been well documented. During the winters of 2002 and 2003, large storm waves off Pilaa, Kauai, flushed muddy terrigenous sediment off of the shallow reef flat. The reef there is now showing signs of recovery (Jokeil et al 2006).

In a study of the circulation in Hanalei Bay, Kauai, Storlazzi et al (2009) showed that the more energetic portions of the bay where shear stress was higher did not accumulate finer gained terrigenous sediment. Where shear stress was lower in the eastern side of the bay, sediments were not flushed out of the bay quickly and some sediment remained for months (Storlazzi 2009).

After a winter storm in 2002 with high precipitation, sediment entered Honolua Bay, Maui, where it remained for over 6 months. The storm was not of abnormal intensity, but flushing by waves did not take place for several months after the storm. Much of the loss in coral cover in Honolua bay has been attributed to this storm and the heavy sedimentation that followed (Dollar and Grigg 2004).

Because of the role that residence time plays in impacting severity, the areas most impacted by sedimentation are areas with low current, a small tidal range, and low wave exposure. The areas least impacted are the current swept front reef or channel, and areas of moderate wave exposure (Fabricus 2005). Overall, the best coral growth where sediment input is high occurs in well-lit, current swept areas with moderate wave action (Fabricus 2005).

## Environmental Conditions in the Study Area

The environmental conditions around Maui lead to spatially and temporally varying levels of sedimentation. I will focus on the environmental conditions that directly affect the three factors that determine the impact of a sedimentation event. Specifically, I will focus on soil type, climate and precipitation, and waves.

## Soil

Soil type is the first factor that influences the severity of sedimentation. As previously discussed, fine-grained terrigenous clays tend to cause greater damage to reefs than do marine-based carbonate sediments. Maui’s soils are relatively homogenous throughout the island. Most are volcanically formed red clays (USDA 1976). The soils are highly oxidized and tend to be nutrient poor. Once settled on coral, their cohesive properties cause them to stick together, making them difficult to re-suspend.

## Climate and Precipitation

Climate and precipitation impact the total sediment load. The intensity and frequency of rainfall impacts sedimentation. Maui has two distinct seasons, the rainy season and the dry season. During the rainy season, the intensity of rainfall is high, often resulting in shears of water running off the land. Droughts are common in the dry season, allowing sediment to accumulate in stream beds and on land until the rainy season.

The timing of heavy rains and large waves has significant ecological consequences (Storlazzi et al 2009). In Hawaii, large rain storms and large waves do not usually coincide. When this coupling does not occur, sediment inputs to nearshore waters are often not removed by waves quickly enough to prevent damage. This decoupling is much different from well studied temperate mountainous coastal ecosystems. The wave climate in Hawaii has a stronger seasonality than stormwater runoff and stream flow (Draut et al 2009).

## Wave Regimes

The Hawaiian Islands are impacted by 4 types of ocean waves: Tradewind waves, North Pacific Swells, Southern Swells, and Kona storm waves. Each of these 4 types of waves approaches the islands with a predictable direction and magnitude (Figure 3). The exposure to waves of these four regimes limits residence time of sediments in a coral reef ecosystem.

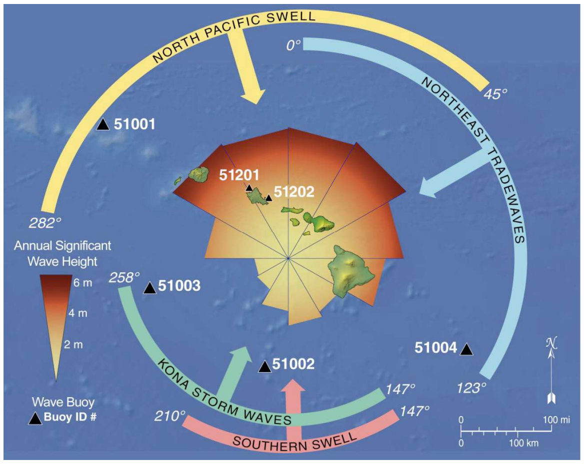


**Figure 3: The 4 major wave exposure regimes are shown around the Hawaiian Islands. Mean direction, range of directions, and annual significant wave height are also shown (Vitousek and Fletcher 2008).**

Northeast trade winds are present most of the year in the Hawaiian Islands, but are of highest intensity from April to November (Storlazzi and Field 2008). Waves generated by tradewinds generally have a height of 1.2 to 3.7 meters, and a period of 5 to 8 seconds. They approach the islands from a mean compass direction of 45º (range 0-90º) (Jokiel 2006).

North Pacific swells are generated by winter storms in the northern hemisphere, and thus reach their peak intensity between November and March. Typical wave heights range from 2.4 to 4.6 meters and periods range from 10 to 17 seconds. They approach the islands from the northwest with a mean compass direction mean of 315º (range 282 to 45º) (Jokiel 2006).

Southern Swells are generated by winter storms in the southern hemisphere, thus are common from June through October. Wave height is generally between 0.3 to 1.2 meters, with a period of 12 to 17 seconds. These waves are smaller and of lower intensity because they take 6 to 8 days to reach the islands from the source, and lose much intensity along the way. They approach the islands from the South, with a mean compass direction of 190º (range between 236 and 147º) (Jokiel 2006).

Kona Storm Waves can occur throughout the year but are most common from October through April. These waves are generated by southerly winds that often precede the northerly winds of a cold front. Wave heights range from 0.9m to 1.5m, with a period of 8 to 10 seconds. They generally approach from the southwest at a mean compass direction of 210º. The direction ranges from 258 to 247º (Jokiel 2006). Kona waves and Southern Swells are often grouped together, as they approach the island from roughly the same direction and have similar wave characteristics.

# Land Use Policy

Because the source of sediments causing damage to Maui’s reefs is on the land, the best way to prevent the damage is by effectively managing the land. Current management practices attempt to limit the sediment load entering the marine ecosystem but do not address what happens to the sediment once it enters the marine environment. Current management practices only account for one of the three factors that influence sedimentation severity, ignoring both soil type and sediment residence time. While soil type is relatively constant throughout Maui, wave exposure, and therefore sediment residence time, is not. Wave exposure should be taken into account in land use planning.

## A History of Effective Management

Ancient Hawaiians have a history of effective land management practices. To understand the current policies dealing with land use, it is important to understand the history of land use and policy on the island. This starts nearly 1500 years ago, when the first Polynesians came to Hawaii (Potter et al. 2003).

The Polynesians brought with them a land tenure system in which land was divided into Moku, or districts, each ruled by a chief family. The districts were further divided into Ahupua'a or wedge-shaped land parcels that extended from the top of the volcano to the deep blue of the ocean, out past the reefs (Figure 4). Each Ahupua'a was managed as a complete interconnected system (Van Dyke 2008). Today this system is known as watershed based management, and has been gaining popularity among managers in recent years.

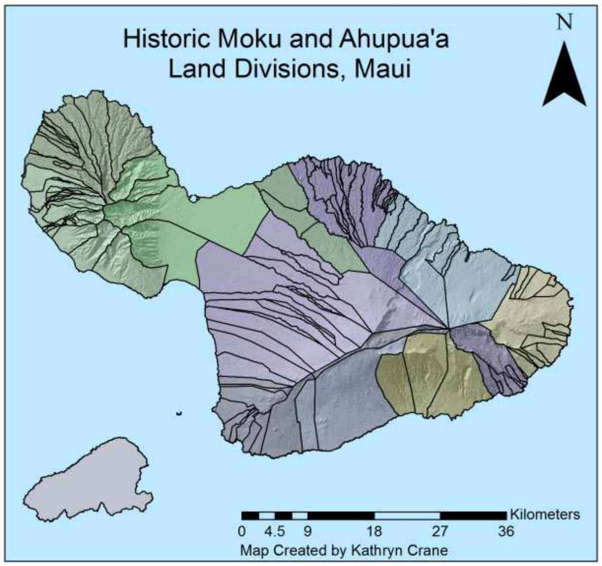


**Figure 4: The historic land divisions of Maui. Moku, or districts are shown in color, and outlines of the Ahupua'a are drawn within each Moku. Data from Hawaii Statewide GIS Program (2010).**

The Ahupua'a were highly modified, but in a way that worked with, not against the natural environment. An important feature of the Ahupua'a were lo'i or taro patches. Taro is a root vegetable that grows in standing water. Management practices included building lo'i near streams, diverting these streams through the Taro patches, and then returning the water back to the stream. This slowed down the water, and gave sediments time to settle out before it entered the ocean (Van Dyke 2008). The Ahupua'a system was effective in managing both the land and the sea, and was able to support a large population while protecting the natural environment.

## The Great Mahele

The Ahupua'a system was in effect until the Great Mahele, or land divide, of 1848. Under immense pressure from foreigners who had recently arrived in the Hawaiian Islands, King Kamehameha III divided the land for individual ownership. This completely dismantled the Ahupua'a system and resulted in the entry of commercial interests enabling a flourishing plantation economy. Agriculture, primarily pineapple and sugarcane, became Maui's top industry. It remained so until tourism began to rise in the mid-20th century. Now tourism remains Maui's top industry (County of Maui 2030 General Plan 2010).

## Current Land Use

As tourism continues to rise on Maui, so does development. Maui's population is steadily increasing, and is projected to do so for the next 20 years. The de facto population is much higher than the resident population because of the amount of tourism present there (County of Maui 2030 General Plan, 2010).

Development has not been distributed evenly throughout the island (Figure 5a-d). The majority of development occurs along the coast. The leeward (west) side of the island is much more developed than the windward (east) side, especially in terms of tourism (Planning Department 2010). The leeward side is more protected from large waves during all wave regimes, and thus has calmer waters, which attract tourists to the island. The leeward side of the island is also where the majority of the largest coral reefs are located. Much of the local population resides in central and upcountry Maui (Figure 5c-d).

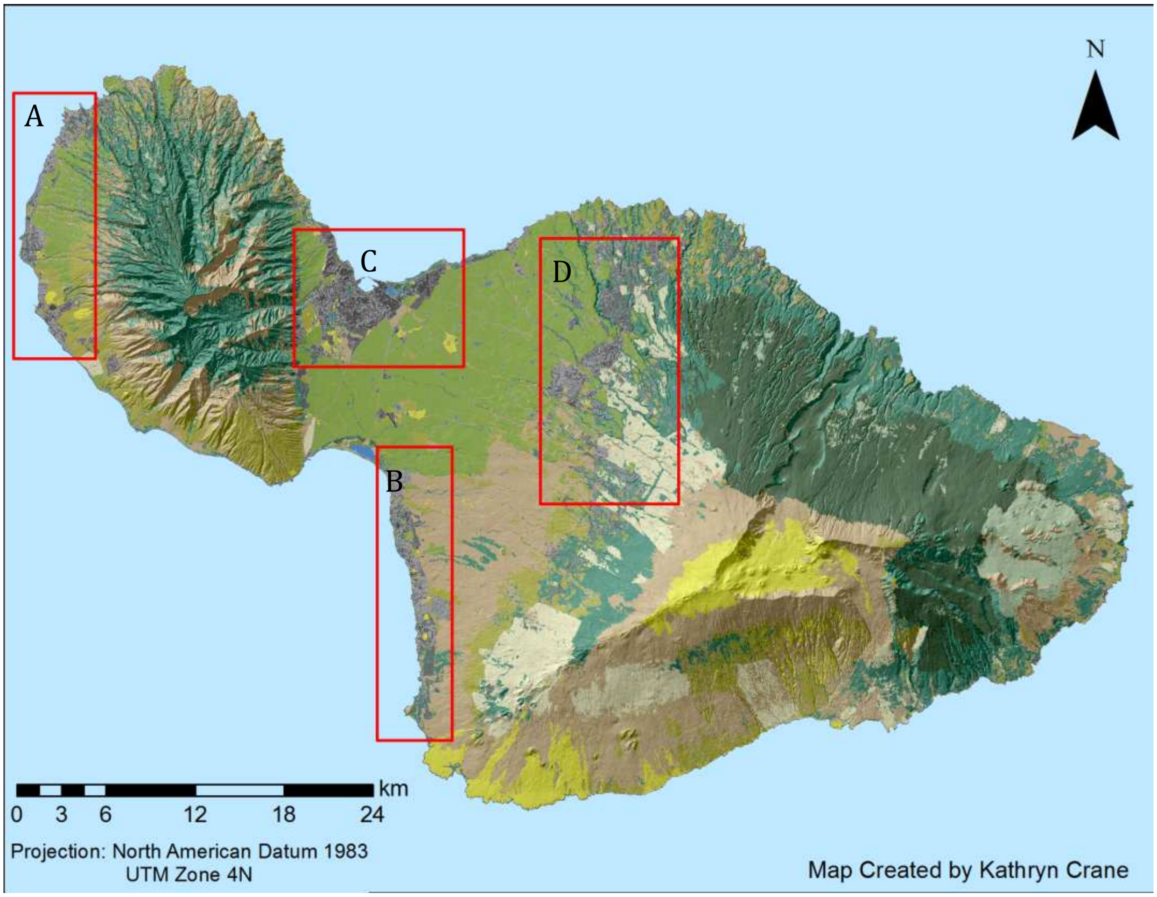


**Figure 5: Current land use land cover of Maui. Impervious surface is shown in shades of gray. Most development has occurred within the red boxes. (A) West Maui is dominated by tourism development and the town of Lahaina. (B) South Maui includes the resort towns of Kihei and Wailea. (C) Central Maui is home to the county seat, Wailuku and the neighboring port town of Kahului. Many locals live here. (D) Upcountry Maui is rather rural, but is becoming increasingly developed. Many locals live in the towns in upcountry Maui. LULC Data from Hawaii Statewide GIS Program (2010).**

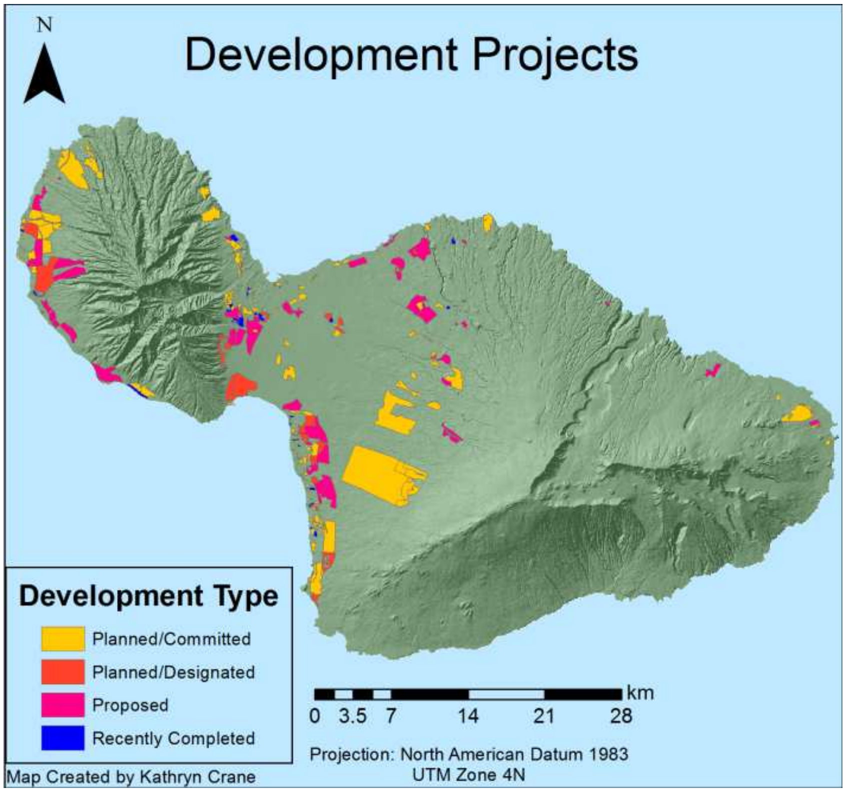


**Figure 6: Locations of current development projects on Maui (Planning Department 2010).**

Development continues to occur in these same areas. There are currently 41 proposed developments being reviewed by the Maui Planning Department and many more that have recently been approved (Figure 6). These projects range from affordable housing developments for local families to multi-million dollar homes in gated communities and large resorts (Planning Department 2010). Development of any kind disturbs the land and exposes soil, thus increasing the potential for sedimentation.

## Current Land Use Planning Policy

The native Hawaiian history plays an important role in current land use management. There seems to be a general understanding of the interconnectivity of the land and the sea which is present in the planning policy. Most current policies dealing with land use planning on Maui are made at the local level with strong involvement from the community. There are several national and state policies that grant authority and responsibility to that local level.

The Coastal Zone Management Act (1972) gives states the authority and funding to create a plan for the management of their coastal zone. State participation is voluntary, but there are several incentives for states to do so. The first incentive is federal funding for the project. The second is federal consistency. In creating the plan, states have a say in federal activities within the coastal zone, in that all federal activity must be consistent with the management plan (Cicin-Sain and Kencht 2000).

The state of Hawaii created their management plan in 1977. The Hawaii Coastal Zone Management Plan (HICZMP) defines the coastal zone as all land and water within state jurisdiction. The plan identifies seven resources to be managed and sets general objectives and guidelines for how these coastal resources should be managed throughout the state. Two specific policies that the plan establishes are the creation of special management areas (SMAs) and shoreline setbacks. The plan gives counties complete responsibility for managing these areas. All other areas within the coastal zone managed by the counties but must be consistent with the HICZMP (Hawaii Coastal Zone Management Program 1977).

The Hawaii Environmental Policy Act of 1979 (HEPA) was modeled after the US National Environmental Policy Act. HEPA requires that all development projects submit an environmental impact statement (EIS) prior to approval. The environmental impact statements must have a section that describes the impacts of the development to the marine environment (HRS § 343). The law does not require any specific actions to be taken once the EIS is submitted, but it does provide information to planning bodies about the development projects.

The Clean Water Act of 1969 (CWA) deals extensively with non-point source pollution (Cicin-Sain and Kencht 2000). Land based sediments are not only a pollutant to the marine environment themselves, but they also carry with them excess nutrients and toxins. The EPA has responsibility and authority in dealing with issues under the CWA, but it has not been used to address sedimentation on Maui.

The CZMP, HICZMP, HEPA, and CWA provide basic guidelines and objectives for land management. These are then translated into policy at the local level. In Maui, this is done by the Planning Department in the *County of Maui General Plan*.

The general plan is divided into three parts: the County Wide Plan, the Maui Island Plan, and a collection of nine community plans. The planning department is currently in the process of approving the Maui 2030 Plan, which is the general plan outlining development throughout the county to the year 2030. The Countywide Plan has been adopted by the County Council in 2010. The Maui Island plan is currently undergoing review.

The General Plan provides more general objectives and goals for development, but also creates regulations regarding sediment control. Some key goals of the plan are to reduce the amount of impervious surface, require sediment control plans from developers, and to create mechanisms to control runoff. The plan also creates directed growth boundaries to limit the amount of suburban sprawl on the island (Figure 7). These boundaries are based on the location of existing infrastructure as well as the desire for open space (County of Maui, 2010). The general plan is more specific in outlining regulations than the other policies, but still leaves much discretion to the planning department in the approval of specific development projects.

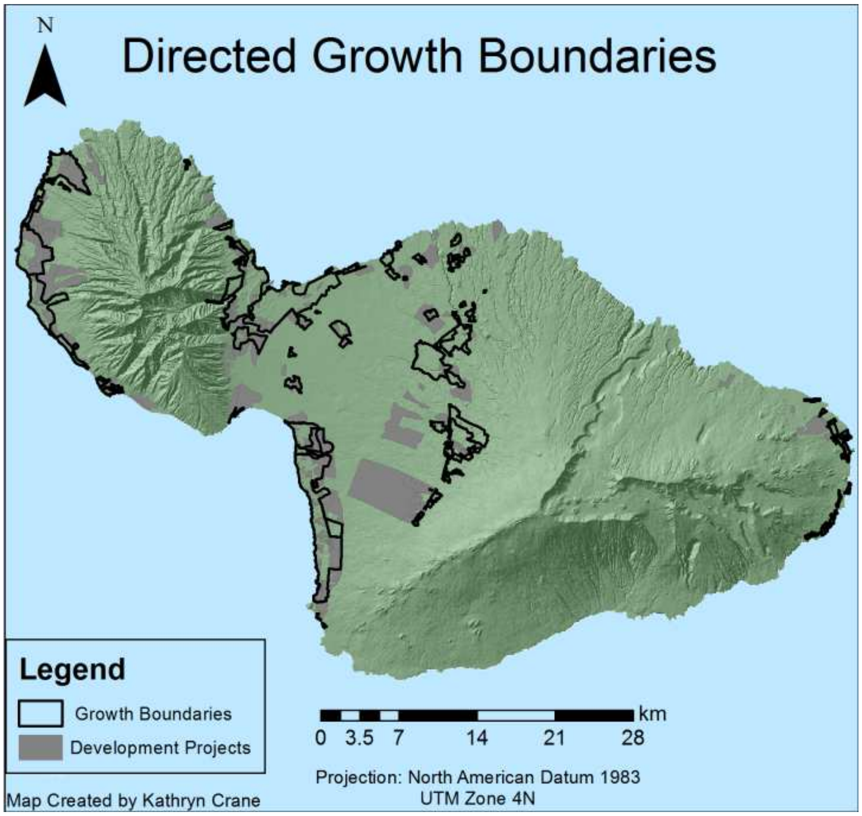


**Figure 7: Directed growth boundaries, DRAFT, presented in the General Plan Advisory Committee's version of the Maui general plan, 2030.**

## Policy Analysis

While sedimentation is addressed by many of the land use management policies that are in place, the issue continues to be a serious problem for Maui's reefs. To be effective, policies should be integrated vertically, horizontally, across sectors and disciplines, across land and sea boundaries, and between science and policy. The three most relevant policies dealing with reef sedimentation (HICZMP, HEPA, and the General Plan) are all relatively well integrated (Figure 8). The most critical gap in integration is across science and policy in the *Maui General Plan*.

| | **Vertical Integration** | **Horizontal Integration** | **Across Sectors** | **Multi-Discipline** | **Land/Sea Integration** | **Cross Science and Policy** |
|---|---|---|---|---|---|---|
| HI Coastal Zone Management Plan | YES | YES | NO | YES | YES | YES |
| HI Environmental Policy Act | NO | YES | YES | YES | YES | YES |
| Maui General Plan | YES | NO | YES | YES | YES | NO |

**Figure 8: Integration of three main policies dealing with sedimentation. The lack of integration between science and policy in the Maui General Plan limits the effectiveness of this policy.**

The Hawaii Environmental Protection Act is well integrated, but carries no political stick. The policy is an information policy, designed to inform the public and decision makers. While this is important, it does not set forth guidelines for how and where development should occur.

The Hawaii Coastal Zone Management Plan is well integrated, but is done so at the expense of policy specificity. The goals and objectives of the plan are clear, but the paths to achieving these goals are not. The specific regulations are left up to the individual counties to enact. There are obvious benefits to local management. One benefit is that those present in the community have a better understanding of the needs and concerns of that community. However, if there is a lack of understanding and integration between science and policy at the local level, the goals and objectives of the Management Plan may not be met.

Land use planning at the county level is well integrated across sectors and disciplines. Members of the community, NGOs, developers, and industry are involved in the process (County of Maui, 2010). It is also well integrated across the land and sea, as are all three policies discussed above.

There are major gaps in the integration between science and policy. The specific regulations at the local level attempt to control sedimentation of the reefs by limiting the amount of sediment entering the system. This is only one of the factors impacting sedimentation severity. There are no regulations that attempt to address the residence time of the sediments once they enter the marine environment.

In order to address residence time, development must be distributed spatially where wave exposure is higher and sediments can be easily flushed from the system. This requires a complete understanding of the physical processes of the nearshore wave environment. While complex models are available to give accurate predictions of wave climate, these models are only accessible to experts in their field, and are thus not very useful to land planners. There is also extensive local knowledge that can be acquired.

Because the General Plan contains directed growth boundaries, sediment residence time can easily be taken into account. In order to do this, it is necessary to have an accurate and accessible model of nearshore wave exposure, as this limits residence time. Once wave exposure is known, land use policy can change to take into account the impacts that this has on sedimentation.

## A GIS approach to Wave Exposure Modeling

In order to successfully prevent widespread coral mortality caused by sedimentation, nearshore wave exposure of fringing reefs must be taken into account. Measuring wave exposure in situ is costly and time consuming. While this data would be useful, it is unlikely that it would become available for much of the coast in the near future. Deepwater buoy data exists, but the buoys are far offshore and do not provide data on the changing wave properties between deep and shallow water waves, providing little information about nearshore exposure. Locations of buoys near Maui can be seen in figure 3.

Relative wave exposure models have been developed to estimate exposure in closed basins caused by locally wind driven waves (NCCOS 2010). WEMo (Wave Exposure Model) is one such model that was developed by the center for coastal fisheries and habitat research. However, these models do not apply to deepwater swells, like those impacting the coast of Maui.

Complex circulation and wave models have been used in numerous papers to describe oceanographic conditions over a small spatial scale (Storlazzi et al. 2008). These models provide detailed information about circulation, wave period, and wave height based on the approaching wave characteristics, bathymetry, and circulation patterns. They are computationally costly and because of this, they can only be run at very coarse scales or in small areas. The complex nature of these models makes them inaccessible to many involved in coastal management. The outputs of these models may also be far more in depth than are needed to predict sedimentation effects on fringing reefs.

What is important to know is how exposed specific reefs are to approaching waves. The more exposed a reef is, the more flushing of sediments can occur, resulting in less potential reef damage caused by sedimentation.

In order to estimate wave exposure, I created a GIS-based model. The model uses similar methods to one created by Puotinen to predict potential reef damage from tropical cyclones in the Great Barrier Reef (Puotinen 2005).

## Methods

The GIS-based wave exposure model was created using the GIS compatible scripting language "Python." The script in its entirety can be found in Appendix A. In order to run the model, a coastline shapefile is needed. For Hawaii, these can be downloaded directly from the Hawaii Statewide GIS Program website (Hawaii Statewide GIS Program 2010). The model generates random points within a specific nearshore area (Figure 9). Depending on the desired scale and resolution of the analysis, the amount of points and size of the area can be altered. For each of these points, calculations are made to estimate openness, relationship to approaching waves, and wave refraction. These three factors are combined to approximate a relative wave exposure value for each point.

For each point, fetch lines (length 60 km) are generated at 5° intervals in all directions. Parts of fetch lines that intersect wave-blocking obstacles are erased. Any cropped piece that is shorter than 10 km is discarded from the remainder of the analysis. Openness is calculated by summing the total number of remaining fetch lines.

In order to determine how the point is exposed to approaching waves, the sum of the fetch lines within 60° of approaching waves in computed. This total value approximates how directly exposed a point is to approaching waves.

Even if a deepwater wave is not approaching a point directly, that wave will refract into the less exposed area. Refraction of waves spreads out the wave crests and causes them to lose some of their energy. The more a wave refracts to reach a given point, the more energy it will lose. To estimate energy lost by wave refraction, the angle of difference between the approaching wave and the nearest complete fetch line was calculated. The larger that value, the more the wave has to refract. This is the refraction value. These three values were weighted appropriately and combined to approximate relative wave exposure.

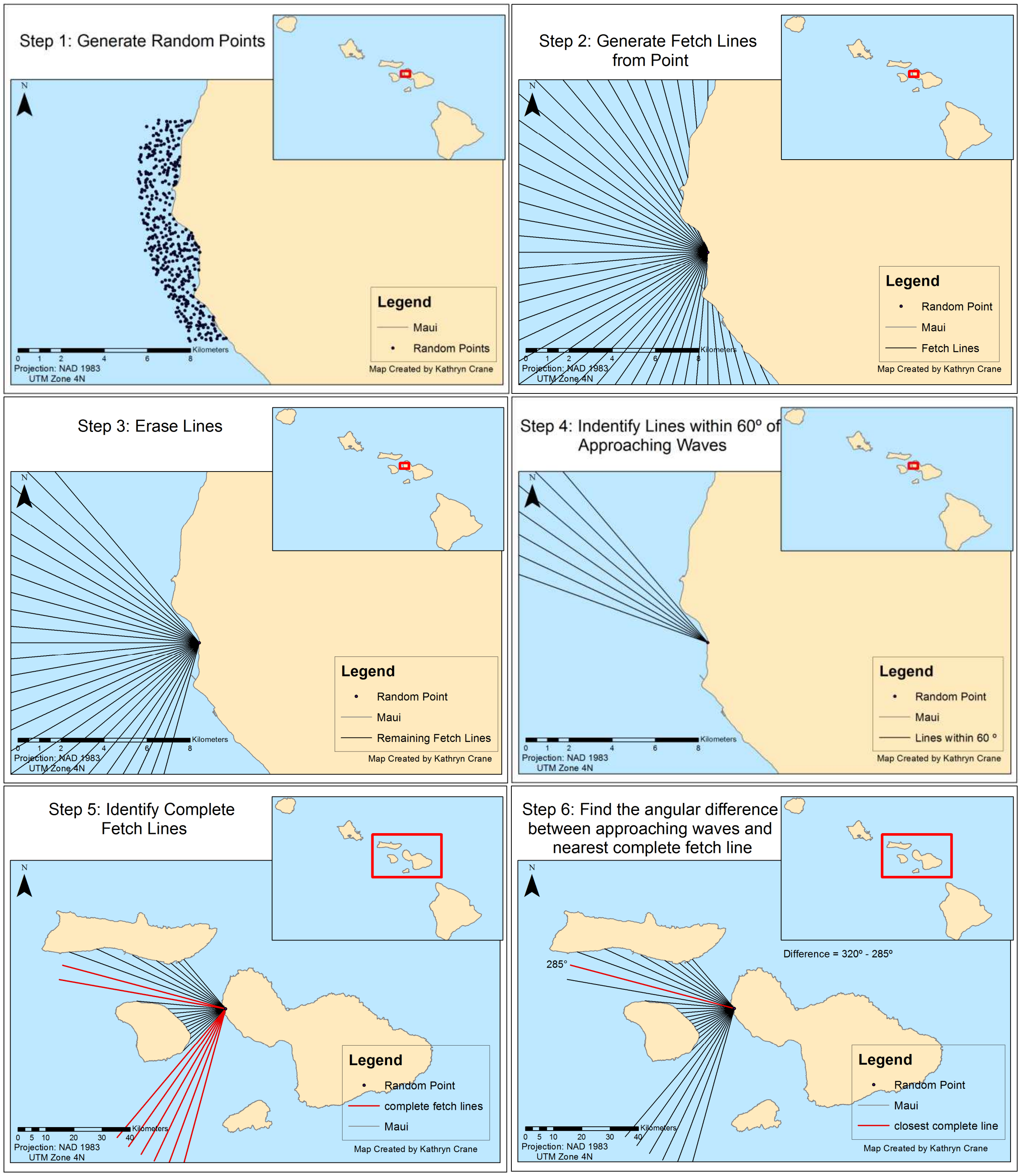


**Figure 9: Visual representation of the steps of the GIS-based model of wave exposure. Base data provided by Hawaii Statewide GIS Program (2010).**

## Testing the Model

In order to test the validity of the model, I ran it for an area previously modeled by the U.S. Naval Oceanographic Office's Spectral Wave Prediction System (SWAPS) version 4.0 wave model. The model was used to determine wave characteristics of the island of Molokai, and the results are presented in a USGS report by Storlazzi et al. (2008). I ran my GIS-based model three times, using the 3 major wave regimes of the Hawaiian Islands that were used in the report.

To compare my model to theirs, I ran the GIS-based exposure model, generating 1500 random points around the coast of the island of Molokai. I interpolated the points into a grid to allow to for an easy visual comparison between the two outputs.

The SWAPS model produces an output of wave height, period, and wave-induced shear stress (Figure 10). The GIS-based model produces and output of wave exposure (Figure 11). While the two outputs are not the same, general trends of both outputs can be compared. In areas with high wave exposure, wave height should be large. Where wave exposure is low, wave height should be lower. As seen below, a similar pattern exists between the two models. While the GIS-based model is simple and can be improved upon in the future, the similarities presented above suggest that the model can provide accurate results in the remainder of the analysis.

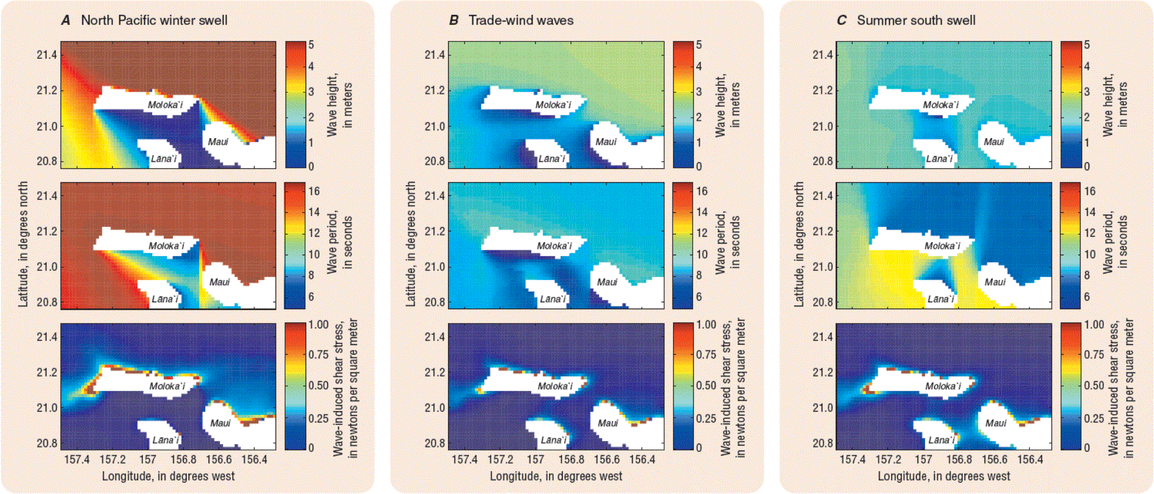


**Figure 10: Wave height output from Storlazzi et al. (2008) using the US Navy's SWAPS wave modeling software. The wave heights generated from the three main wave regimes are shown around the island of Molokai.**

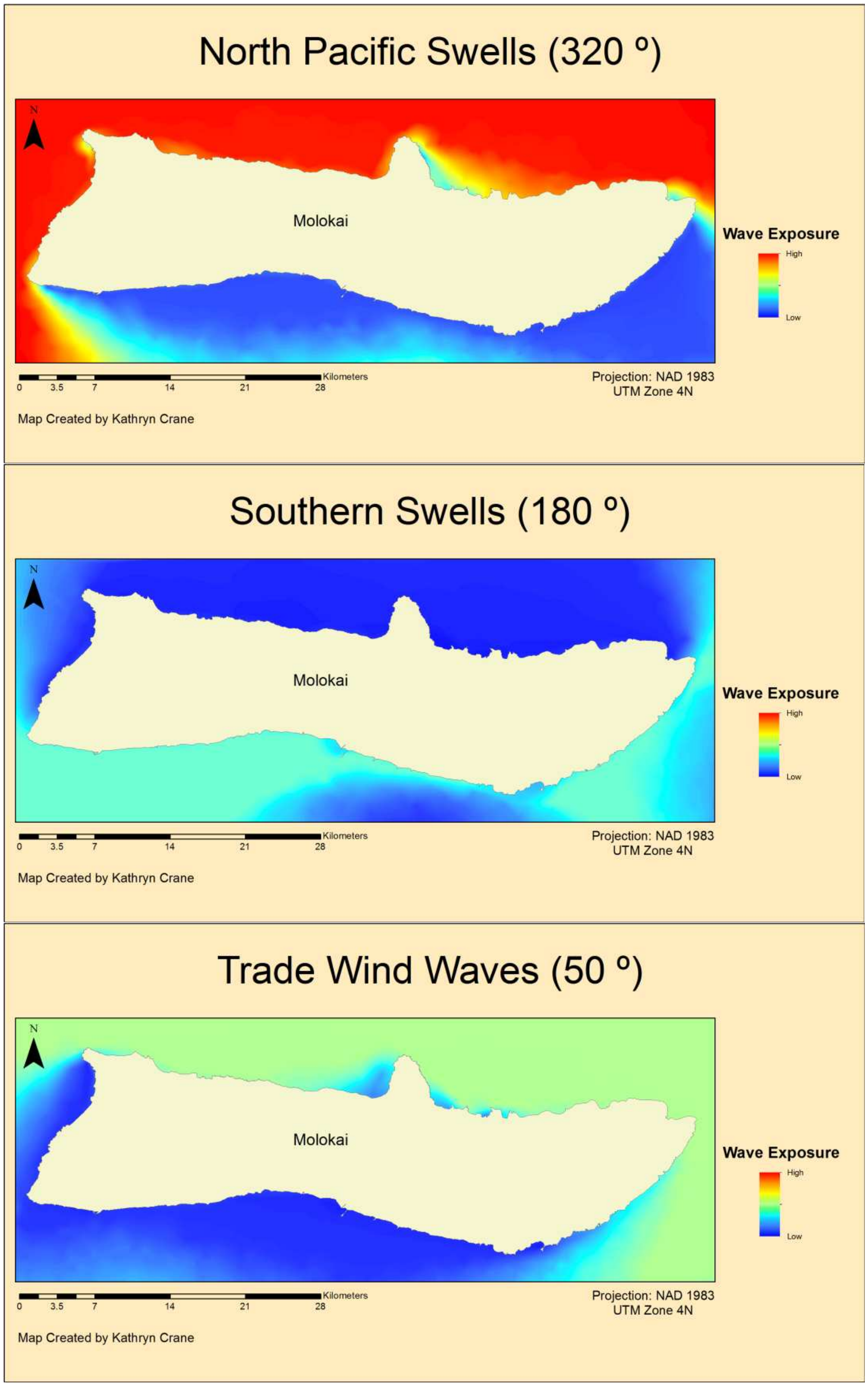
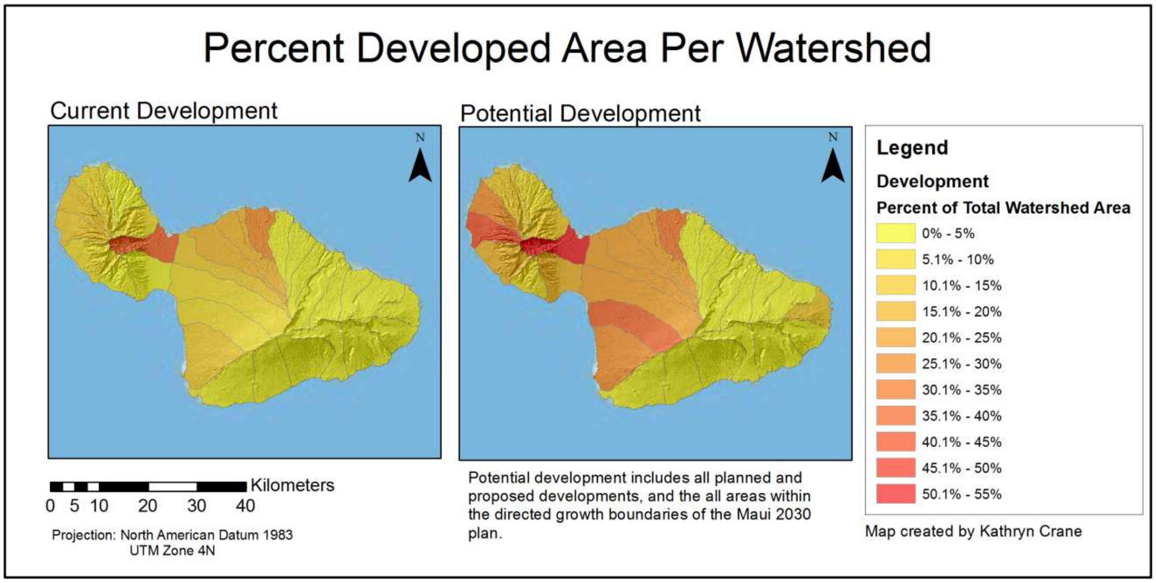


**Figure 11: Interpolated output of the GIS-based wave exposure model for three of the major wave regimes, shown around Molokai, Hawaii.**

## Wave Exposure, Maui

The coral reefs and nearshore waters around Maui experience temporally and spatially varying levels of wave exposure. The exposure changes with the type, direction, and strength of waves, and how protected the nearshore waters and reefs are from these waves. Using the GIS-based wave exposure model described above, I evaluated reefs that are potentially threatened by changes in development.

As development will not occur uniformly around the island, I focused the analysis where development is projected to increase the most. In keeping with the idea of watershed management, and the connectivity of the mountains and the sea, I evaluated the change in developed area per watershed (Figure 12).


Percent Developed Area Per Watershed

Current Development

Potential Development

Potential development includes all planned and proposed developments, and the all areas within the directed growth boundaries of the Maui 2030 plan.

Projection: North American Datum 1983
UTM Zone 4N

Map created by Kathryn Crane

**Figure 12: Percent developed area per watershed in Maui, comparing current land use and projected and proposed development. Data from Planning Department (2010) and Hawaii Statewide GIS Program (2010).**

Potential development includes all areas within the proposed urban growth boundaries of the Maui 2030 plan, as well as the development projects that have been proposed and/or approved.

Much of the island is not expected to grow at all. Much of East Maui has no proposed or approved developments and is not within any urban growth boundary. Most of the development that can be expected will occur in central Maui (in the Wailuku/Kahului urban center), the leeward coast of west Maui, and in south Maui (in the Kihei area) (Figure 12).

The watershed with the greatest potential increase in developed area is the Kahoma Stream watershed, near Lahaina in west Maui. The percent increase here is 30.8%, resulting in a developed area of 44% of the watershed (Figure 13).

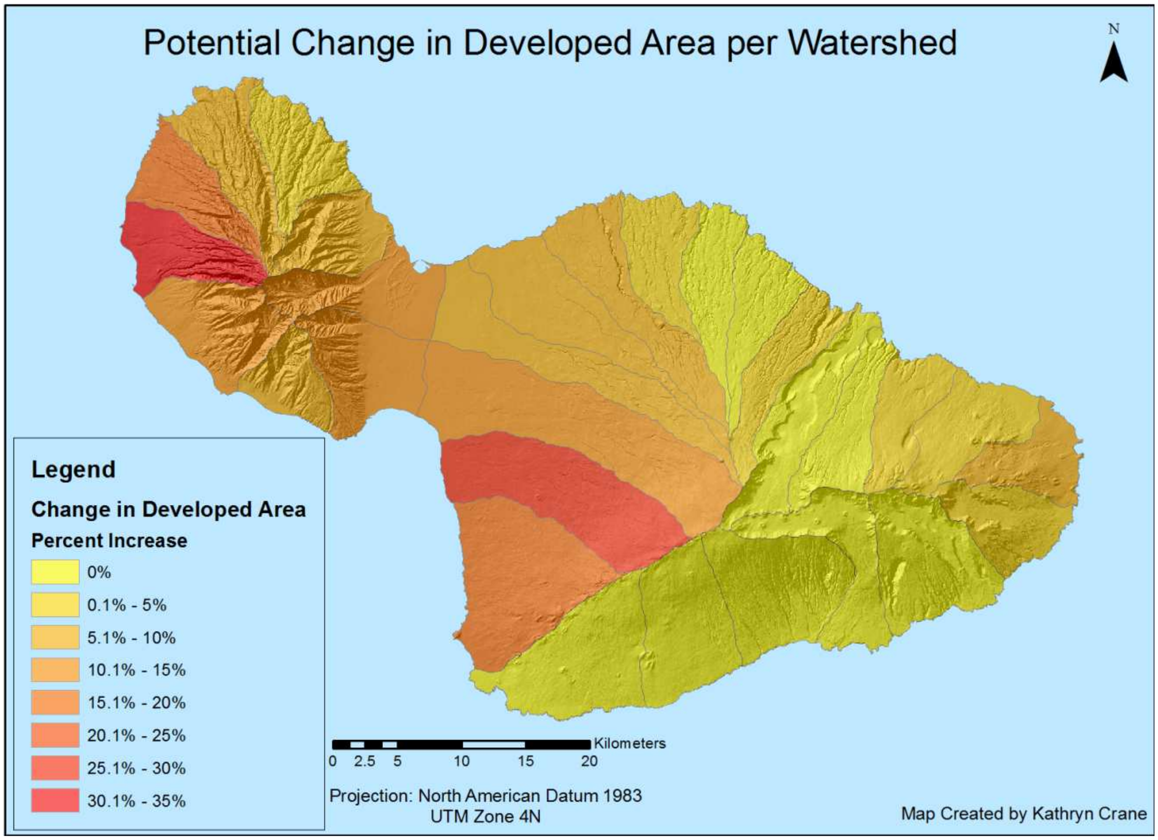


**Figure 13: Percent change in developed area per watershed from current land use to potential development. Assumes development of all approved and proposed development projects, and development within the directed growth boundaries. Data from Planning Department (2010).**

## Results

The nearshore area of the Kahoma stream watershed is most exposed to northern swells and southern swells. Since trade wind waves refract around the island, the watershed is less exposed to these waves.

Some of the fringing reefs experience low exposure during all 3 major wave regimes (Figure 14). The northern side of Mala Wharf is a reef that is protected from all three swells. This reef is a popular site for divers and snorkelers as the complex structure of the wharf has led to colonization of many coral species.

The southern tip of Kaanapali is another site with limited exposure throughout the year. This area is south of the resort development, but development is expected to expand in the future.

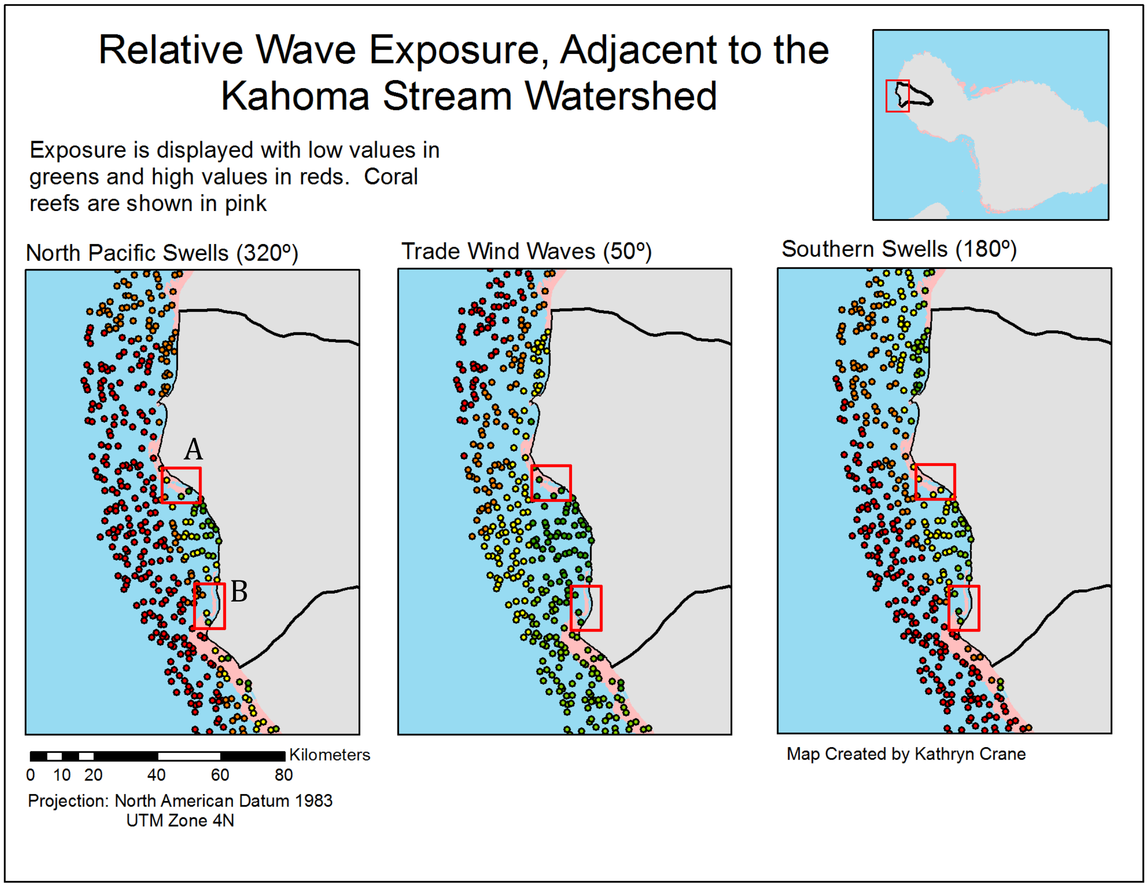


**Figure 14: Results of wave exposure model on Kahoma stream watershed. Red boxes highlight the coral reef locations where wave exposure is low during all three wave types. (A) South Kaanapali. (B) Mala Wharf.**

## Implications for Development

Development or other land use alteration that would increase sediment runoff from land adjacent to Mala Wharf and South Kaanapali have the potential to cause significant harm to the reefs there as wave exposure in these areas is low (Figure 14).

In order to identify specific areas where development poses the most significant risk in the watershed, I used previously delineated sub-watersheds to select the sites that drain to the selected reefs (Figure 15). In these areas, significant caution should be taken, and regulations should be more stringent in preventing the introduction of sediment to nearshore waters.

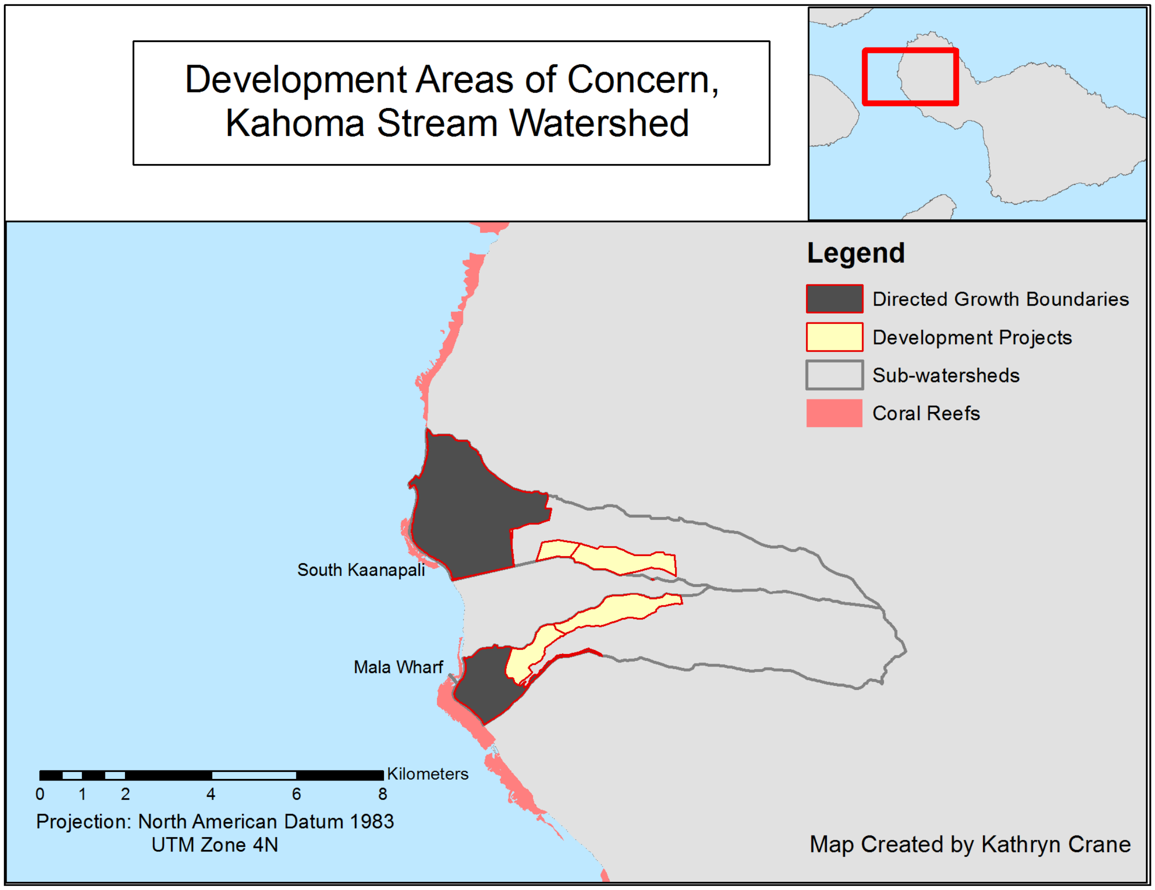


**Figure 15: Results of the sub-watershed analysis. Areas outlined in red pose the most significant threat to the coral reefs of South Kaanapali and Mala Wharf.**

## Policy Recommendations

It is generally agreed upon in the literature that ecosystem based management is needed in order to address the issue of coral reef sedimentation (Wolanski et al. 2006). The manifestation of this into policy is another problem altogether. Because of Maui's history of land use management and the effective Ahupua'a system, this seems to be better translated into policy here than in many other places. However, there are still many improvements that can be made in the land use policy of Maui that would prevent excessive sedimentation of the fringing reefs. Current policy is designed to limit the volume of sediment running off the land and into the nearshore waters. The policy also needs to include spatially explicit regulations that require additional sediment control measures where wave exposure is low.

Long term coral monitoring suggests that management efforts should be concentrated in areas where wave circulation is low, like in protected embayments (Dollar and Grigg 2004). While sediment control measures should be required for *all* development, increased regulations should be imposed in areas draining into low wave exposure areas.

Because the Maui 2030 plan includes spatially explicit development plans, the directed growth boundaries, it would be relatively simple to implement additional regulations regarding sediment control in certain areas.

In land areas draining into waters of low exposure, like those selected in the previous analysis, there are many additional regulations that would limit sedimentation. Sediment filtration removes more sediment from runoff than any other method. While this is more costly than sediment removal methods such as sediment basins and drainage ditches, it is much more effective.

Reducing the amount of impervious surface allows runoff to slow down and percolate into the soil. This reduces the total volume of the runoff, and thus the sediments. Limiting the density of development reduces the total amount of impervious surface.

There should be increased limits to the amount of exposed soil allowed during construction. Reducing the amount of exposed soil limits the sediment vulnerable to erosion. There are also more costly methods, such as pervious pavement, that would be beneficial.

In some locations, wetland restoration would be beneficial. This would not be a feasible option in the areas described above, as historic wetlands are not present there. In other locations however, this is an effective way to slow runoff and give sediment time to settle out of the water before entering the marine environment.

In locations where soil is already exposed due to overgrazing or fallow agricultural land, smart, well-planned and well-executed development may actually result in reduced sedimentation. While this is not a popular recommendation, especially on Maui, it is an option. However, it is essential that this development be low impact and the recommendations described above are followed.

Sedimentation is only one of the many things to be taken into account when planning for development. The protection of Maui’s reefs is important to the government, people, and economy, but needs to be balanced with the other needs as well. It may not be feasible, either economically or infrastructurally to require costly regulations throughout the island. However, if key reefs are identified for protection, land conservation and habitat restoration can be focused on areas that would benefit the most from these actions. I recommend that the county of Maui select several reefs to be protected, and begin enacting stricter regulations there. These new regulations can be evaluated to determine their effects and then decide on the next course of action.

## Future Data and Research Needs

The need for more research and better models is significant. Development in Maui is not likely to stop in the near future. We need better ways to predict and limit the consequences of this development (Rogers 1990). The GIS-based model presented in this paper is a rough tool that does not take a number of oceanographic variables into account. It is, however, a step towards a user-friendly way to visualize potential nearshore wave energy and the implications it presents for sedimentation. This model could and should be improved upon, without sacrificing accessibility and computational efficiency. It is essential to keep such models as simple as possible so they can be run for large spatial scales and fine resolutions. They must also be user friendly, be easily interpreted, and made available to managers and planners.

The sediment transport mechanisms on complex bottoms such as coral reefs is much more complicated than sloping sandy bottoms (Storlazzi et al 2009). These systems, which are more studied, are much easier to predict. More research is needed regarding sediment transport in coral reef ecosystems. In order to determine how much wave exposure is enough to effectively and efficiently remove sediments from the reef, more research needs to be conducted, both in the laboratory and in the field.

Long term data is needed to better determine the impacts of sedimentation and the recovery of reefs. Models should be complemented with new information about the response of coral to sedimentation. There is a current inability to accurately predict the impact of increasing rates of sedimentation at a time of unprecedented development (Rogers 1990).

With reliable models of sediment input and sediment removal, land use planners will have a better understanding of the potential impacts of changes in land use to fringing coral reefs. With this understanding, planners can better manage human activity to prevent sedimentation and the resulting coral mortality.

# Acknowledgements

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# Appendix A: Wave Exposure Python Script

```
## Kathryn Crane
## Advanced GIS
## Final Project
## The following script estimates nearshore wave exposure of randomly generated points.  It takes into account wave breaking
##  obstacles, refraction, and openness (depth or flatness) of the coast line.
##_______________________________________________________________


#Import modules
import arcpy, os, sys, math

from arcpy import env

#set workspace
env.workspace = r'X:\FinalProject\Scratch'

spatial_reference = r'X:\FinalProject\Maui_10\maui10_prj.shp'
arcpy.env.overwriteOutput = 1
print "starting"

#generate random point
outpath = 'X:\FinalProject\Scratch'
constrain = 'X:\FinalProject\Scratch\Ocean_pieces.shp'

arcpy.CreateRandomPoints_management(outpath, "samplePts", constrain, "", 400, 50, "POINT")

arcpy.AddXY_management("samplePts.shp")
print "done generating points"

#add field that sums the fetch lines with ang_near1 value of 1
arcpy.AddField_management("samplePts.shp", "sum", "LONG", 9, 3)
arcpy.AddField_management("samplePts.shp", "total_fet", "LONG", 9, 3)
arcpy.AddField_management("samplePts.shp", "min_ang", "LONG", 9, 3)
arcpy.AddField_management("samplePts.shp", "REI", "LONG", 9, 3)

rows5 = arcpy.UpdateCursor("samplePts.shp")
row5 = rows5.next()

while row5:

    #for each point, get the X and Y values to be used in the analysis
    ux = row5.getValue("POINT_X")
    uy = row5.getValue("POINT_Y")

    userx = float(ux)
    usery = float(uy)

    #print userx
    #print usery

    wave_ang = 320

    outputFC = arcpy.CreateFeatureclass_management(r'X:\FinalProject\Scratch', "fetchlines.shp", "POLYLINE", "", "DISABLED",
"DISABLED", spatial_reference)

    arcpy.AddMessage("making new field")

    #create new field of the angle of the line
    infeatures = "fetchlines.shp"
    fldName = "angle"
    fldName2 = "Ang_diff"
    precision = 9
    scale = 3

    arcpy.AddField_management(infeatures, fldName, "LONG", precision, scale)
    arcpy.AddField_management(infeatures, fldName2, "FLOAT", precision, scale)
```

```
arcpy.AddMessage("creating fetch lines")

cur = arcpy.InsertCursor(outputFC)
distance = 60000


for angles in range (0, 360, 5):

    #convert degrees to radians
    real = 90 - angles
    #print angles
    radians = real * 0.0174532925

    #calculate changes in x and y to get the new point
    ychange = (math.sin(radians)) * distance
    y1 = usery + ychange
    xchange = (math.cos(radians)) * distance
    x1 = userx + xchange

    P2 = arcpy.Point(userx, usery)
    P1 = arcpy.Point(x1, y1)
    lineArray = arcpy.Array()
    lineArray.add(P1)
    lineArray.add(P2)
    angleline = arcpy.Array()
    angleline.add(lineArray)

    feat = cur.newRow()
    feat.shape = angleline
    cur.insertRow(feat)

del cur

#Create an update cursor and update values
cur = arcpy.UpdateCursor(outputFC)
cur.reset()
rec = cur.next()

for angles in range (0, 360, 5):
    rec.setValue(fldName,angles)
    cur.updateRow(rec)
    rec = cur.next()
del cur

#create and populate field giving the difference between approaching wave and fetch line
cur = arcpy.UpdateCursor(outputFC)
cur.reset()
rec = cur.next()

for angles in range (0, 360, 5):
    ang_diff = abs(wave_ang - angles)
    if ang_diff < 180:
        rec.setValue(fldName2,ang_diff)
        cur.updateRow(rec)
        rec = cur.next()
    else:
        ang_diff2 = abs(360 - ang_diff)
        rec.setValue(fldName2,ang_diff2)
        cur.updateRow(rec)
        rec = cur.next()
del cur


arcpy.AddMessage("Determining if approaching wave is within open angle range")

#create yes/no field
fldName = "ang_near"
precision = 9
```

```
scale = 3
arcpy.AddField_management(outputFC, fldName, "LONG", precision, scale)

#populate the yes/no field, 1 if the angle of wave approach is near that value, 0 if not
cur = arcpy.UpdateCursor(outputFC)
cur.reset()
rec = cur.next()

yes = 1
no = 0

#get all angles within 60 degree range of approaching wave
if wave_ang > 30:
    minAngle = wave_ang - 30
    minAngle2 = minAngle
    maxAngle2 = minAngle
else:
    minAngle = 0
    minAngle2 = 359 - (30 - wave_ang)
    maxAngle2 = 359

if wave_ang < 329:
    maxAngle = wave_ang + 30
    minAngle2 = maxAngle
    maxAngle2 = maxAngle
else:
    maxAngle = 359
    minAngle2 = 0
    maxAngle2 = (wave_ang + 30)-360


for angles in range (0, 360, 5):
    if wave_ang > (angles - 5) and wave_ang <= angles:
        yes = 2
        rec.setValue(fldName,yes)
        cur.updateRow(rec)
        yes = 1
        rec = cur.next()
    elif minAngle <= angles and maxAngle >= angles:
        rec.setValue(fldName,yes)
        cur.updateRow(rec)
        rec = cur.next()
    elif minAngle2 <= angles and maxAngle2 >= angles:
        rec.setValue(fldName,yes)
        cur.updateRow(rec)
        rec = cur.next()
    else:
        rec.setValue(fldName,no)
        cur.updateRow(rec)
        rec = cur.next()

del cur


arcpy.Erase_analysis("fetchlines.shp", "coast_n83.shp", "fetch_int.shp")
arcpy.MultipartToSinglepart_management("fetch_int.shp", "fetch_sing.shp")

arcpy.AddField_management("fetch_sing.shp", "Length", "LONG", precision, scale)
arcpy.CalculateField_management("fetch_sing.shp", "Length", "!shape.length!", "python")

#Make fetch lines into layer
layer = "fetch.lyr"
output = "open_fetch.shp"
arcpy.MakeFeatureLayer_management("fetch_sing.shp", layer)


#Select Fetch Lines that intersect with shoreline, and write to a new output file
arcpy.SelectLayerByLocation_management(layer, "BOUNDARY_TOUCHES", layer)
arcpy.SelectLayerByAttribute_management(layer, "REMOVE_FROM_SELECTION", "\"Length\" < 10000")
```

```
    arcpy.CopyFeatures_management(layer, output)

    #arcpy.AddField_management("open_fetch.shp", "L_sum", "LONG", precision, scale)
    #arcpy.CalculateField_management("open_fetch.shp", "L_sum", "[Length] * [ang_near]", "VB", "")

    fldname = "final_ang"
    arcpy.AddField_management("open_fetch.shp", fldname, "LONG", precision, scale)


    rows = arcpy.UpdateCursor(output)
    row = rows.next()

    while row:
        ang = row.getValue("ang_diff")
        if row.getValue("Length") == 60000:
            row.setValue(fldname,ang)
            rows.updateRow(row)
            row = rows.next()
        else:
            row.setValue(fldname,180)
            rows.updateRow(row)
            row = rows.next()

    del row
    del rows

    arcpy.Statistics_analysis("open_fetch.shp", "stats.dbf", [["ang_near", "SUM"], ["final_ang", "MIN"], ["ang_near", "COUNT"]])

    rows = arcpy.SearchCursor("stats.dbf")

    for row in rows:
        ang_sum2 = row.getValue("SUM_ang_ne")
        num = row.getValue("COUNT_ang_")
        diff = row.getValue("MIN_final_")

    del rows


    row5.setValue("sum",ang_sum2)
    rows5.updateRow(row5)
    #70 possible

    row5.setValue("total_fet",num)
    rows5.updateRow(row5)
    #total possible is 12

    row5.setValue("min_ang",diff)
    rows5.updateRow(row5)
    #max is 180
    REI = ang_sum2 * 5 + (180 - diff) + (num / 2)
    row5.setValue("REI",REI)
    rows5.updateRow(row5)
    row5 = rows5.next()
del row5, rows5

print "Complete"
```