Chapter 9
Beach Erosion and Loss

Early in Hawaii's history, government recognized the need to protect certain valuable resources: beaches were not among them. Watersheds were set aside to protect our source of water. Reefs were set aside to protect nearshore fisheries. Forests were protected for their ecological and climate functions. But beaches were never designated as a special environment worthy of protection. This was a mistake, as now beaches are being lost on every island due to seawall building and overdevelopment along our coastline. As a result local communities and government agencies are engaged in a struggle to protect beaches by building protections into the system of existing laws. This Sisyphean effort is highly taxing to the good will and resources of the public and their governmental partners.

Among Hawai'i's greatest treasures are her beaches. Their loss, whether measured in terms of disappearance, degradation, or access, is a loss to the ecosystem, the economy, and the culture. Rising water level is one of nature's primary tools for reshaping beaches and migrating them landward. In addition to global sea-level rise, land subsidence, tidal fluctuation, and mesoscale eddies, the level of the sea also varies on much shorter time scales. Waves and storm surges are the sea-level changes we can see altering the beaches daily. As sea-level rises, either in the short term or the long term, the beach must shift upward and landward. This change in beach position is known as *shoreline retreat*, but typically it is described as *beach erosion*. It requires that a broad swath of the coastal zone be free of development so that the beach and community infrastructure do not collide.

Beach erosion is a term used to describe the actual loss of beach, as occurs temporarily on some of Hawai'i's beaches in the high wave months, and is often seen permanently in front of seawalls where the coast has been chronically retreating. During beach erosion, beaches gradually narrow and may eventually disappear altogether because they are experiencing a sediment deficiency, a loss of sand.

Sea Level Changes that Impact Beaches[1]			
Phenomenon	**Time Scale**	**Magnitude**	**Predictability**
Global Warming	50 to >100 years	2-10 mm/yr	Predictable
Interdecadal Oscillation	10 to 30 years	10-40cm	Unpredictable
El Niño	2-5 years	30-60 cm	6-9 months lead
Annual Cycle	1 year	10-40 cm	Predictable
Intraseasonal Oscillation	40-60 days	10-20 cm	15-30 days lead
Mesoscale Eddy	20-60 days	5-15 cm	15 to 30 days lead
Fortnightly Tide	14 days	4-5 cm	Predictable
Large-scale Weather Systems	3-7 days	10-30 cm	0-10 days lead
Tides	<1 day	1-3 m	Predictable
Storm Surges	5 hours	2-4 m	0-2 hours lead
Wave Group Setup	20 minutes	1 m	10 minutes lead
Individual Waves	15-25 seconds	2-15 m	Unpredictable

Coastal erosion, another common term, describes the landward movement of the beach and loss of the abutting land in the process. Unlike beach erosion, sand is not necessarily lost during coastal erosion. This is because many of our low-lying coastal lands are composed of marine sands deposited there by persistent winds and ancient high seas from 3,000 years ago (the "Kapapa Stand of the Sea").[2] Coastal erosion releases this sand and it nourishes the transgressing beach allowing it to stay wide and healthy even as the shoreline migrates landward.

Migrating Upward and Landward Through Space and Time

"Migrating upward and landward through space and time." This is a famous phrase among coastal scientists. It describes the behavior of a beach, or other coastal environment such as a tidal wetland, a reef, or an estuary, when sea level is rising. It means that a coastal environment needs unrestricted access to the adjacent land or it will drown under the rising water. Rising sea level forces coastal environments to migrate up onto the land, replacing formerly terrestrial environments with tidal environments. Dunes become beaches, streams become estuaries, and fields (and neighborhoods) become wetlands. If this route of migration is blocked, the coastal environment will disappear.

In the past several centuries most beaches have had to adjust to rising sea level worldwide. A retreating beach simply changes its position in space as it migrates, maintaining the same general appearance as before and probably containing some of the same sand. If the abutting land is composed of sand, coastal erosion creates little problem for the beach because it uses this sand to sustain the environment. After all, sand is the lifeblood of beaches. However, migrating upward and landward through space and time does create a huge problem for buildings and roads built too close to the shoreline. And therein lies the rub – protecting the land with a seawall will lead to beach loss. Allowing the beach to continue migrating will damage roads and buildings that lie in its path. What should we protect – the beach or the buildings?

One obvious approach to this problem is to avoid it in the first place. Knowledge of where and at what rate beaches are eroding and can be used to guide the way we build along our shoreline. Now, for the first time, Hawai'i citizens know the rate and location of beach erosion on Kauai, Oahu, and Maui.[3] In fact, county authorities on Kauai and Maui use the rate of beach erosion to determine where a building or road can be built. The rate of erosion is used to calculate a *construction set-back* which is the distance from the shoreline that determines where construction can take place. This planning tool attempts to avoid the erosion problem by scaling the set-back to the rate of erosion.[4] On Maui, the construction setback distance is calculated as fifty times the annual rate of beach erosion plus 20ft. On Kauai it is seventy times the annual rate of erosion plus 40ft. The idea behind these laws is to prevent the construction of a home or other building close to an eroding shoreline. Ideally erosion is avoided on Maui for fifty years and on Kauai for seventy years (the average life of a wood-frame house).

How much setback will be enough later this century as sea level approaches 3.3 ft (1 m) above present? This is a problem that has not yet been fully addressed by planning authorities. The Kauai setback does include a fixed distance to accommodate the effects of sea-level rise (20 ft) but whether this will be adequate and for how long, is unknown. Kudos to Kauai officials, at least they have made an attempt to deal with the problem.

The exact relationship between an increment of sea-level rise and an increment of shoreline retreat is not well understood. Hence, it is difficult to predict how much erosion will be caused by sea-level rise. But it is possible to make an estimate. The width, steepness, and geometry of a beach have a characteristic form that depends on the size of sand grains and the energy of waves. Coarse sand grains tend to build steep beaches, and fine sand grains tend to build beaches with gentle slopes. High waves will move these grains offshore and lower the slope, promoting gently dipping beaches that can dissipate the wave energy further offshore. These are referred to as *dissipative beaches*. Beaches that are steep and tend to reflect wave energy back toward the ocean are called *reflective beaches*. Most beaches exist in a state of dynamic equilibrium among these factors, constantly shifting from reflective to dissipative and accumulating a range of sand grains, as the tides, winds, and waves vary throughout the year.

Scientists use a *beach profile*, a topographic cross-section of a beach, to describe these shifts in geometry. A beach profile is measured perpendicular to the shoreline and runs from the land to the sea. It includes the dune, the dry sand beach, the foreshore, and the offshore portion of a beach in the surf zone. The profile can be described by the distance (L) offshore where approaching waves first affect the bottom and the depth at that place (D). Typically the ratio L/D is about 100, though it can vary between fifty and two hundred depending if the beach is reflective (closer to fifty) or dissipative (closer to two hundred).

As sea-level rises, the profile shifts landward and upward to regain its equilibrium profile; the L/D ratio of ~100. It achieves this by eroding the shoreline, which on a natural beach should consist of a sand-rich dune. If however, the shoreline consists of a lava outcrop, a clay bank, a seawall, or some other non-sandy barrier, the beach will experience a sand deficiency and will eventually disappear. Since L/D is approximately 100, the change in D due to sea-level rise can translate into horizontal beach erosion two orders of magnitude greater than D. Hence, with global sea-level rise currently at approximately 0.12 in/yr[5], this translates to one foot per year erosion.[6] Notably, this is about the average rate of coastal erosion that has been measured on the islands of Kauai, Maui, and O'ahu.[7] However, the tide gauges among these islands do not record rates of rise equivalent to 0.12 in/yr. They record lower rates of sea-level rise, closer to 0.06 to 0.1 in/yr[8]. Hence, if beach erosion were responding only to sea-level rise the average rate would be less than we measure. Either our estimate of L/D is incorrect and should be closer to 200, or beaches are affected by more factors than just sea-level rise (for instance they can be affected by human impacts to sand availability), or some combination of these.

If we stick with L/D~100 as a best-case scenario, the amount of shoreline retreat accompanying a 1 m (40 inches) rise in sea level by the end of the century will be approximately 100 m or 330 feet.[9] This amount should serve as a guideline for developing tools to manage beach conservation and coastal hazard mitigation under our warming climate.

Do all beaches migrate upward and landward through space and time? No, *beach accretion* describes the process of a beach widening in the seaward direction. Such a beach is surely a rare treasure in this era of rising global sea level. Accreting beaches exist where there is a healthy and rich availability of sand. Two examples of accreting beaches include portions of Kailua Beach, O'ahu, and Hanalei Beach, Kaua'i. The source of sand to Kailua is thought to be a large sand field located offshore. Hanalei sand is probably supplied by currents that bring sand to the mouth of the bay from the Princeville and Anini shoreline. Waves pick up this sand and deliver it to the beach. Of interest, both Kailua and Hanalei beaches have narrowed in the past half-century despite their seaward advance, because aggressive vegetation such as *Morning Glory* and *Naupaka* grow across the open sand faster than the beach is able to widen. Kailua beach is actually narrower today than during WWII despite the fact that the water's edge is more than thirty feet further seaward.[10]

Beach Flexibility

Found at the boundary between land and sea, the beach is one of Earth's most dynamic environments. It is said among coastal scientists that "the only reliable constant on the shoreline is the condition of perpetual change."[11] A beach evolves through time in a balance or dynamic equilibrium between several factors, including: quantity and type of beach sand, energy of the waves, sea-level change, and the shape and location of the larger coastline; when one factor changes, others adjust accordingly. The ability to change shape according to natural factors reveals it as an extremely durable system when left to its own resources. Humans, however, have proven their ability to destroy this otherwise indestructible environment.

As beaches erode and eventually disappear from short-sighted coastal management practices, the protection they offer as a buffer against storm waves also disappears. Homes along Hawaii's shores will experience greater damage as sea level continues to rise and eventually accelerate[12]. This is evident in the fact that one of our major insurers, State-Farm, now no longer insures homes within 1,500 feet of the shoreline.[13] Other insurers are following suit. Meanwhile, for homeowners still able to get insurance, rates will continue to rise. It will likely become so bad that, as has now happened along the coastline of Florida, insurance for ocean flooding and storm damage can only be obtained from a centralized state-managed fund because there is no commercial profit to be made insuring homes on the coast – they are too frequently destroyed.[14]

Dunes: Canary in the Coal Mine of Interagency (non)Cooperation

One of the environments critical to beach survival is the coastal sand dune system. Unfortunately for Hawaiʻi, our coastal dunes are nearly extinct. Flattened and mined so that the view from our pools and living rooms is unobstructed, the sand dunes that formerly lined our shores were Nature's guarantee that beaches would have a savings account of sand during times of high waves, high sea levels, and storms. There are some still rare undeveloped shores where coastal dunes may be found and studied: Papohaku Beach along the west Molokaʻi shoreline, portions of Mokuleia on Oʻahu's north shore, areas in beach parks where dunes have not been flattened such as Bellows Beach Park, Baldwin Beach Park and Waihee region on Maui, and others. Miraculously, Kailua Beach is trying to grow new dunes where it is still accreting in the central region. These are deserving of careful protection.

Most beaches in Hawai'i lack abundant offshore sand sources. The primary source of sand on a chronically eroding shoreline is the dune system located along its landward edge. But these have not historically been protected by management authorities.

One reason dunes have not been protected is because they often fall under county jurisdiction and not all counties are aware of their importance. In Maui County, "filling" (changing the shape of) a dune is not permitted unless it is with beach quality sand. Kauai County also has specific rules governing dune management. But in the case of the City and County of Honolulu, dunes are not protected other than that they may fall within the coastal construction setback – but even then they are allowed to be landscaped out of existence. Many homeowners tend to flatten dunes without a permit because we have insufficient enforcement of coastal laws. This is a consequence of having planning and permitting personnel trained only in planning, rather than including a few coastal scientists among the team. After all, since a large aspect of planning function is to preserve the environment, it would be rational to have some environmentally-trained staff.

On paper, counties have the same goal of protecting the coastal environment as does the state. For instance, Chapter 23 Section1.2 of the Revised Ordinances of Honolulu states that for the purpose of shoreline setbacks:

"It is a <u>primary policy of the city to protect and preserve the natural shoreline</u>, especially sandy beaches; to protect and preserve public pedestrian access laterally along the shoreline and to the sea; and to protect and preserve open space along the shoreline. It is also a secondary policy of the city to reduce hazards to property from coastal floods."[15] (emphasis added).

Unfortunately, the authors of this ordinance did not specify that preserving coastal dunes was a critical aspect of "protecting and preserving the natural shoreline," and management personnel apparently have not historically recognized that flattening dunes causes damage to the beach. On the other hand, why should they worry about beach loss when the beach falls under state jurisdiction, not theirs?

Along the majority of Hawai'i coasts, jurisdiction cuts straight down the center of the beach-dune system and awards half (the dunes) to the counties to manage and half (the beach) to the state to manage. Talk about a recipe for disaster - that's like asking one person to operate the brakes in your car while someone else operates the accelerator. If they don't talk to each other clearly and often and with a single goal, you can be sure you are headed for a car wreck. And hence, because of multi-agency seawall building on eroding shores, we have lost one-quarter of the length of beaches around the island of Oahu.[16] Had city, state, and federal staff operated in an integrated fashion, focused on a single over-riding policy to "*<u>to protect and preserve the natural shoreline</u>"*[17] this unconscionable level of environmental destruction probably would not have happened.

Coastal agencies do not talk to each other clearly and often, and they may not have the same goal; the state Department of Land and Natural Resources wants to preserve environments, while some counties may not care as much about protecting the environment as they simply want whatever shoreline uses to be legal – conservation v. compliance. How did simple compliance come to take precedence over preserving the shoreline? Many planning agencies are understaffed and over worked. These have evolved away from actually performing a conservation function and into a daily routine of processing the torrent of permit applications (to develop the shoreline) in a manner that achieves compliance with governing law. Actually achieving the purpose of preserving the shoreline environment as called for by county ordinance is too difficult with thin staffing levels.

A lack of adequate communication between agencies in different jurisdictions, and a focus on compliance and not conservation, is how one may get a permit to build a seawall on a retreating shoreline, or construct a swimming pool on what should be a dune, or bulldoze down a dune and plant grass to get an ocean view from the lanai. What should be a coordinated coastal zone management system with a unified goal (*to protect and preserve the natural shoreline*) is too often a chain of separate agencies that may resent the advice and comments offered by sister agencies, and just as frequently ignore it. You may recall from Chapter 1 that we identified the thief of our beaches as the same system of management we created to protect it – now you may understand what we mean.

The state shoreline separates the sand-storing dunes from the sand-needing beaches – promoting the demise of each.

The Shoreline

The line of jurisdiction separating state and county lands is known as the *certified shoreline*, and it is defined by the upper reach of the waves on the beach, other than storm and tsunami waves.[18] It is the line from which the construction set-back is measured. It is also the line seaward of which the public has access along the beach. While the official Hawai‘i "shoreline" tends to lie further landward than the shoreline of many other states, and therefore gives the public greater access, it has also spelled death to our system of sand-storing coastal dunes. Compared to the split jurisdiction system we presently have, a single entity, or a lead agency that managed dunes and beaches together would provide better conservation.

What happens to beaches during sea-level rise?

Although the relationship between shoreline position and sea-level rise is complex, sea-level rise ultimately forces a shoreline to migrate landward. This has been proved here in Hawaiʻi by the discovery of fossil, naturally-cemented beaches several centuries to millennia old, located underwater offshore on our reefs, and by the erosional response of beaches to extreme high tides that occur on occasion (see Chapter 8). Though the migration of a beach under rising seas may not greatly alter its width if sediment continues to be available, its shape may change depending on the slope and topography of the land surface, changes in wave and current energy, and shifts in sand supply and movement.

As sea level rises a beach will shift landward to stay at the water's edge. Naturally cemented beach sand, marking the former position of the beach, can be stranded offshore by the migrating shoreline. These fossil beaches are proof that beaches migrate upward and landward through space and time.

As mentioned in Chapter 8, the physical effects of sea-level rise can be grouped into five categories: marine inundation of low-lying developed areas including coastal roads, erosion of beaches and bluffs, salt intrusion into ground water and surface ecosystems, higher water tables, and increased flooding and storm damage due to heavy rainfall. All of these effects have important impacts, but the first two have had and are continuing to have very dramatic impacts on coastal regions worldwide.

Coastal erosion is most likely a product of sea-level rise when no other obvious impact to sediment availability can be identified, although the exact relationship is not well understood. As mentioned earlier, a beach profile has a characteristic shape that depends on the size of sand grains and the energy of waves. As sea-level rises, the profile shifts landward to regain this geometry and erodes the adjacent shoreline. Since this beach geometry is maintained, the rate of shoreline recession and the rate of sea-level rise have a relationship. This relationship indicates that by the end of the century, lands within approximately 330 ft of today's shore are vulnerable to erosion. Next time you visit a beach, take a minute and assess the intense infrastructure, roads, houses, buried pipes, airports, and other community assets that lie within a football field of the shoreline – How will we ever deal with the coming calamity of sea-level rise? We need to stage a statewide retreat from the shore, and we need to implement it as policy now.

Is coastal erosion a national problem?

According to a study prepared for FEMA by The Heinz Center for Science, Economics and the Environment in 2000, approximately 25% of homes and other structures within 500 feet of a U.S. shoreline (including the Great Lakes) will fall victim to the effects of coastal erosion within the next sixty years.[19]

> "[The *Evaluation of Erosion Hazards* report] provides for the first time a comprehensive assessment of coastal erosion and its impact on people and property along our nation's ocean and Great Lakes shorelines," said former FEMA Director James Lee Witt. "The findings are sobering. If coastal development continues unabated and if sea levels rise as some scientists are predicting, the impact will be even worse."[20]

The worst hit areas include the Atlantic and Gulf of Mexico coastlines, which are predicted to account for 60% of nationwide losses.[21] Costs to U.S. homeowners will average more than a half billion dollars per year in the form of increased insurance premiums, replacement of damaged buildings, and engineering measures to counteract erosion. Additional development in high erosion areas will lead to higher losses, according to the report. Highly protected areas of large East Coast cities will not be adversely affected because they have already armored their shoreline in replacement of the formerly natural environment.

As a result of this study, FEMA is recommending that coastal communities take steps to avoid erosion.[22] This *avoidance policy* is designed to circumvent the predicted future of high nation-wide costs, human hardship, financial burdens to homeowners, and negative impacts to shoreline environments that suffer when erosion and human land use collide.

Where does beach sand come from?

Sand supply remains an essential variable in sustaining Hawaii's beaches. For instance, a few beaches in Hawaiʻi have maintained their position over the last century, despite decades of rising seas, while Kailua, Kahana, Hanalei and a handful of other beaches have actually grown seaward with time. This amazing behavior stems from a robust and uninterrupted supply of sand. In the case of Kauai's Hanalei beach, trade winds push a couple thousand cubic yards of sand each year into Hanalei Bay from the eastern shoreline of the island. This sand accumulates in the bay and causes the beach to grow. In fact, the entire coastal plain of Hanalei underlying the North Shores' quaint village and taro fields has accreted seaward for nearly 4,000 years under this constant influx of sand! Interrupt this sand supply in the Princeville area and miles away world famous Hanalei Beach will suffer.[23]

Another example of the dominance of sand supply over sea-level rise is found at Kailua Beach, Oʻahu. Sand from a deep channel cutting through Kailua's reef migrates onto the beach under certain wave conditions. Although local reefs originally created this sand, the majority of it now arrives on the beach through the offshore sand channel. Longtime residents of the beach can point to new sand dunes that have formed in the past decade, seaward of the previous dune ridge. But to preserve this gift, and to manage our beaches in accordance with FEMA's recommended *avoidance policy*, it is important that new development not be allowed to push its way further seaward. As sea level continues to rise it is unclear how long beach accretion can sustain itself and permission to build on accreting lands is a sure ticket to future seawalls and beach loss.

While the typical image of a beach includes a smooth ribbon of white sand stretching into the ocean, this does not always hold true because beaches comprise different substances. In Hawaiʻi, beach sand originates from numerous sources including streams, eroding land, lava flows, biological erosion of submarine limestone, and the shoreward transport of skeletal remains of marine organisms. If you pick up a handful of white sand from your favorite Hawaiian beach, chances are it is hundreds to thousands of years old – the product of *bioerosion* (several critters chew through rocky reefs and produce sand in the process) on old fossil reefs located offshore with the addition of slow biological production of sand over great lengths of time.

Much of the sand needed by Hawaiian beaches during periods of high waves and sea-level rise comes from dunes that store beach sand until it is needed by the beach to counteract erosion. When natural dunes are removed to make room for lawns and homes this sand is no longer available to the beach and it typically experiences chronic erosion.

Most of the sand particles you find on Hawaii's white sand beaches are actually pieces of coral, algae, urchin spines, and shells along with smaller mixtures of volcanic minerals and bits of rock.[24] *Koʻa* (coral) is a tiny animal that surrounds itself with its own hard home of calcium carbonate ($CaCO_3$). A coral reef is made by millions of Ko'a all building new tiny homes on top of the old ones over centuries (see Chapter 10). Animals such as the *uhu* (parrot fish) and the *ʻina uli* (pastel sea urchin), create sand by scraping and boring into the reef for food and shelter. Sand is also full of tiny hard-shelled single-celled plankton organisms called *foraminifera*, sea snails, and the alga *Halimeda* that hardens and turns white after it dies. Carbonate (white) sand in Hawai‘i is a natural substance that actually “grows” on the reef. Look very closely at a handful of reef sand and you will find that nearly every grain used to be alive.

On all islands, streams carry sand-sized volcanic fragments down from the mountains towards the shore adding these to the reef detritus that collects on beaches. On the Big Island, volcanic clasts arrive in overwhelming quantity delivered by coastal currents, or eroded from bluffs immediately behind beaches creating some of its surreal black sand beaches. Big Island black sand beaches are formed from eroding volcanic sea cliffs, cinder deposits, and grains produced when lava rapidly chills to glass as it enters the cool sea. Green Sand Beach, probably the Big Island’s most famed beach among sand and mineral collectors, owes its shade to the dominant green-tinted grains of *olivine*, a mineral of magnesium-iron silicate that is derived from eroded volcanic bedrock. On Maui, Red Sand Beach provides another example where beach sand is a direct product of erosion from adjacent reddish cinder cone deposits.

Although carbonate sand is associated with reefs, the abundance of such organic fragments does not always mean that the beach sands’ immediate source is from offshore. Much of the sand in eroding beaches comes from reworked dune sand and fossil beaches located landward of the modern beach. These older deposits collected over the past 4,000 years when sea level was a few feet higher than its present level. The higher *Kapapa Stand of the Sea* retreated between 2000 to 500 years ago and uncovered the coastal plains where we currently live, leaving behind stranded dunes and beach ridges: Waikiki, Waimanalo, Kailua, Punalu‘u, Sunset Beach, Kapa‘a, the Mana Plain, Kihei, and many other flat sandy coastal plains emerged as the seas withdrew. Before being developed, these places had topography like corduroy, made of undulating beach and dune ridges.

Now, because of a warming atmosphere and a warming – expanding – water column, sea level has reversed and is rising around the world, and on each Hawaiian Island, and is reclaiming this land. With shoreline retreat occurring among so many Hawaiian beaches, the principal source of sand is through erosion of the adjoining land; if it is sand-rich with a healthy dune, the beach will benefit, if it is sand-starved with a degraded dune or a rocky backshore, the beach will suffer.

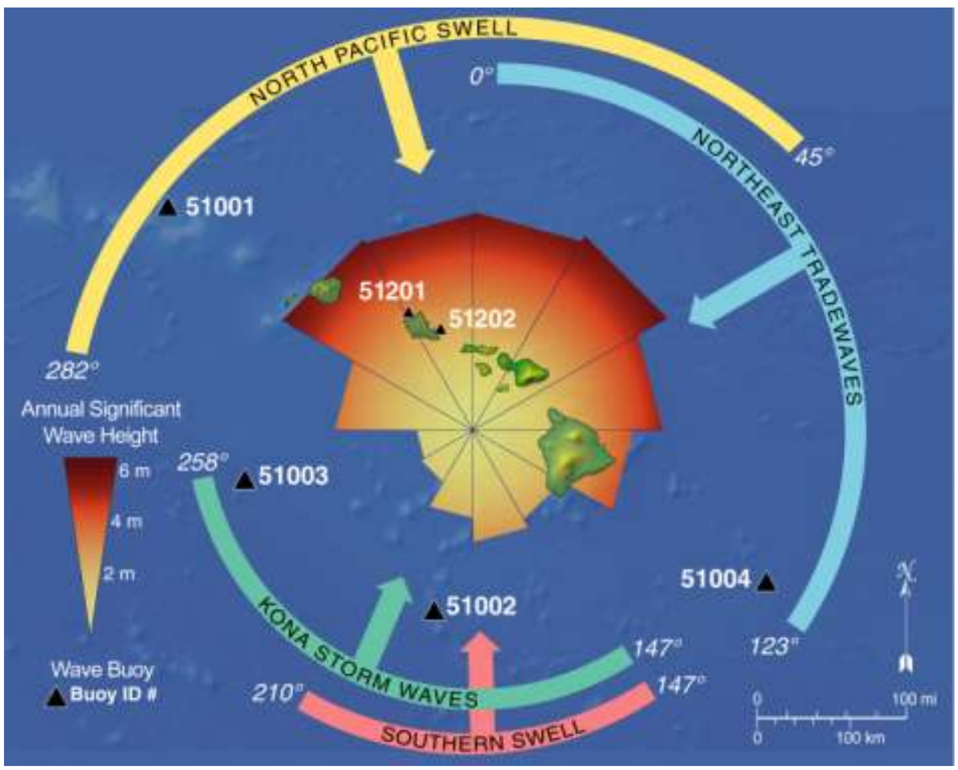
A tenuous relationship exists between the slow production of sand by the reef and its persistent accumulation on a beach. An uncaring human hand can all too easily sever this fragile balance. Sand, like fresh water, is a resource to be understood, managed, and conserved. Historically, we have not done this well as evidenced by the proliferation of seawalls and beach loss on every island[25].

What happens to a beach during a storm?

A storm is an unpredictable region of high winds that makes waves. Storm waves are different from the seasonal large swell that arrives every winter on the north shores and every summer on the south shores. Waves associated with storms are steeper and more erosive than swell of equivalent height, but both have an impact on a beach; when both hit a beach they tend to change the beach profile from a reflective to a dissipative state by removing sand from the beach and temporarily storing it offshore for the duration of the storm.

When a storm encounters the Hawaiian Islands, bringing with it heavy winds and agitated waves, thick ribbons of beach sand get rearranged. As the first thumping waves rake sand into the ocean, it piles offshore, forming a protective barrier for the beach – a sand bar. This barrier is characteristic of a dissipative beach profile and it causes waves to break further offshore. The now-flattened beach enables waves to expend their energy over a broadened zone and by the time the wave hits the beach it has expended much of its force. Reefs also protect beaches by dispersing wave energy. In places like Waikīkī where the dune is gone and beaches are depleted of sand, water may surge onto adjacent terraces and into pools during particularly energetic storms and swell events.

A lot of sand may also move sideways along the front of a beach due to *longshore currents* generated by high waves that are sometimes aided by flowing tide currents. For instance, at Sunset Beach the wave energy is so high that even sand bars cannot form and the majority of sand moves sideways to find shoreline segments offering some shelter from the wave energy. A particular beach may gain or lose sand in this process.



Waves arrive on Hawaiian shores from all directions. This diagram[26] *plots the average height of the highest third of the waves (a statistical measure known as the "significant wave height") arriving from thirty degree segments of the compass (12 segments in all). The shade of red (dark to light) in each segment represents the significant wave height. Wave types include North Pacific Swell, Northeast Trade waves, Southern Swell, Kona Storm Waves. Locations of wave monitoring buoys are also shown.*

Once a large swell has passed, fair weather waves deliver sand back to the beach, and winds and high tides send it back into the dunes, restoring them, at least partially, to their original state. However, if beach equilibrium is seriously disturbed by a major storm or high swell, the restoration process may take months, or even years. In some cases a beach may never fully recover its lost sand because *downwelling currents* moving offshore can carry sand beyond the edge of the reef into deep water. On other occasions, the recovery of natural beaches after high swell and storms can be complete, yet it may have found a new equilibrium landward of its original position resulting in net coastal erosion or shoreline retreat (land loss). If a storm or high swell causes permanent sand loss from the beach, shoreline retreat and the erosion of dune sand is one way to make up for it – maintaining a wide beach at the expense of a strip of abutting coastal land.

Keep in mind that these descriptions are quite generalized. Every Hawaiian beach will respond to high waves differently, just as each storm or high swell will affect a beach in a different fashion. Portions of Waikīkī Beach widen when there is high summer swell and erode when there are Kona storm waves. Sometimes the sand moves out to sea to an extent that it never returns to its original position. This is what scientists call the "depth of no return," and it varies from beach to beach. For example, off the east coast of the U.S., the depth beyond which sand is less likely to return is usually considered to be thirty to forty feet. Off Hawai‘i, the depth of no return is likely to be more variable, as irregular offshore topography on the reef may trap some of the wave-derived sand. Aerial photos of Hawaiian shorelines indicate that some beach sand may move down well-developed channels on the sea floor and into deep water.

Why is there an erosion problem?

Fundamentally, the problem with erosion is linked to construction along the shoreline. Were there no homes, roads, or hotels on the beach, erosion would not be a problem. Erosion is a natural process where it is not the product of human actions. This being the case, the erosion problem is certain to increase in Hawai‘i and elsewhere as Americans and others rush to the shore to build their homes.

Hundreds of thousands of Hawaiian residents and millions of visitors every year use island beaches for recreation, sport, business, or sustenance. On any given beach, however, only a few dozen individuals at most have access to beachfront buildings, whether homes or businesses. Indeed, along most of our beaches many of the homes are rentals, owned by someone who does not live there and who spends the money in another economy. In conjunction with decades of poor sand management, this small group of shoreline dwellers has created the predicament of property vulnerable to coastal hazards. Likewise, these same few eventually create the beach erosion problem by building seawalls and other structures that protect their investment, but destroy the beaches which belong to the public. Indeed, the decision to build a seawall on a chronically eroding beach is a tacit statement by the owner and the permitting agencies that a private home, hotel, or roadway is more valuable than the beach. In many cases the decision has been made that the protection of a single home with a seawall takes precedence over the needs of the thousands of people who may use that beach and the natural ecosystem of which it is a part.

So we ask you, which *is* more important: buildings or beaches? Property owners regard this question as absurd, but is it? On Rapa Nui, there was a time when the question should have been asked, "Which is more important, pleasing the Gods, or preserving the trees?" When the last tree was lost and the environmental consequences triggered a crisis, the answer became apparent. Hopefully this won't become the scenario for Hawaii's economy. Will your quality of life decrease when our beaches disappear?

What causes coastal erosion?

Coastal erosion has many causes, not all of which are known or completely understood. Yet, there are three proven events that lead to shoreline retreat: 1) human interruption of natural sand movement and sand supply 2) high waves and currents leading to natural deficits in sand-supply, and 3) sea-level rise which drives the beach to reposition in a more landward location. Typically on Hawaiian coasts, all three of these operate together to varying degrees.

One of the principal causes of beach erosion is the obstruction of the natural sand supply to a beach. When natural sand supply is impounded by a seawall or other structure, it inevitably leads to deterioration of the beach. Once the beach has either significantly narrowed or completely vanished, currents running parallel to the shore no longer have any sand to transport to neighboring beaches. These *down-drift beaches* then become targets of erosion, become starved of sand, and retreat landward at an increased rate. Thus shoreline armoring delivers a double whammy: 1) beach loss in front of the wall if the shoreline has been chronically retreating, and 2) sediment supply loss to the entire beach system.[27]

Kalama Park and Halama Street, Kihei, Maui, is a classic example of poor beach management. In the early 1970's a massive 3,000 foot long stone revetment was installed at Kalama Park, and almost immediately its beach disappeared.[28] Much of the beach loss was due to *placement loss*, the simple loss of beach underneath the footprint of the structure because it was built on sand. On the adjacent coast to the north, house after house was forced to build a seawall as the sand loss at Kalama infected the entire region. Dozens of walls went up, yard after yard of beach disappeared over the next thirty years, and an embittered community fought with permitting authorities trying to stem the tide of illegal seawall construction. Regulatory battles were fought on each property. Meanwhile, that huge black wall still sits at Kalama holding its secret – if it were removed, the sands would return.[29]

The development of our islands over the last century has depended heavily on Hawaii's beaches for a low-cost supply of sand. Used as an aggregate in concrete or spread on the sugar cane fields as fertilizer, sand has been collected for 150 years in Hawaiʻi. Even today, evidence of sand mining can be seen on beaches, and both private individuals and municipal agencies still conduct sand mining in some places. When you take your next chip shot out of the bunker, bend over and see if that sand looks familiar.

The Waimea Bay shoreline on Oʻahu's north coast is now known for a cluster of offshore rocks that include the infamous "jump rock." Swimmers leap off a thirty-foot rock above the ocean and plunge into the shallow waves. Astonishingly, less than 100 years ago, "jump rock," was nearly buried beneath the sand and the shoreline was located 200 feet seaward of its present position.[30] Over the years, as the sugar companies demanded more and more sand for the production of sugar cane, sand was shoveled out by the truckload, until the shoreline eventually retreated past the excavated rocks.

Because sea-level rise and beach and coastal erosion problems will probably only intensify over time, finding "tools" to manage these problems becomes crucial. This generation must strive to maintain the quality of the state's shorelines for the generations to come. Here is a list of three publications providing important guidance.[31]

This stretch of Ewa Beach illustrates many of the things we do wrong in managing our beaches. The sand dune was not protected, chronic erosion has narrowed the beach so that it is gone at high tide, public access is difficult, and homes are vulnerable to tsunami, storm surge, and high waves. Sea-level rise will greatly worsen this situation and today's wide and healthy beaches (such as Kailua and Waimanalo) will look like this later in the century if we do not make plans soon for an alternative future.

How fast is shoreline retreat taking place?

No general answer can be given to the question of how fast the shoreline is retreating, for it varies across the globe. In Hawaiʻi, rates of retreat range from less than half a foot per year to over nine feet per year. The average rate of eroding shorelines on Maui is about one foot a year, and on Kauai it is about the same[32]. But every beach is unique, and each has its own pattern of responding to the multiple forces of sea-level rise, sand availability, and wave stress. To see erosion rates for specific coastal locations go to the UH Coastal Erosion website: http://www.soest.hawaii.edu/asp/coasts/.

The Shape of Things to Come

While Hawaii still has many wide and beautiful beaches, there are too many places where the next generation is set to inherit a coastline ringed with decayed seawalls, narrow eroded beaches, and turbid polluted water. It is time for coastal communities to decide which beaches we will protect forever as a legacy for our children and grandchildren. If we don't act soon, we are guilty of shortsighted planning and dodging the politically difficult but critically important work of saving the Hawaiian shore. It is time to plan for a retreat from the shore.

Some of the Hawaiian shore is in great shape and has not experienced erosion or pollution. However, it is undeniable that over time the slow creep of erosion and pollution has expanded its presence on every island: 25% of the length of beaches on Oahu have been lost to shoreline hardening[33], miles of beaches have been lost on Maui[34], Kauai has seawalls along several stretches of beach and erosion threatens many homes[35], Kona community groups are worried about how to recover lost beaches, and protect the few that remain. In 2001 the EPA issued a list of over 100 Hawaiian beaches, streams, and estuaries polluted with sediments, nutrients, bacteria and trash.[36]

As these and many other sources document, major segments of the Hawaiian shore have been subjected to a combination of pollution and beach loss. This trashing of the coastline is only going to increase if we do nothing to slow, stop, and reverse the burgeoning development. For example, viewed from the sea, the Kahala shoreline is a solid stone wall from Black Point to Waialae Beach Park. At high tide there is no beach to speak of, and public access is difficult and hardly worth the trouble. Lanikai beach continues to disappear. The beach there is less than one fourth its original size.[37] Numerous access paths that in recent years led to sandy beaches now end in precipitous drops into turbid waves. Until recently the area immediately south of the remaining beach looked like a war zone of sand bags, loose boulders and waves slapping the undersides of exposed housing foundations. Now it is simply a solid black wall in the water.

Kailua is one of the last long pristine beaches on windward O‘ahu. But even Kailua is feeling the building boom. The current generation of homes is old and being replaced by large multistory cement manors only forty feet from the shoreline. A history of sand accretion is now being buried under poured concrete slabs as new homes are allowed to creep seaward of the existing house line. These homeowners will demand seawalls when erosion strikes – and it will strike as sea-level rises over coming decades – and those seawalls will kill Kailua Beach. Try walking the shoreline of Ewa Beach at high tide. You will have to run between wave crests along an endless avenue of seawalls. The beach is mostly a memory.

In fact, an evolutionary sequence has become apparent. Coastlines with modest development and a wide set back from the water are slowly changing into polluted urban concrete jungles. Waikiki, Kahala, Lanikai, Ka‘a‘awa – each a chapter in the urbanization of the Hawaiian shore. Will we let the last remaining beaches of Hawai‘i fall prey to our questionable history of coastal planning? Contrary to recommended FEMA coastal construction guidelines, state setback rules do not recognize erosion patterns when siting a house on the beach.[38] They do not require any special coastal building code. They do not recognize lot orientation or road placement. And they require a standard setback from the shoreline regardless of how fast that shoreline is moving landward.

As the miles of damaged beaches throughout Hawai‘i attest, this is a recipe for both environmental calamity and consumer fraud. Homeowners who benignly seek to live along a beach they love are being granted construction permits from authorities only to find themselves forced to destroy the beach in order to protect their homes.

Establishing place-based *beach preservation zoning districts* where no coastal armoring will ever be allowed can save the remaining healthy beaches of Hawaiʻi from the historical pattern of degradation. On Oahu, Waimanalo Beach, Kailua Beach, Malaekahana and Kahuku beaches are a precious heritage that needs protection. Sunset and Kawailoa beaches will disappear if armoring is allowed where the shore is undergoing chronic erosion. Beaches at Mokuleia have already been damaged due to seawall construction; this should stop. Leeward beaches are vulnerable to seawall construction to protect Farrington Highway. Agencies should commit to moving the road but never allowing damage to the beach. The Waianae coast has a rich system of long sandy beaches that should always be protected. For Waianae residents who want a glimpse of how highway protection is an effective destroyer of beaches, travel Kamehameha Highway from Kualoa to Kaʻaʻawa and see the future of sea-level rise.

Opinion: It is time to stage a retreat from the shore.

It is time to stage a retreat from the shore. A state-wide policy of retreating from the shoreline will require buy-in from county, state, and federal agencies, and the creation of a truly integrated planning function that abandons the jurisdictional schism created by the certified shoreline. The issues will be complex and political forces against the program will be strong because the winds of change are always perceived as threatening to those who benefit from the status quo. But it is the right thing to do. Let us leave the gift of beaches for our children to enjoy.

Shoreline retreat will need to include myriad tools embedded within state, county, and community planning venues. Among these will be the use of variable setbacks such as those already adopted on Maui and Kauai. On Maui, a new home must be set back a distance equal to 50 years of erosion plus 20 feet. On Kauai the set-back accounts for the width of a lot, with wider lots requiring greater setbacks, and in general the setback accommodates 70 years of erosion plus a 40 foot buffer zone. On Oahu, agencies are considering place-based management plans that involve the community at all levels.

Other tools will require purchasing homes threatened by erosion. A number of methods should be considered for this: reverse mortgages offered by the state and funded by general obligation bond issues wherein owners turn over homes at the end of receiving a fixed period of payments; a homeowner donation program; tax relief for businesses or families in exchange for ownership transfer of coastal property to some beach authority; transferable development rights for businesses; county, state, and federal land conservation funds; land swaps of mauka lands in exchange for prime coastal lands; and others. A number of fees are generated in the coastal zone such as land lease fees, the real estate transfer tax, coastal property taxes, local business proceeds, and others. Some portion of these could be set aside to fuel a conservation fund for purchasing developed lands that are sand rich, along otherwise pristine beaches that are likely to need protection in a future of rising sea level. Of course it makes little sense to purchase rocky lands for beach conservation (unless it is to enhance public access, preserve a view plane, or some other conservation reason). These will yield no sand when eroded under high sea levels. Sandy lands are the primary target for conservation and these should be pried free of the grasp of development so that they may respond naturally to coastal processes.

Also to be considered should be a moratorium on all seaward creep of existing development. This could include a mix of no longer allowing any building on accreted lands, amending state rules so that no new certified shorelines are allowed seaward of prior shorelines, disallowing the "string line" of neighboring properties to be broken by new building, and employing a combination of variable setbacks and disallowed new development on beaches with a combination of eroding and accreting lands. For beaches with a significant population of transient vacation rental properties, converting these to public lands would have less impact on the local community or local families since they are being operated as businesses and not as residences. Lastly, is there a legal basis for enacting a "freeze" on all existing coastal development? This question should be explored as the scientific certainty of global sea-level rise is already sufficient to support a statewide declaration of emergency planning for Hawaii's beaches.

It should be noted that Hawaii has largely escaped the dramatically accelerated beach erosion that will accompany sea-level rise rates in coming decades. Our history of erosion is mostly due to modest rates of historical sea-level rise, human mismanagement, and natural coastal processes. In other words, we have time to enact our retreat from the coast and it may not be until we approach the second half of the century that the worst of our future may appear. With a few decades of opportunity to design and implement a pull back from the shores of paradise, time is on our side.

Why worry about beaches?

A beach's health serves as a barometer for measuring our success at living with the shore. The great irony of Hawai‘i losing its beaches and dunes is that they represent the proverbial golden egg of the state's economy: beaches for tourism, beaches for vital habitat, beaches as a critical point in the ahupua'a between land and sea, and beaches for the last line of defense against the impact of hurricanes, tsunami, and high waves. And of course, beaches represent the quality of life in Hawaii.

Unfortunately, in comparison to other coastal states, Hawai‘i has historically had some of the weaker political will primed to conserve this resource. This trend needs to change if the beaches of Hawai‘i are to survive and thrive.

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[1] R. Lukas, pers. comm.

[2] Fletcher, C.H., Jones, A.T. (1996) Sea-level highstand recorded in Holocene shoreline deposits on Oahu, Hawaii. Journal of Sedimentary Research. 66.3, p. 632-641; Grossman, E.E., and Fletcher, C.H., (1998) Sea level 3500 years ago on the Northern Main Hawaiian Islands. Geology, April, v. 26, no. 4, p. 363-366; Grossman, E., Fletcher, C., and Richmond, B. (1998) The Holocene sea-level highstand in the Equatorial Pacific: Analysis of the insular paleosea-level database. Coral Reefs. Special Issue on Holocene and Pleistocene coral reef geology: v. 17, p. 309-327.

[3] The University of Hawaii Coastal Geology Group maintains a website that serves rates of coastal erosion for the beaches of Kauai, Oahu, and Maui http://www.soest.hawaii.edu/asp/coasts/index.asp Erosion data can also be found on the County of Maui, Planning Department Coastal Zone Management website http://www.co.maui.hi.us/index.asp?nid=865

[4] Hwang, D.J., 2005. Hawaii Coastal Hazard Mitigation Guidebook, University of Hawaii Sea Grant College Program (UNIHI-SEAGRANT-BA-03-01), 216p.

[5] See the University of Colorado, Sea Level Change website http://sealevel.colorado.edu/ which periodically releases interpretations of the mean trend of satellite altimetry data recording global sea level. See also the NASA

Jet Propulsion Laboratory Global Climate Change website
http://globalclimatechange.jpl.nasa.gov/news/index.cfm?FuseAction=ShowNews&NewsID=16
[6] See Chapter 8.
[7] Fletcher, C., Rooney, J., Barbee, M., Lim, S.-C., and Richmond, B. (2003) Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, Special Issue No. 38, p. 106-124. And, Oahu Civil Defense Agency, Multi-Hazard Pre-Disaster Mitigation Plan for the City and County of Honolulu, Hydrologic Hazards: Coastal Erosion (Sept. 2003). Also calculated from the latest coastal erosion rate data on Kauai and Oahu per the website maintained by the University of Hawaii Coastal Geology Group, supra note 3.
[8] There are several sources of sea level data for Hawaii. See the University of Hawaii Sea Level Center website at http://uhslc.soest.hawaii.edu/ Also see the NOAA tide gauge website which reports long-term rates of water level change for gauges both in Hawaii and across the country and the world. This page provides the long-term rate for the Honolulu tide gauge http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1612340 Honolulu, HI (1.50 +/-0.25 mm/yr or approximately 0.06 in/yr).
[9] See Chapter 8.
[10] State of Hawaii, Department of Land and Natural Resources, Office of Conservation and Coastal Lands, Kailua Beach Management Plan, p 2; and see Norcross et al., Annual and Interannual Changes on a Reef-fringed Pocket Beach: Kailua Bay, Hawaii, Marine Geology 190, p. 553-580 (2002).
[11] See, e.g., Ocean Studies Board, Mitigating Shore Erosion Along Sheltered Coasts, National Research Council (National Academic Press 2007), stating, "Coastlines are perpetually changing—some from natural processes—some from human activities—many from both."
[12] Several studies predict that sea-level rise has accelerated in the 21st Century as compared to the 20th Century. See http://sealevel.colorado.edu/; see also, Church, J. A. and N. J. White., 2006. 20th century acceleration in global sea-level rise, *Geophys. Res. Lett.*, 33(1), L01602. See also studies that predict future sea-level position which can only be achieved by an acceleration in the rate of global sea-level rise compared to present rates. For example, the study by Pfeffer et al., 2008, Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 5 Sept., v. 321, n. 5894, p. 1340-1343 predicts sea level approaching or exceeding 1 m above present by end of the 21st Century which would require global rates reaching a rate of ~10 mm/yr.
[13] Anita Lee, State Farm to Hike Rates About 13%, Drop Others, Sun Herald, www.sunherald.com/199/v-print/story/619838.html.
[14] See Citizens Property Insurance Corporation at https://www.citizensfla.com/.
[15] Chapter 23, Section 1.2, Shoreline Setbacks, Revised Ordinances of Honolulu. For more information, see http://www.co.honolulu.hi.us/refs/roh/23.htm.
[16] Fletcher, C.H., Mullane, R.A., and Richmond, B.M. (1997) Beach loss along armored shorelines of Oahu, Hawaiian Islands. Journal of Coastal Research, v. 13, p. 209-215.
[17] Revised Ordinances of Honolulu, supra note 15.
[18] County of Hawaii v. Sotomura, 55 Haw. 176, 517 P.2d 57 (1973).
[19] FEMA, Evaluation of Erosion Hazards (April 2000), available at http://www.heinzctr.org/publications/PDF/erosnrpt.pdf.
[20] FEMA, Significant Losses From Coastal Erosion Anticipated Along U.S. Coastlines (June 27, 2000), http://www.fema.gov/news/newsrelease.fema?id=7708.
[21] Evaluation, supra note 19.
[22] See FEMA, Erosion at http://www.fema.gov/plan/prevent/floodplain/nfipkeywords/erosion.shtm.
[23] Calhoun, R.S., Fletcher, C.H. (1996) Late Holocene coastal-plain stratigraphy and sea level history at Hanalei, Kauai, Hawaiian Islands. Quaternary Research. 45, p. 47-58.
[24] Harney, J.N., and Fletcher, C.H. (2003) A budget of carbonate framework and sediment production, Kailua Bay, Oahu, Hawaii. Journal of Sedimentary Research, v. 73, no. 6, p. 856-868. And Harney, J.N., Grossman, E.E., Richmond, B.M., and Fletcher, C.H. (2000) Age and composition of carbonate shoreface sediments, Kailua Bay, Oahu, Hawaii: Coral Reefs, v. 19, pg. 141-154.
[25] Beach loss due to coastal armoring is documented in several publications. See for instance Fletcher, C.H., Mullane, R.A., and Richmond, B.M. (1997) Beach loss along armored shorelines of Oahu, Hawaiian Islands. Journal of Coastal Research, v. 13, p. 209-215; Fletcher, C., Rooney, J., Barbee, M., Lim, S.-C., and Richmond, B. (2003) Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, Special Issue No. 38, p. 106-124.
[26] From Vitousek, S., and Fletcher, C.H., 2008. Maximum annually recurring wave heights in Hawaii: Pacific Science, v. 62, n. 4:541-553. In this paper the authors conduct a statistical analysis of the wave records from buoys

in Hawaiian waters. They identify the annually recurring significant wave height (the average of the highest 1/3 waves) to be 7.7+/-0.28 m and the top 10% and 1% wave heights during the annual swell to be 9.8+/-0.35 m and 12.9+/-0.47 m, respectively, for open north and northwest Pacific swell. Data are also provided (see Table 2 in the paper) for $H_{1/3}$, $H_{1/10}$, and $H_{1/100}$ for each of 12 30^o compass windows around the islands.

[27] See Ocean Studies Board, Mitigating Shore Erosion Along Sheltered Coasts, Ch. 2: Understanding Erosion on Sheltered Shores, National Research Council (National Academic Press 2007).

[28] Gary Kubota, Weather, Seawalls Cited in Maui Beach Erosion, Star Bulletin (June 10, 2002).

[29] Rooney, J.J.B., and Fletcher, C.H. (2005) Shoreline change and Pacific climate oscillations in Kihei, Maui, Hawaii. Journal of Coastal Research, v. 21.3, p. 535-547.

[30] J.F. Campbell and D.J. Hwang, Beach Erosion at Waimea Bay, Oahu, Hawaii, Pacific Science, Vol. 36, No. 1 (1982).

[31] Eversole, D., and Norcross-Nuu, Z., 2006, Natural hazard considerations for purchasing coastal real estate in Hawaii – A practical guide of common questions and answers. University of Hawaii Sea Grant College Program, UNIHI-/SEAGRANT-BA-06-03. Hwang, D.J., 2005. Hawaii Coastal Hazard Mitigation Guidebook, University of Hawaii Sea Grant College Program UNIHI-SEAGRANT-BA-03-01, 216p. Hwang, D.J., and Okimoto, D., 2008. Homeowners handbook to prepare for natural disasters, University of Hawaii Sea Grant College Program, UNIHI-SEAGRANT-BA-07-02, 98p. All three of these documents available from the University of Hawaii Sea Grant College at http://www.soest.hawaii.edu/SEAGRANT/communication/publications.php

[32] These statements are made on the basis of data served on the website of the University of Hawaii Coastal Geology Group; supra note 3.

[33] Fletcher et al., Beach loss, supra note 16.

[34] Fletcher, C., Rooney, J., Barbee, M., Lim, S.-C., and Richmond, B. (2003) Mapping shoreline change using digital orthophotogrammetry on Maui, Hawaii. Journal of Coastal Research, Special Issue No. 38, p. 106-124.

[35] http://raisingislands.blogspot.com/2008/02/new-kauai-shoreline-erosion-bill-among.html

[36] Region 9, EPA, News Release, 11/19/01 "EPA issues revised list of polluted waters in Hawaii" see http://yosemite.epa.gov/opa/admpress.nsf/d2a3eb622562e96b85257359003d4809/bac39fa61819d766852570d8005e1462!OpenDocument

[37] See State of Hawaii, Department of Land and Natural Resources, South Lanikai Beach Gets New Sand Through Partnership Project, News Release (March 23, 2000).

[38] Go here http://www.fema.gov/rebuild/mat/fema55.shtm, for FEMA's Coastal Construction Manual.