Chapter 6

Awiwi! Awiwi! O pea o`e I ka wai

"Quick, quick or the waters will stop you"

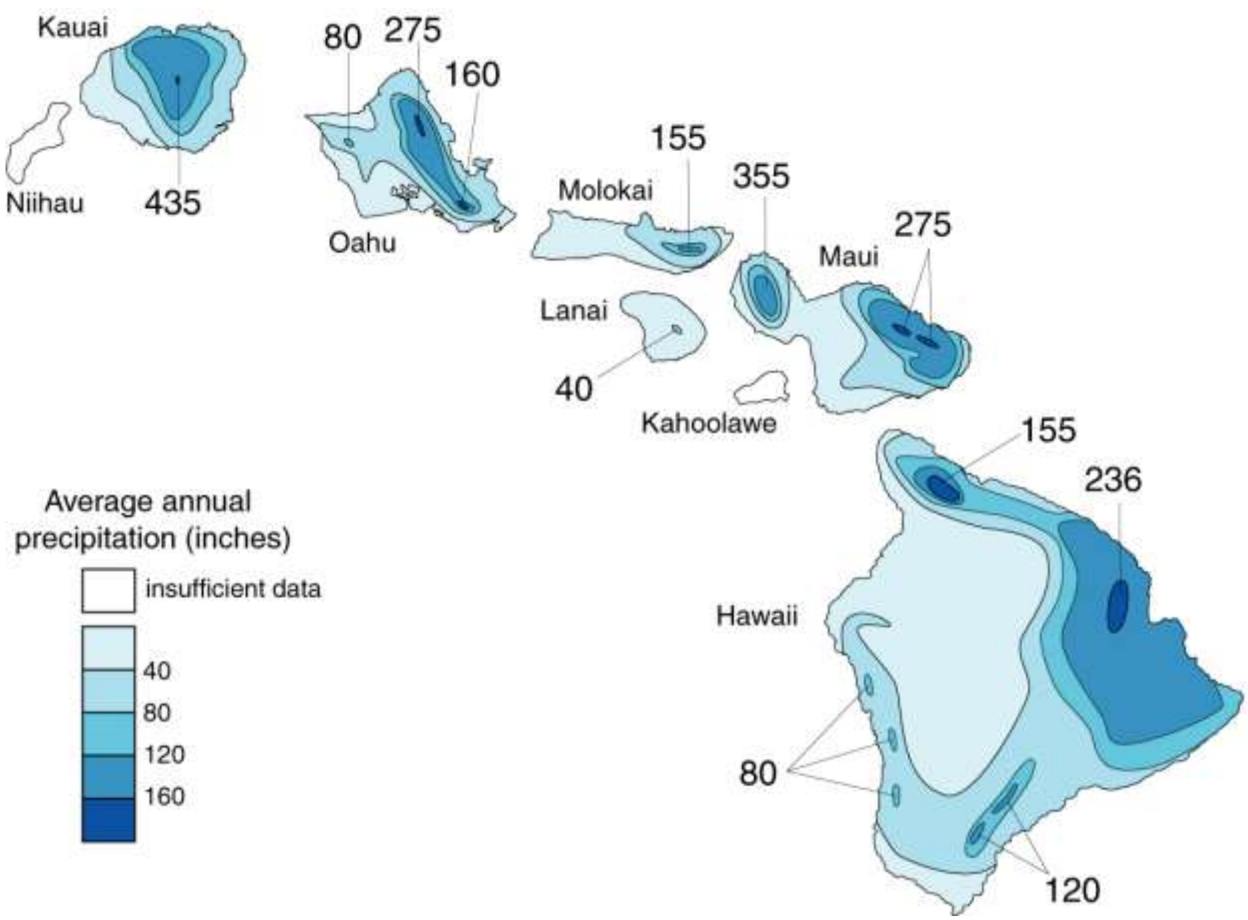
Stream Flooding and Mass Wasting

I have sometimes sat on the high bank of a streamlet, not more than fifteen to twenty feet wide, conversing with natives in the bright sunshine, when suddenly a portentous roaring, like the sound of many waters, or like the noise of the sea when the waves thereof roar, fell upon my ears, and looking upstream, I have seen a column of turbid waters six feet deep coming down like the flood from a broken milldam. The natives would say to me, 'Awiwi! Awiwi! O pea o`e I ka wai' – "Quick quick, or the waters will stop you." -Rev. Titus Coan "*Life in Hawai'i*"[1]

It's no fluke that one can usually predict Hawai'i's daily weather forecast: "Today's weather will be partly cloudy, with passing showers windward or mauka, and temperature's ranging from the mid-70's to mid-80's." This balmy climate provides one more reason why Hawai'i's moniker is "paradise." While the warmest daytime temperatures in summer infrequently exceed the mid-90s, the chilliest nighttime temperatures in winter rarely fall below the mid-50s. The difference in average daytime temperature at sea level throughout the year is only around 11^{o}F, making the Hawaiian Islands home to Earth's most temperate climate. But as you have learned by now, weather in paradise has a volatile side.

Two seasons dominate the Hawaiian climate: summer (*kau wela)* and winter (*ho'oilo)*. Summer extends from May through October, accompanied by the misnamed "gentle" trade winds. On any other shore, consistent twenty-five miles per hour winds gusting to thirty-five miles per hour are hardly considered gentle. These persistent air currents blow towards the equator from the northeast in all northern hemisphere oceans and are so reliable that for centuries the global trading industry under sail relied on their consistency. In Hawai'i, they provide constant, natural air-conditioning throughout the spring and summer. Yet beyond the soft winds and seasonally tranquil north shore waters, the summer also ushers in threatening tropical storms that develop in the eastern Pacific.

From October through April, Kona conditions interrupt the trades (and can do so any time of the year), bringing the frequent rain and cool, cloudy weather of winter. Kona storms derive their name from the typically-sheltered west coast on the Big Island where local southerly winds or stagnant air dominate, resulting from the shadowing effect of the high volcanoes. Occasionally, a Kona storm, originating from the south or southwest, will stall over Hawaiʻi, bringing persistent, island-wide rain, strong winds, and high surf that can cause flooding and property damage. These wet events can lead to remarkably dangerous and unpredictable flash flooding in normally tranquil streambeds.



Trade winds deliver moisture to the northeastern sides of the islands, making these the wettest regions in Hawaii. Large-scale storm systems passing near the islands, usually from the south and southwest, provide rainfall to southern shores that are otherwise dry.[2]

Not only do wind patterns significantly control the Hawaiian archipelago's weather and microclimates, but so also do high elevation mountains. In areas where onshore trade winds are obstructed by tall mountains, the moist warm air rises up the mountain slope, cooling on its ascent and condensing into heavy cloud cover and rainfall on the windward side. Hawai'i's preeminent example of this orographic rain is Kaua'i's Mount Waialeale, which receives a drenching 460 inches (thirty-eight feet) of rain a year.[3] In sharp contrast, the dry air descending down Kaua'i's leeward side creates local semi-arid conditions. Polihale Beach on the west side of the island receives a mere eight inches of rain a year.[4] This pattern is similar for most of the islands with the windward side receiving frequent rain squalls and the leeward side boasting eternal sunshine.

Streams in Urbanized Hawaii

On windward sides, the locale of year-round streams, most channels hold dozens of large boulders. Sure-footed hopping from one large rock to another can get you across most streams with flowing water. If you travel to the leeward side of an island, you will notice that the dry streambeds also contain a population of alien massive boulders seemingly dropped off by a county work crew. What force of water does it take to roll a five foot high solid block of rock and carve the sharp corners off to make it as round as a manapua? These boulders are the tell-tale signs of powerful floods that characterize our watersheds. Tranquil streams can become frothing rapids, ten feet deep, moving fast enough to quickly drown the strongest of swimmers unfortunate enough to be in the way.

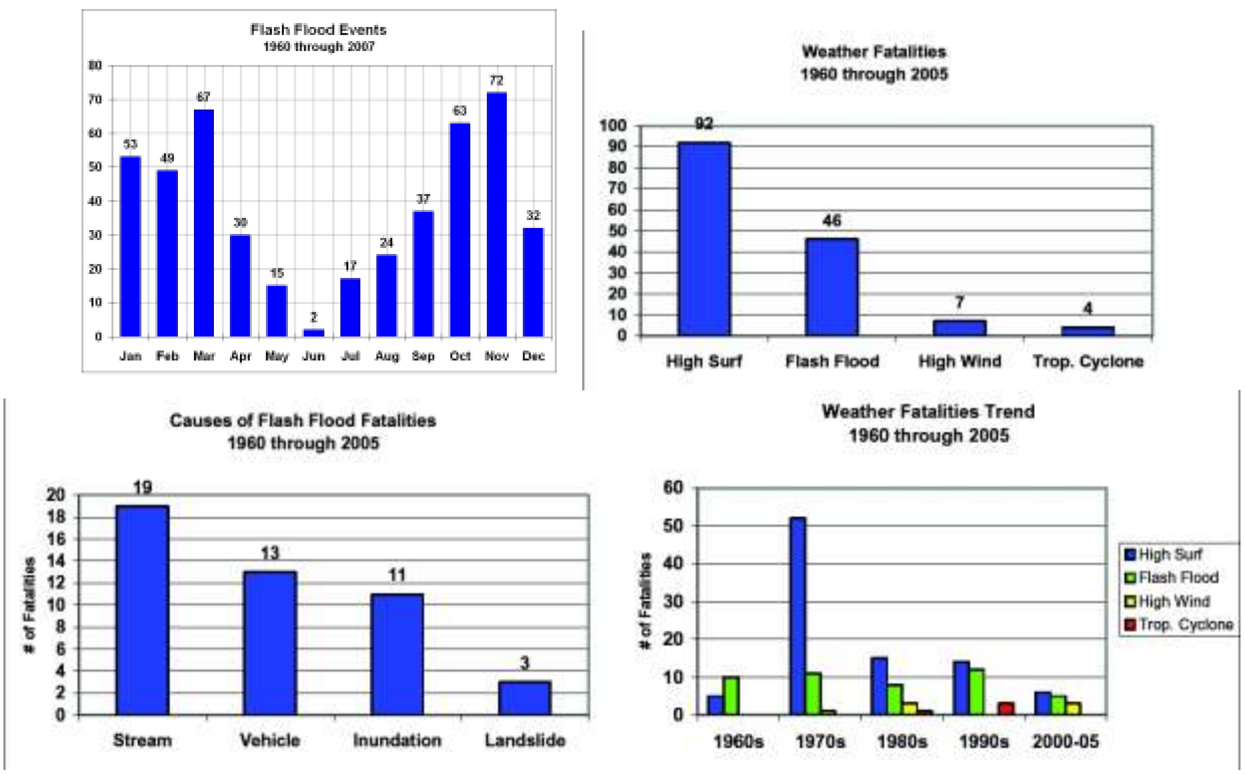
Homes were flooded, roads closed, and emergency shelters filled as families flocked to find help during the floods that affected the Big Island from October 28-November 3, 2000.[5]

Because of potential flooding, streams flowing through urban areas have been un-naturally contained into concrete walls and channels. Block these channels during a storm with debris such as tree trunks, thick piles of banana leaves, or other refuse and the wave of backed up water that escapes can jump out of a channel into a neighborhood and flow with sufficient force to tear a house from its foundation – and has on more than one occasion.

Most flooding in Hawai‘i is caused by Kona Storms (but not all), which drift slowly over watersheds and release torrents of precipitation that arrive too fast for it to be absorbed into the ground. Flash floods like this can roar down a stream valley in minutes. But other types of flooding present a hazard in our islands as well.

Flash Floods: a River of Surprise

Flash floods in Hawai‘i can occur during any month of the year. There have been 461 flash floods in the past 48 years which averages nearly 10 per year throughout the state[6]. However, these events are most frequent during the wet season of October through April. As the graphs show, October and November have the highest flash flood event frequency. Flash floods are the leading cause of *direct* weather related deaths in the state of Hawai‘i, far exceeding the toll caused by high wind events and tropical cyclones. Although high surf causes the most weather-related deaths in the Hawaiian Islands, these are considered to be *indirect* weather impacts since the waves are often formed far from the island chain.[7]



Flash floods are the leading cause of <u>*direct*</u> *weather-related deaths in Hawaii. High surf is the leading cause of* <u>*indirect*</u> *weather –related deaths.*[8]

Particularly notable flash floods occurred in February to April of 2006 when 28 flood events throughout the state caused 7 deaths and more than $50 million in damages. In Manoa, the flash flood in October, 2004 resulted from an extreme rainfall of 8.7 inches in only 5 hours and led to more $100 million in damage through Manoa valley and on the University of Hawaii campus. November of 2000 was accompanied by flash flooding on the Big Island and resulted in $70 million in damage due to 37 inches of rainfall in a 24 hour period. These and other similar events provide clear warning that in Hawaii when it rains, it pours.

Flooding on O‘ahu

Flooding on O‘ahu most frequently occurs where steep hillsides meet low-lying coastal plains, such as those found along the windward side: Kahuku, Laie, Ka‘a‘awa, Kualoa, Kāne‘ohe, Kailua, and Waimanalo. On the leeward side, normally the site of dry and sunny weather, Mapunapuna, portions of Waikīkī, Mānoa Valley, and the watersheds of east Honolulu all have flooding histories. Heavy damage from flooding occurs a couple of times every decade, most recently in 1987, 1991, 1993, 1994, 2006, and 2007.[9] The heaviest rainfall in Kāne‘ohe occurred in October 1991, when fifteen inches fell in forty-eight hours leading to intense flash flooding.[10]

In the spring of 2006, Laie and Ka‘a‘awa experienced a failure in their storm drains during a six week long drenching.[11] A combination of forces overwhelmed the drainage system including heavy runoff onto the flat coastal plain from steep watersheds, high seas driven by sharp trade winds that flooded drainage outlets with salt water, extensive debris washed off yards and open lots that blocked channels and pipes designed to carry flood waters into the ocean, and the refusal of saturated ground to absorb any more precipitation after weeks of rain. Communities along the highway, at the base of the steep mountain slopes, and throughout the flat coastal plain all flooded to depths as high as five feet within homes. Coastal homes are susceptible to a double whammy: stream mouths and storm drains that normally funnel rainwater to the sea are susceptible to flash flooding at high tide, during onshore winds, and in high wave events. This is because channeled flow reaches a sea that is unusually high, blocking drainage paths. As a result, a stream channel can fill with water when it is unable to discharge its liquid load to the sea. This condition is going to worsen with time as sea level continues to rise, now at rates that are accelerated over the 20th century (see Chapter 8 for more on Sea-Level Rise).

The most severe flooding events on O‘ahu occur where low-lying lands are heavily developed. The land surface is armored with impermeable concrete, forcing waters to run along the surface rather than soak into the ground. The worst of these lands are those that lie below, or near, sea level. Wells show that the water table rises and falls with the tides, and even rises and falls with groups of high waves breaking in the surf zone. Hence, when the ocean rises at high tide and during high wave events, and as sea level continues to rise due to global warming, the ground water table reaches and often breaks through the land surface. When this happens simultaneous to heavy rainfall, flooding in the coastal zone is nearly impossible to avoid. If you have a house that is built with post and pier architecture and sited several feet above the land surface, you stand the best chance of avoiding the hazard.

During the first fifteen days of November 1996, record-breaking rainfall occurred along the Waianae Coast. Twenty-one inches fell in an area normally subject to annual rainfall of only two inches. In Ewa, 12.5 inches fell in seven hours on the fifth of that month, leading to flooding of the low limestone plain and its wide neighborhoods and paved surfaces.[12] When undeveloped, limestone is filled with pits, holes, and subterranean tunnels that easily funnel away heavy rains. To a geologist, the idea of flood waters occurring on limestone seems as unlikely as an ocean without waves. The fact that Ewa is capable of flooding is stark testimony that the natural geology has been ignored by drainage specialists when instead it could have been efficiently incorporated into mitigation plans. Buried under yards of impermeable cement that direct surface waters to a few insufficient storm drains (often flooded by high tide), an entire landscape of permeable water-absorbing limestone lies in dry impotency under the impervious cement of the Ewa Plain. A simple and inexpensive solution would have been to work with the natural characteristics of the geology by using *permeable cement* on roadways and sidewalks. Permeable cement, invented over two decades ago, allows run-off to seep into the underlying substrate rather than flood in torrents into a few inadequate canals that run to the sea.

Perhaps the most severe flooding in recent memory was the New Years Eve flood of 1987 which, in less than 24 hours, caused over $34 million in damage to some of Oʻahu 's most densely settled residential areas. Rainfall along the Ko'olau range separating windward Waimanalo and Kailua from Hawaii Kai and east Honolulu received a heavy drenching that caught meteorologists and civil defense authorities by surprise. High clouds masked the event from satellite observation, and the area had sparse radar coverage at the time. This extreme event was equivalent to a 200 year storm that accumulated as much as 20 inches of rainfall over a 24 hour period in some areas[13]. Torrential rain led to flash flooding in Waimanalo and Hawaii Kai, debris flows in Niu Valley, levee breaching in Kawainui Marsh in Kailua, road closures, and damage to over 1200 homes. A population of 40,000 people in east Honolulu was isolated by road closures; stranded with little public aid for hours as the storm developed at the height of New Years revelry. Compounding the problem was difficulty rounding up emergency personnel due to the celebratory date, inability to reach stranded families due to ongoing flooding and debris flows in the most affected areas, and the unrelenting intensity of rains which made rescue operations dangerous to all involved. Blockage of drainage systems by rocks and debris caused unanticipated diversions of floodwaters, resulting in extensive damage to many upland neighborhoods not accustomed to flooding. Meanwhile, in Waimanalo, a low-lying region, floodwaters inundated homes with up to 5 feet of swirling water at the peak of the runoff.

Other severe events on Oʻahu include October 1981 flooding of Waiawa Stream after heavy rains that led to $786,000 damage, and January 1968 flooding in Pearl City, which caused $1.2 million in damage.[14] Worst of all, $80 million of damage was caused to the University of Hawaiʻi when Mānoa Stream jumped its carefully channelized banks after ten inches of rain fell in only a few hours in late 2004.[15] Careful maintenance of debris buildup in the channel might have prevented this expensive catastrophe.

Flooding on Kauaʻi

On Kauaʻi, stream flooding is characterized by frequent flash floods as well as prolonged flooding associated with slowly passing rainstorms that saturate the soils. The situation is worsened when development ignores nature's cues – such as the wetlands that were buried in soil and cement to allow for the Kalapaki Bay Marriott on Kauaʻi. In 2006, when heavy rains and debris blocked a culvert upstream of the hotel, two dozen rooms were flooded and sinkholes appeared in the parking lot.[16]

Kauaʻi receives between twenty and eighty inches of annual rainfall along the coast, and more than 400 inches at the higher elevations of Mt. Waialeale.[17] Flash floods resulting from a storm on December 14, 1991, that dropped over twenty inches of rain in twelve hours over Anahola, tragically wiped out an entire family causing five deaths, intense flooding, stream bank failures, erosion, and landslides, totaling more than $5 million in property damage.[18]

Urban flooding results from heavy rains on impervious surfaces (Kevin Kodama, NWS)

Such events are not uncommon. On January 24-25 1956, forty-two inches of rain fell in thirty hours on the northeast side of Kaua‘i leading floodwaters to rise ten feet above normal in the streams between Kilauea and Anahola.[19] The Hanalei River, which most directly drains the wettest region of Mt. Waialeale, overflows its banks at the coast nearly every rainy year. Some years are considerably more damaging than others, for example, November 1955, January 1956, April 1994, September 1996, and March 2006.[20] In September of 1996 for instance, nine inches of rain were recorded in twelve hours along the coast and an undetermined amount fell in the uplands. This event led to flooding of Hanalei town and temporary closure of the Hanalei Bridge, the residents’ sole access to the rest of the island leaving them with no hospital and no government aid.

In the western and southern portions of Kaua‘i, the flooding hazard is primarily due to standing water that will not drain, especially after Kona storms. Waimea River, for example, has a long record of flooding dating back to 1916, and includes numerous occasions where its channels overflowed after storm-fed precipitation in Waimea Canyon at the head of the watershed.[21] The challenge to mitigating stream flooding is largely one of obtaining adequate warning in the case of flash floods, and in improving the style and location of development in areas of known flood history.

Unfortunately, a new flooding concern has entered our consciousness – dam failure. The deaths of seven people due to overtopping of the Kaloko reservoir in northeast Kaua‘i on March 14, 2006, revealed a hidden killer.[22] With the demise of sugar has also come the end of careful dam maintenance. Reservoirs built in the last century to ensure the thirst of sugar fields was adequately met have since fallen into neglect and decay, and potentially criminal abuse. In the past, the state and land owners were careful to monitor, measure, and maintain the million gallon holding ponds. Throughout the last century state engineers had faithfully performed safety checks on Hawai‘i's dams with clockwork precision. But in the past decade, someone dropped the ball and dams throughout the state have gone unchecked for flaws, proper maintenance, and other basic steps to ensure public safety. As records indicate, it has been years since dams have been inspected.

Searchers with dogs looked for bodies in the mud and debris after the Kaloko Dam break on Kaua‘i released a roaring, tree-snapping torrent of water and raised fears about the safety of dozens of similar dams across Hawai‘i. (cbsnews.com)

With no one watching, one dam - the Kaloko Reservoir - was neglected to the point of tragedy; it became a deadly trap waiting to be sprung by the wrong weather conditions. What led to the flood is unclear. Was it unauthorized changes to the dam? Poor maintenance? Lack of government oversight? Or another example of human engineering that was under-designed for the extremes of nature? Whatever the root cause, heavy rains finally pushed the dam beyond its breaking point and a wall of water eighteen feet high rushed like a tsunami through the valley below. Snapping trees like twigs, the churning cauldron cut a three mile swath of destruction to the sea, wiping out homes, roadways, and entire forests.

Flooding on Maui

Stream flooding on Maui is not only common, but is the very agent responsible for making it famous as the Valley Island. The deep V-shaped valleys of west Maui have been carved by over one million years of stream flow. Along the eastern half of Maui, the mountains and valleys are much younger and as a result the valleys and streams are not as well developed. Most of the streams cut steeply down to the narrow coastline of Hana, often in cascading waterfalls. Annual rainfall is greatest (360 inches) at the summit of west Maui and nearly as high (280 inches) along the flanks of east Maui just below the trade wind inversion.[23] Rainfall tapers off dramatically toward West Maui and Haleakala and is lowest (<15 inches) in the vicinity of Kihei and Lahaina.

Despite the general trend of fewer historic stream floods along the arid south slope of Haleakala and more frequent severe floods in the wetter regions of central Maui, flooding in dry areas such as west and southwest Maui is common. Flooding in areas around Lahaina and Kihei are in part a result of the abrupt transition in slope at the base of the highlands and the behavior of flash flooding. Many historic floods in these two areas occurred after heavy precipitation at higher elevations that fed narrow stream channels, and channelized drainages near the arid coast, to the point of overflow. Flash floods due to heavy precipitation, in some cases equaling the average annual maximum, have occurred throughout the historical record.

During the week of January 14-22, 1990, over twenty inches of rain fell on many parts of Maui causing significant flooding in the coastal zone.[24] The north central portion of Maui and the Hana coast, however, have the greatest stream flooding histories. Nearly once a decade, a major flood emanates from Iao Valley bringing sheets of water down into the urban centers of Kahului and Wailuku. Events such as on November 30, 1950, and November 2, 1961, produced enormous volumes of stream discharge out of the Iao Stream Valley and generated sheet flows on the coastal plain below.[25]

In addition to flooding from stream channels, portions of Maui, notably the Lahaina regions and Kihei, are vulnerable to standing surface water flooding that refuses to drain into the ground. This may interrupt transportation and damage low elevation buildings. Standing surface water develops after intense rainfall events where poor soil permeability and urbanization prevent adequate drainage. Along the road to Hana, temporary road closures are common due to flash floods and mudslides from the steeper slopes of East Haleakala.

Flooding on the Big Island

Stream flooding in the coastal zone of the Big Island of Hawai‘i results from heavy precipitation on the steep mountain slopes of Mauna Kea, Mauna Loa, and Kohala, as well as flash flooding from extraordinary rainfall events on the coastline itself. Kilauea and Hualalai volcanoes are located in more arid regions but occasionally do receive intense rainfall that causes flash floods. Annual rainfall ranges between 300 in on the slopes of Mauna Kea above Hilo, to below ten in on the arid regions of Kawaihae and South Point.[26] Soils that can absorb precipitation are better developed on the older volcanoes of Kohala and Mauna Kea, so mudslides and landslides are more common along the coastal cliffs of the Waipio and Hamakua coasts.

The young lavas that comprise the coastal terraces of Mauna Loa, Kilauea, and portions of Hualalai, are very porous and have less soil development. Often, heavy precipitation simply infiltrates into the rock and flows toward the sea in underground streams. As a result, stream flooding is generally less of a hazard on the younger coastlines. Nonetheless, many occurrences of island-wide stream flooding have been reported which are associated with precipitation from passing tropical storms and hurricanes or their remnants.[27]

Flooding along the wet, windward side of the island has been common and rather expected due to the large input of rainfall. Much of the windward coastline is relatively steep and so runoff occurs in deep channels that reach the shore below steep cliffs. Most of the flooding that has caused damage has been flash flooding during extreme rainfall events that bring about “sheet flow” (open sheets of water flowing across the land) between stream channels.

The Hilo and Puna areas are probably the most frequently flooded and hardest hit by flash floods on the Big Island and perhaps in the state. Severe flooding occurred in 2000 and again in 2003, 2004, and 2006. On November 18-20, 1990, thirty inches of rain fell in the region bringing about intense flooding of the low-lying coastal areas.[28] What is more surprising is the degree of flooding that the more arid regions of the Big Island have sustained. The Kohala and Kailua-Kona Coasts have a long and active history of flooding largely due to flash flooding and intense storms. From 1997 to 2001, the South Kohala and Waikaloa areas have experienced intense flash flooding that has caused considerable damage.[29]

According to the data from the last fifty years, on average a damaging flood event occurs on the Big Island every two years.[30] During this past fifty years, however, the threat due to stream flooding has increased dramatically because of the risk taken to develop extensively in flood prone areas.

Official Notices

The National Weather Service provides us with warnings when flash floods are imminent[31]. They issue bulletins to the media who in turn make you aware of potential weather problems. The first warning is a “Flood Potential Outlook”. This is issued 2-4 days ahead of a possible flooding event. Within 0-2 days of a potential event the National Weather Service will issue a “Flash Flood Watch”. This means it is time to prepare for flooding; families should account for members and modify planned activities to achieve maximum safety and protect against exposure to a dangerous situation.

A “Flash Flood Warning” will be issued when flooding is imminent or already occurring. This means there is a direct threat to life and property and immediate action should be taken to avoid the threat and protect oneself, ones family, and ones property. Flash Flood Warnings are usually issued for a portion of a county; hence the public can assess the degree of applicability to their particular situation and location. “Flash Flood Statements” will also be issued to alert the public about specific occurrences such as roadways that are not useable, or other types of site-specific information.

Flood Insurance and Flood Damage at Home

For information on flooding in your neighborhood, refer to a Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM). FIRM’s are produced by the National Flood Insurance Program (NFIP). These maps depict potential flood water surface elevations as a probability of annual occurrence. They provide information on areas subject to flooding and are used by your home insurance company to calculate your insurance premiums. They are used to guide future development away from flood-prone areas and to regulate development that is proposed to occur within such areas. The National Flood Insurance Program is a Federal program which was established to allow property owners in participating communities to purchase insurance against losses from flooding. Participation in the NFIP is based on an agreement between local communities and the Federal Government that states if a community will adopt and enforce a floodplain management ordinance to reduce future flood risks to new construction and substantial improvements in Special Flood Hazard Areas, the Federal Government will make flood insurance available within the community at a low cost.

Unfortunately, updates to flood maps have not kept up with development in Hawaiʻi. Each year, numerous properties not officially mapped as “flood prone” are flooded. Call your Flood Coordinator (587-0248) for information about flooding. Or ask your local librarian to show you the Flood Insurance Rate Map for your community.

Besides purchasing flood insurance, you can strengthen areas in your home. Proactive mitigation activities include:

1. Clearing debris from your gutters and storm drains and alerting proper authorities to debris in flood channels and storm drains in your neighborhood;

2. Elevating the main breaker or fuse box in your home as well as the utility meters above the anticipated flood level;

3. Adding a waterproof veneer to the exterior walls of your home and sealing all openings, including doors, to prevent the entry of water;

4. Anchoring an external water or propane tank so that a flood does not wash it away. An unanchored tank outside your house can be driven into your walls, and it can be swept downstream, where it can damage other houses.

5. Cleaning and maintaining storm drains, ditches, adjacent channels, and gutters around your home and removing debris from your property to allow free flow of floodwater.

6. Monitoring debris build-up in your neighborhood stream channel. Call the county public works crew when it is obvious that clearing is needed.

Flood insurance covers the value of your home and/or its contents; whether you live in a flood zone or not, you should purchase flood insurance as an additional rider on your principal insurance coverage. Don’t think that you are immune from flooding because you live in a high location. In Hawaiʻi, it is important to know that even homes on steep streets and high grounds are vulnerable to flash flooding, intense rainfall, and stream overflow onto streets. If you have a flood insurance policy, you can be reimbursed for all your covered losses, even if a disaster is not federally declared. In contrast, if you do not have flood insurance and your home is damaged in a federally declared flood, you may get federal disaster assistance in the form of a loan - repayable in full - with interest. An average policy from the National Flood Insurance Program costs about $300 per year for $100,000 of coverage in high-risk areas. In low and moderate-risk areas, the cost is about $100 a year.[32] Compare that low cost to paying back a $50,000 disaster home loan which will cost an average of $300 a month - for an average repayment of twenty years! Keep in mind that as many as 25% of flood insurance claims come from non-high-risk areas. In addition, rain damage is covered under flood insurance but not homeowners or hurricane insurance.

To learn more about insurance call FEMA's National Flood Insurance Program at 1-888-CALL-FLOOD, or contact your local insurance agent. It pays to get flood insurance for your home.

Heavy Rains Can Do More Than Flood

A sometimes overlooked aspect of heavy rains in Hawaiʻi is the damage they produce that is not related to flooding. For instance, during the lingering Kona conditions in spring 2006, sewage pipes burst in Waikīkī, Waimanalo, Enchanted Lake, and elsewhere across the island of Oʻahu.[33] In most cases, events such as these result from high water pressure due to rain water seepage into aged and perforated sewer pipes. In Waimanalo, the overflow was delivered directly into the ocean, closing three miles of polluted beaches to the public. Ten thousand gallons of sewage flowed into Enchanted Lake, which in turn delivered the pollution into the ocean through the center of Kailua Beach Park, closing the entire length of two and a half mile long Kailua Beach.

In Waikīkī, work crews repairing a burst pipe diverted raw human sewage from dozens of hotels directly into the Ala Wai Canal for five days. Forty eight million gallons of untreated sewage emptied into the ocean.[34] Sadly, the worst bacterial measurements were recorded at popular surf sites Ala Moana Bowls, Rock Piles, and In Betweens. Worse, beaches were closed along the length of Waikīkī, ground central for Hawaiʻi tourism, to prevent bacterial infections among the many swimmers and surfers. Captain Paul Marino with the City lifeguards said of the mess "the beaches from the Royal Hawaiian Hotel to Sans Souci are now yellow, smelly with a brownish tint."[35]

The dumping of raw sewage and the delivery of soil-laden waters containing the dissolved wastes of our roads, yards, and sidewalks have an unknown, but likely negative effect on the animal life of our reefs. Debris on beaches, layers of silt, and freshwater delivered at un-naturally high rates through our system of concrete stream channels all foul coastal waters every time a Kona storm settles in for a stay among the islands. While Konas are perfectly natural events, the products that their rain waters deliver to the ocean reflect the waste of our society. Like flushing the toilet, heavy rains send human waste of all types into our coastal playground.

Channelizing Watersheds

Flooding is one of Hawaiʻi's most frequent, damaging, and dangerous hazards. Have we responded to this threat in the best manner? The Mānoa channel that backed up with debris and flooded residential properties and the campus at the University of Hawaiʻi at Mānoa in 2004 causing over eighty million dollars in damage, was built to prevent flooding, not be the cause of it. In addition to occasionally not doing their job as planned, these channels destroy the native aquatic ecosystems of our streams.

Ideally, streams in Hawaiʻi should have natural beds and banks. Cool, clear water should meander through features such as pools and riffles that also provide habitat to native species. Naturally overhanging vegetation should provide shade from the hot subtropical sun for the indigenous ecology. Instead, dozens of cement causeways have been built by authorities to contain the raging torrents that now develop after hard rains because of our hardened watersheds. These replace the natural soft substrate of the streambed with a slick concrete surface and armored banks that offer no habitat to native species, and prevent normal stream behavior. Channels also replace nature's own version of a flood mitigation system – the flood plain. Normally, flood plains lie on either side of a stream channel and carry excess water and sediment during flood conditions. They are as much a part of a stream environment as the beach is part of an ocean. Channelization projects replace flood plains and encourage neighborhoods to be built on lands that have been repeatedly flooded throughout history.

Channelized streams tend to be free of overhanging vegetation, so they are exposed to the full heat of the sun, significantly increasing the water temperature. Each of these modifications from natural conditions (accelerated water flow, decreased habitat, and increased water temperature) has a negative impact on the ability of native species such as the o`opu (the native goby) to survive in the stream. Introduced species such as tilapia tend to be more robust than native species and are better able to survive in channelized streams. As we channelize more and more streams, we not only reduce the habitat available for native species but we also increase the amount of habitat for their competitors.

Channelization alters the natural rate at which a stream transports sediment and freshwater and delivers them to the shoreline. Silts, clays, and sands that would normally be stored by a stream along its floodplain and in its channel are instead carried to the sea. This leads to sediment pollution in the estuary that occupies the stream mouth and a deluge of freshwater with every rainfall. Brackish water species adapted to tolerate estuary conditions cannot take this chemical and material stress and ultimately disappear. Many of these species and the organisms they feed on are marine fishes, so with the decline of estuaries comes an impact to our coastal fishery, the reef, and even offshore species.

Often forgotten is the fact that huge flood channels destroy wetlands that nature originally designed to mitigate flood hazards. But since we now build houses, streets, and entire communities in former marshy floodplains, their original function is forgotten and we cut these same communities in half with cement channels. A more rational approach is to avoid the flood hazard by mapping the geologic tell tales of floods, look for floodplain deposits, statistically predict the frequency and water height of flooding, and build our communities out of the way. Channelization should be discouraged in most cases in favor of simply avoiding the floods by not building our homes in their path. Homes can be engineered with post and pier construction methods to lift them above flood elevations, and property owners can be required to manage precipitation that falls on their property rather than seeing it diverted it into storm drains.

Is it possible that some communities might be redeveloped to recover and restore former floodplains? Yes, they have done just that in Sacramento and other communities trying to restore the natural ecology of their streams.[36] These places exercise flood avoidance by removing poorly sited homes and streets. In urbanized watersheds we can engineer a solution: retrofit a natural streambed component in channelization projects, use permeable surfaces when paving a watershed, design no-build corridors along stream banks, buy-up the most hazardous properties to return them to an undeveloped state, and construct catchment areas on undeveloped lots and open lands.

Rock Falls, Landslides, and Hawai‘i's Unstable Hills

The watersheds and slopes of Hawai‘i are the setting for a process geologists call *mass wasting*, where heavy clusters of rock and soil unhinge from a hill and slide, tumble, and ooze downwards under the unending influence of gravity. This process includes rock falls, landslides, slumps, debris avalanches, and debris flows – but one term, mass wasting, is the common and adequate descriptor.

- Heavy rains in spring 2006, spawned a dozen mass wasting events that backed up traffic and closed lanes during peak rush hour traffic on Kailua's Pali Highway. It was fortunate that no one was hurt by the various mudflows, debris slides, and rock falls that rained down on the highway that season.[37]
- On March 6, 2000, rock and debris fell onto Kamehameha Highway at Waimea Bay. A new, $4 million stretch of highway has been constructed thirty-eight feet makai to mitigate future risk to motorists.[38]
- A mudslide in Makaha swept away several cars and bikes and left rocks and mud in the lobby of the Makaha Valley Towers condominium in November 1996.[39]
- On Woodlawn Street in Mānoa Valley a whole series of houses are slowly sliding down a hillside.
- In Aina Haina and Niu Valley several houses are slowly sliding downhill.[40]

A Persistent Problem

In 1999, tragedy struck one of paradise's most admired destinations, Sacred Falls. This eighty-foot-high waterfall, popular with hikers, is located in the lush, upper Kaluanui Valley on O‘ahu's windward side. On Mothers Day, May 9th, while dozens of tired hikers were sunbathing around the deep blue pool at the base of the waterfall, a mass of rock and soil separated from the valley upper wall and rocketed down the sheer cliff onto the unsuspecting families.[41] Free-falling boulders the size of cars and masses of dirt, cobbles, and sharp-edged rock accompanied the mass as it crashed to the ground in the narrow confines of the valley. Eight people were killed instantly, another thirty-two were injured. Those who survived this shocking disaster didn't notice any discernable event that would trigger such a catastrophe; no earthquake, no drenching rain, nothing specific to dislodge the rock. Yet two unseen culprits were at work among the Hawaiian hills: gravity and time.

Regrettably, the horrifying event at Sacred Falls was not a unique occurrence. Many examples of slope failure have been documented across the island chain although, unlike the catastrophe at Sacred Falls, there is often an obvious perpetrator, a trigger to start the moving slope. Two of the most common triggers for landslides are earthquake vibrations that reduce soil adhesion to the ground and heavy rains that saturate unattached debris sitting on bedrock, adding to its weight and lubricating the slide surface.

Hawai‘i's violent earthquake of April 1868 followed a period of torrential rain that triggered several slides, and a mudflow that buried thirty-one people and 500 livestock in the Wood Valley of the Ka'u District.[42] The November 1983 earthquake on the Big Island generated landslides on precipitous slopes all around the island, and destabilized hillsides that later collapsed from heavy rainfall.[43] Driving rain prompted several slope failures on O'ahu in November 1965.[44] One, the Pali Highway slide, released 20,000 tons of rock and mud over a four-day period. Although each of these catastrophes was unpredictable, the damage they caused could have been diminished through specific mitigation strategies based on an analysis of vulnerable areas.

Unstable slopes are found among most of Hawaii's steep hillsides.

Potential damage from rock falls and small slides can be avoided or reduced by reinforcing the ground with steel fencing, steel mesh netting, and slope stabilization with grouting and the use of anchored gabions. These techniques are most commonly used to stabilize artificial cuts into bedrock and are only employed as a final option since they have to be maintained regularly. Another solution for stabilizing soils is to remove the threat by blasting away overhangs, or by grading steep slopes to lower, more stable angles.

But modifying slopes to improve safety can be unpopular. Residents don't like to see heavy engineering in the pristine hills of Hawai'i. Open views are important attributes to the beauty of our daily Hawaiian lifestyle – who wants to look at heavy gauge steel fences among the placid greenery? Caves holding artifacts and other sacred sites dot the hillsides in hidden abundance and it is disrespectful, even sacrilegious, to alter the character of these legacies. Of course, cost is always a concern. Shoring up a hillside that has displayed no immediate impact to our safety, at a cost of millions, is often far down the "to-do" list of local legislators and agencies.

When Islands Fall Apart

Among the awe-inspiring natural features of the Hawaiian Islands are the dramatically beautiful *pali* that are found on every island. These sheer, vertical rock faces of ancient basalt lava flows are hundreds to thousands of feet high and often drop directly to the coast.

The geological history of these immense cliffs is a tale of mass-wasting on a prodigious scale. The cliffs are initially formed by massive landslides that take away whole pieces of an island, they later evolve and often retreat under the forces of erosion that continue to assault their steep slopes.. To understand this process, it is important to understand that the Hawaiian Islands are composed of what are essentially piles of glassy volcanic rock. This rock (produced by basaltic magma) solidified within only a few minutes of reaching the seafloor or atmosphere where it cooled. With so little time to crystallize, the lava has the strength of glass and is very brittle because it has no crystalline structure.

Although no one was present to witness when these pali formed, it is hypothesized that swelling of a volcano associated with magma intrusion prior to an eruption causes a flank of a shield volcano to break off and slide into the sea. This is possible because from the floor of the sea to the surface the islands are composed of glassy talus – literally a pile of rugged marbles.

Evidence in support of the mass landslide hypothesis is found in several observations. Maps of the sea floor show topography that is consistent with a landslide source. Submarine fields of chaotic debris can be traced back to the islands where some of the highest pali are located. Additionally, the main shield volcanoes composing the islands have incomplete outlines. Rather than the expected broad oval shape, each of the two shields forming the island of Oʻahu show only half their base – each forms an open crescent rather than the closed oval of a complete volcano. The same is true of the island of Molokaʻi. Missing pieces can be found some distance offshore where they have presumably slid in the course of a prodigious mass wasting event.

Scientists have identified over fifteen giant landslides surrounding the Hawaiian Islands.[45] These slides are some of the largest known on Earth, and most have taken place throughout the past four million years. The youngest landslide is estimated to have occurred only one hundred thousand years ago. Today, geologists consider a phase of island mass wasting to be an important chapter in the formation of all Hawaiian Islands and perhaps other islands of similar origin around the world.

Debris Flows and How to Avoid Them

Debris flows are fast moving slope failures that begin as a shallow landslide on a steep incline during intense rainfall. The sliding mass of clayish soil, weathered bedrock, and vegetation turns fluid as it pours downhill. A debris flow may carve its own path or follow shallow drainage channels down a hillside, dragging along anything in its path. If the avalanche turns soupy from gathering lots of soil, the term mudflow may be more fitting, although its thinner texture doesn't diminish a mudflow's power to carry boulders or cars. An ancient mudflow deposit on Maui's south coast, near Kaupo, is 325 feet thick, over two miles wide, and contains blocks of rock over forty feet across![46] Debris flows are frequent visitors on the heels of prolonged rainfall that saturates hillsides.

U.S. Geological Survey studies have identified approximately 1,800 debris flow sites in the Honolulu District between the 1930's and 1989.[47] These studies were instigated because of the New Year's Eve storm of 1987-1988, when twenty-three inches of rainfall triggered more than 400 debris flows in the Niu, Kuliouou, and Hahaione valleys. The torrential rain also contributed to slow-moving landslides that persisted long after the storm in the Kuliouou, Moanalua, and Mānoa valleys, as well as in Aina Haina. However, these events were not completely surprising because many pre-1930's deposits and topographic features associated with earlier slides have been found in all of these valleys and in many cases have been built upon by entire subdivisions.

While debris flows are surprisingly common, there are ways to avoid them:

1. Avoid construction on or at the base of steep slopes;

2. Avoid run-out areas at the mouths of gullies, gulches, and narrow stream valleys;
3. Keep away from regions where scars of previous events can be identified;
4. Identify areas where other indicators of down-slope movement exist, such as leaning trees or structures and hummocky topography;
5. Do not construct in areas where native vegetation that anchors the soil has been cleared.
6. Get advice from a consulting geologist or engineer if questions persist.
7. A detailed report on landslides, debris flows and rock falls is available from the City and County of Honolulu[48].

If a building or home is already located on an unstable slope, only a few options exist to reinforce the soil. One can revegetate the hillside with native plants, grade slopes to a more stable angle, install drain systems to de-water slopes, anchor one's house to bedrock, and avoid increasing the load on the slope. Of course, one could always consider relocation if these options aren't effective. Much of the information on how to avoid a debris flow applies to slow-moving landslides as well.

Creepy Hills

Slow-moving landslides encompass relatively large areas of ground that gradually and sporadically move downhill. As a slide creeps downward, moving like a massive earthworm, part of its bulk may stretch and fracture, while other areas compress and fold due to its sheer size. If any structures such as houses, streets, sidewalks, or utilities are carried on top of the landslide, they too will suffer the irregular buckling that can result. The resulting damage ranges from minor flaws to total structural collapse.

Shortly after the Waiomao subdivision in the upper Palolo Valley of O‘ahu had been completed, the first signs of slope instability appeared.[49] Cracks in walls and poured slabs, framing out of square, displaced landscaping; these were the first sure signs of unstable ground. By the second year of its existence, Waiomao experienced a nine-inch rain that aggravated these instabilities. Within three years the side effects of slow creep were becoming alarmingly obvious as water mains and utilities that suffered damage were relocated in an attempt to compensate for the ground's inexorable movement. This continued for several years, until the landslide had consumed forty homes and thwarted every attempt to stabilize the subdivision. Several years later the subdivision was completely abandoned and the city purchased the land and converted it into a park – a memorial to the costs of ignoring the geology when developing the land.

There are two lessons to be gleaned from the Palolo example. One: Avoid this situation at all costs by integrating a thorough geo-hazard analysis into all development plans. Two: If such an analysis is not possible before development, the only safe and cost effective option once the hazard is identified is to relocate. Slow-moving landslides move a very small fraction of an inch per day, creating an essentially unobservable process. Any building caught in this kind of motion can be damaged slowly enough to mislead the owner into thinking a few repairs will solve the problem. But the problem is irresolvable and damage can continue to the point of endangering the residents of the dwelling. Fortunately, there are signs that can reduce the risk of a homeowner buying a residence that will take him or her for a ride.

Trying to predict future sites of slow-moving landslides is not 100% accurate and can be extremely tricky. Knowing the factors associated with such slides at least provides guidelines for evaluating an area's risk. The key lies in knowing how to decode the evidence.

- First, these events occur in areas along the margins of valleys on relatively low slopes of 5° to 25°, near the base of steeper valley walls.
- Second, beware of dark, clay-rich soils, characterized by clay minerals that expand and swell when wet, and shrink and crack when dry. These clay-rich soils exist within the region of moderate rainfall (thirty-nine to seventy-nine inches per year) and can act as slick surfaces for the slow-moving slides.
- Third, it is heavy rains that initiate the first movement of slow-moving landslides and periodic reactivation of the slippage. Once a slide begins to move, evidence of the shift can be spotted in the form of scarps (a steep slope or cliff formed by erosion or faulting), soil surface hummocks (irregular rises or humps), offsets in curbs, cracked driveways and foundation walls, windows and doorframes and other linear features, uniformly curved trunks among a stand of trees, and bulges of soil in the middle or lower reaches of a slope.
- The City and County of Honolulu has a map of unstable slopes subject to debris flows. Check this before considering any real estate purchase[50].

Avoidance is Always Easier – But where do we find the information?

The watersheds of Hawai‘i are the birthplace of our waters. But they are not the tranquil, cloud-shrouded regions they may appear from afar. Nestled between valley walls are flash floods, rock falls, debris flows, creeping hillsides, and torrential rains. Knowing the geologic clues that Mother Nature always leaves for our discovery can spell the difference between catastrophe and serenity on these verdant slopes. Avoiding hazards means knowing how to find them in the first place. Geologic analysis should be part of every development and the final factor in siting everything from homes and roads to pathways and parks.

Unfortunately, the State of Hawai‘i has no lead science agency. In fact, being the only state in the union without a state geologist and lacking an office of the state geological survey, there is literally nowhere for citizens to turn for geologic information. Would you like to see a map of unstable slopes? A map of streams prone to flash flooding? The latest report on mass wasting in Hawai‘i or regions vulnerable to rock falls? None of this information is available to the public. In fact, neither is there a collated body of literature on rock and mineral resources, sand and gravel reserves, soil erosion, or any number of geological issues of critical importance to public safety and resource management.

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