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Anja Christina Reissberg

Viable Systems to **prevent** human **tragedy** – the **Hawai'ian example**

Mastering natural catastrophies

edition MALIK

Managing natural catastrophes

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Managing natural catastrophies

Viable Systems to prevent human tragedy – the Hawai‘ian example

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German preface for editionMALIK

Die alte Welt vergeht,
weil eine neue Welt entsteht.

Wirtschaft und Gesellschaft gehen durch eine der tiefgreifendsten Umwandlungen, die es geschichtlich je gab. Als Begriff wählte ich 1997 dafür »Die Große Transformation«, denn bereits damals war das Ausmaß des heraufziehenden epochalen Wandels deutlich zu sehen. Was heute lediglich als eine finanzielle und ökonomische Krise zu eng gesehen wird, kann weit besser als die Geburtswehen der neuen Welt des 21. Jahrhunderts verstanden werden.

In dieser neuen Welt werden Organisationen eine höhere Ebene des Funktionierens erreichen. Sie werden doppelt so gut wie bisher funktionieren, aber nur die Hälfte des Geldes dafür benötigen. Die universelle Herausforderung wird für sie das Meistern von bisher noch nie erfahrener Komplexität durch neues Management sein.

Geld ist dafür aber weit weniger wichtig als Intelligenz, Vorstellungskraft, Information, Kommunikation und Gestaltungswille. Das neue Wissen hierfür und darauf gestützte neue, biokybernetische Lösungen sind bereits da. Deren Kern sind die ®Evolutionären Naturgesetze aus Kybernetik und Bionik für das Selbstorganisieren und Selbstregulieren. Diese Gesetze zu verstehen und sie zu nutzen, ist das neue Kapital der neuen Welt und die Grundlage für Leadership von Personen und Organisationen.

Die editionMALIK ist die Plattform für das zuverlässige Funktionieren von Organisationen in der hochkomplexen Umwelt des 21. Jahrhunderts. Sie ist die systemische Orientierungs- und Navigationshilfe für Leader, die den Wandel vorausdenken und -lenken.

Fredmund Malik
St. Gallen, Januar 2010

Über Malik sagt der Doyen des Managements, Peter F. Drucker:

> »Fredmund Malik has become the leading analyst of, and expert on, management in Europe as it has emerged in the last thirty years – and a powerful force in shaping it … . He is a commanding figure – in theory as well as in the practice of management.«

Introduction: Natural disasters in the light of management cybernetics

Natural disasters seem to be on the rise worldwide and their increasing frequency and dimension [Munich Re Group, 2004] make them more and more the focus of society's concern [Annan, 1999]. But do natural disasters really occur more often than before? Are they more disastrous because of their physical manner or because they are socially constructed, with society increasingly 'getting in nature's way'? The latter appears to be the case. For example, globalization has led to more direct linkages of distant places than existed in the past. The rising interconnectedness and dependency of elements within human systems increase this complexity while the nature of those connections gets more complicated and the number of system elements increases. Factors such as population growth, agglomeration of population and capital value in metropolitan areas, rising living standards, settlement and industrialization of very exposed areas, vulnerability of certain elements and groups in modern society, and the increasing number of high-risk technologies, all play a role [Munich Re Group, 2004]. Further, an increasing complexity of infrastructure, especially communication systems, makes human society more vulnerable to natural hazards. Trust and dependency on information technology, in particular, enhances vulnerability even more. Environmental degradation, such as surface sealing, global warming and climate change, are other dynamic pressures on the stability of human systems. Consequently, the effects of events like natural disasters are felt more quickly. A more effective response is needed in order to address these many negative impacts.

In the Pacific, small island states are especially vulnerable to hurricanes ('typhoons', 'cyclones') due to their small size, isolation, fragile ecological systems, poorly developed infrastructure, limited fresh-water and other natural resources, fragile economies, limited financial and human resources and low elevation above sea level. Among these islands, the Hawaiʻian Islands have the highest population density of them all [Pacific Regional Environment Program, 2003]. Urbanization has increased the concentration of people and capital in Hawai'i's coastal areas, especially on O'ahu. A direct hit on O'ahu by a hurricane would put in jeopardy a significant portion of its population and economic wealth. Further, Hawai'i's isolation makes outside assistance very difficult to provide – the neighbor islands, the west coast of the United States, and Guam are the nearest responders. Transportation of resources by air or sea takes on average five hours or several days, respectively, coming from the west coast of the United States or Guam. Infrastructure damage to the islands will limit the functionality of those life-sustaining transportation corridors.

In response to these vulnerabilities, an effective disaster-management system must be based on the fact that the nearest responders are the State's least damaged islands. Except for the limited assistance that the least damaged islands might provide, Hawai'i State Civil Defense estimates that the population of the Hawai'ian Islands will be without outside assistance for at least one week after a major hurricane event [Teixeira, 2007b]. Focusing on O'ahu, Ed Teixeira, Deputy Director of Hawai'i State Civil Defense, has observed that planning for a high-impact-low-probability event like Hurricane Katrina on O'ahu has not much evolved: 'because it was unthinkable and too hard to think about' [Teixeira, 2007b].

Society's concerns are often underrepresented in disaster management decisions since long-term mitigation measures often cannot compete with short-term politically motivated measures and funding sources are polarized, which results in a continuation of the present situation regarding the disaster vulnerability in Hawai'i. Often, disasters are exacerbated by policy problems and thereby caused vulnerabilities due to failure to address root causes, for example by certain land use or settlement policies, population distribution or degrading habitats [Comfort, 1999]. These are initiated under the legal framework of development policy. The complex problem of disasters consists of four factors: first, the rate of social and environmental change exceeds organizational capacity to manage it effectively. Secondly, the understanding of the components and consequences of that change is inadequate. Third, interactions among individuals, organizations and governments are uninformed and fourth, change in public policy and practice is needed. 'If the complexity of interacting scientific, social, political, and economic conditions exceeds the existing capacity for organizational control, decisions taken by local actors govern the direction of the evolving process' [Comfort, 1999, p. 42]. Yet, an integrated process of hazard reduction requires coordinated action across jurisdictional and disciplinary boundaries. Building resilient communities as a policy is at the core of the participatory approach and is one of the main solutions academia offers. Management Cybernetics offers such participatory and non-hierarchical approaches that are capable to reduce vulnerabilities on all scales.

The assumptions of the Federal Emergency Management Agency (FEMA), expressed in the Concept of Operations (CONOP) for a catastrophic hurricane impacting the State of Hawaiʻi, offer little consolation [Federal Emergency Management Agency, 2007]. A massive federal effort will be needed, it states, because Oʻahu's support infrastructure faces potentially catastrophic inundation and damage: the main power production facilities (both electric generation and liquid fuels), Honolulu International airport, and the cargo-handling facilities at Honolulu harbor and Pearl Harbor. The *problematique* is further exacerbated because 80 % of Hawaiʻi's population lives on Oʻahu and is especially vulnerable due to lack of resources. Making the situation worse, the other islands are dependent on Oʻahu for energy, food and other commodities, which will greatly limit their ability to assist Oʻahu. No transportation for evacuation will be available or feasible; the evacuation of tourist population faces similar issues of capability and feasibility [Rosenberg, 2007b]. Air evacuation of visitors leaving the State of Hawaiʻi would require 400–500 aircrafts, Boeing 747 equivalent [FEMA, 2007]. Even if it would be considered, prioritizing evacuees would become a problem. The most pressing problem will arise in the aftermath when in a competitive situation mass control becomes a major issue. In case of a false warning, the governor would possibly face 180,000 angry tourists, an upset airline and hotel industry and a low chance of getting elected again. Overall, the governor can make only recommendations to the Tourist Board, which is an independent commercial board. The Board could start canceling people coming in and making people leave [Rosenberg, 2007a]. Reality, as seen the night before Hurricane Katrina hit New Orleans 2005, looks very different: hurricane parties are abound.

Overall, hurricanes are by far the most costly disasters in Hawaiʻi (see Table 1).

From 1860 to 1962, floods from tsunamis, hurricanes and rainstorm caused more than 350 deaths and over $82 million in property damage in Hawaiʻi. Damage from floods from 1963 to 1982 total about $395 million [Department of Land and Natural Resources, 1996]. Hence, within 20 years the damage developed fivefold compared to the 100 year period. For a period of 20 years in comparison, it would be a 25 fold increase. Numbers cannot be directly related in this way, but the trend for the tremendous increase in damage potential is obvious. It results mostly from increase in population density and increase in value and agglomeration of value in the Hawaiʻian Islands. Therefore, a massive federal effort is assumed for a major hurricane impacting the whole State of Hawaiʻi.

Since the risks and damage potential of natural events cannot be changed or managed, it is crucial that human-caused vulnerabilities be kept to a minimum. One way to achieve this is through an effective and efficient disaster management system, which this dissertation aims to explicate by critiquing and offering suggestions to improve the effectiveness of disaster management on Oʻahu. The VSM aims at enhancing effectiveness of the elements already in place, rather than proposing new disaster management elements. Lessons learned from this case could be applicable to the management of disasters of any type and size in Hawaiʻi.

Vulnerability leads to destabilized social systems – what does management cybernetics have to offer? Vulnerability can be defined in a Variety of ways. For the purpose of disaster management, it is 'the characteristics of an individual or social group or a situation to anticipate, cope with, resist and recover from the adverse effects of a natural hazard' [Blaikie, et al., 2004]. In cybernetic terms, vulnerability is the potential for a system to become unstable. When unstable for a certain time and not returning to a stable system, the system becomes non-viable. The timeframe for a system to become then viable again is called 'Relaxation Time'. Vulnerability can be caused by a Variety of sources internal and external to the system. For example, disasters can be socially produced displaying internal disturbances: instabilities persist in the daily routine of people's lives such as a incorrect flood-plain mapping system leaving a family ignorant to the fact that evacuation is necessary at certain times or simply a non-working fire-extinguisher. Those facts by itself are not a threat but in connection to other events, such as a flood or fire, they become key to a circumstance developing into a disaster or not. Ultimately, the term lends itself to many aspects of interest – e.g., physical, natural, environmental, social, economic or cultural vulnerability – and therefore underlines the need for a holistic approach. This also means that the vulnerability of the whole system depends on the vulnerability of its units. This gives rise to the argument that the government should be responsible for or give leadership in making society a safe and secure place in form of integrating anticipatory disaster mitigation into development strategies. This systemic viewpoint underlines the statement that the whole is more than the sum of its parts, which argues against reductionism and advocates a holistic approach, such as the VSM. It is also helpful to elucidate the challenge of complex systems through relating viability and stability. A system is viable if it remains stable in the face of an unexpected event [Beer, 1994a]. In terms of the disaster management system, viable means capable of responding effectively, or remaining invulnerable. Even though small instabilities can endanger the viability of the system as a whole a certain minimal degree of instability within the system does not yet risk its viability because those systems are capable to survive by absorbing certain perturbations [Holling, 1977]. Setting those limits on a small scale will help to alarm the system at large to avert a viability-threatening concatenation of events, even if every single circumstance seems only as a small disregardable risk. But, risk and vulnerability are two sides of one coin. Increasing vulnerability leads to increased disaster risk. Hence, reducing vulnerability by building disaster-resilient communities is key to disaster risk reduction. In a systems thinking view, vulnerability and the risk of incurring instabilities within the system at large has great potential to be stabilized through revealing the driving mechanisms and deep structures. In another stance, the social sciences emphasize that risk cannot only be defined in terms of physical damage, but have to include risk perception or acceptance. Behavior is greatly affected by whether or not risk is taken voluntarily, since people's risk posture (i.e., if they are risk averse, risk neutral, or risk-seeking) has been shown to vary along this dimension.

Overall, a disaster is the destabilization and disruption of the social system, its units – communities, social groups, individuals – and its connectivity. The environmental, economic and social reverberations caused by this destabilization lead to positive feedback loops until countermeasures balance the system as a whole and it returns to a stable state again. This systems approach is valuable, since it is multi-dimensional, includes all temporal and spatial scales, and emphasizes the disturbance of the collective routine. The Environment of the system affects the system with natural and human-induced disturbances – for example, a natural hazard such as a hurricane. My work incorporates all natural disturbances, also termed hazards, that are the trigger of 'natural' disasters as well as the human-induced aspects. Since a disaster can be caused by a Variety of hazards, e.g. by hurricanes, earthquakes or tsunamis this systemic approach is applicable to all hazard types.

Management cybernetics was chosen because much of hazard management research only describes what goes wrong during hazards and why things do not work. Some approaches offer explanations for damages, such as people's poor perception of the phenomena and poor choices of response, the nature of the geophysical phenomena themselves or the nature of insti-

HAWAI‘I’S COSTLIEST NATURAL DISASTERS

A preliminary damage estimate of $80 million from the Oct. 30 Flooding in Mānoa Valley would make it the fourth-costliest natural Disaster in Hawai‘i history. Here’s a list of the state’s worst:

1.	**Hurricane ‘Iniki**	Sept. 11, 1992	$2.6B, 4 dead
2.	**Hurricane ‘Iwa**	Nov. 23, 1982	$307M, 3 dead
3.	**Big Island flood**	Nov. 1, 2000	$88.2M
4.	**Floods**	Jan. 6-14, 1980	$42.5M
5.	**New Year’s flood**	Dec. 31, 1987	$35M
6.	**Tsunami**	May 22, 1960	$26.5M, 61 dead
7.	**Tsunami**	April 1, 1946	$26M, 159 dead
8.	**Kīlauea Lava Flow**	1990	$21M
9.	**Floods**	Mar. 19-23, 1991	$10M- $15M
10.	**O‘ahu flood**	Nov. 7, 1996	$11M

Source: Hawai‘i Civil Defense

Table 1: The most costly disasters in Hawai‘i

tutions that create or exacerbate risk and vulnerability for society or particular groups within it. Ways to improve hazard management in general and in a proactive stance are rarely addressed. As a fresh breeze, management cybernetics offers solutions. This work is original and unique because the VSM was never applied to disaster management systems, a loosly coupled network of systems that are hibernating and not always in place.

The VSM lends itself perfectly for this analysis because it deals with messes – not defined problems – and can illuminate why things go wrong. Its theory says that the sum of the elements is greater than the sum of its parts. Instead of examining the cause and effect in a linear manner, the VSM specifically looks at the links that hold the system together in a holistic fashion and therefore takes a system’s full complexity into account. Since the VSM can integrate quantitative and qualitative measures, it can provide a common language and framework to discuss the management support and coordination needed by the groups working in the very complex field of disaster management – private and governmental agencies, non-governmental and volunteer organizations. Improvements to communication channels within and between disaster management organization can save valuable time and can promote high levels of effectiveness and efficiency. The VSM can support research incorporating different disciplines without having its basic structure and dynamics obfuscated. Highly valuable is its ability to diagnose hibernating and temporary systems that jump in and out of existence.

Viability is most commonly understood in terms of longevity and persistence, where success is measured in terms of survival, but the VSM does not neglect organizations that are less long-lived and based on goal-oriented action. Beer's main message in *The Heart of Enterprise* [Beer, 1994a] specifically states that the aim is not single-goal oriented, e.g. maximizing profits, but viability and survival, which is ensured through effective organization. The reader needs to understand that in essence the means for survival, the 'how', are most important. Hence, effectiveness of the Hawaiʻian disaster management system is the measure of viability per se, independent of how long this organization exists. Moreover, two aspects should be highlighted to show the VSM's applicability to disaster management: time – a disaster needs a quick response – and smooth coordination – not confusion. One advantage of using Beer's VSM in a disaster management context is its convenient framework for experiencing and examining interactions among several groups responding to a disaster. This also includes the democratic management style within volunteer organizations and the command and control approach used by the military. The VSM enables one to distinguish among the different operations and management units along with their communication channels and this secures its flexibility in terms of different management styles. Specifically temporary disaster management systems, which jump in and out of existence depending on when a disaster strikes, do not necessarily have a base of commonly understood conventions and relationships on which to build. The methodology is explicitly linked to this purpose and involves 'qualitative measures of cohesion, identity and ethos as well as the more usual quantitative measures' [Leonard, 1993, p. 79].

From a practical standpoint, the federal disaster management system is constituted by the Federal Emergency Management Agency's (FEMA) Incident Command System (ICS), which is a systems approach. So it is both inviting and highly useful to diagnose this system with a similar approach coming from the same field of thinking. Overall, the VSM seemed to have great potential to improve the effectiveness of hurricane hazard management.

1. The Hawaiʻian hurricane tale

The Hawaiʻian Islands lie at about 157 degree Western Longitude and 20 degree Northern Latitude (see Figure 1) and are the most remote islands worldwide. Extending from the Big Island of Hawaiʻi to Kure Island, the State of Hawaiʻi extends 1200 miles, and is composed of 26 islands, reefs and sea-mounts. The Islands of Hawaiʻi are shown in Figure 2 [FEMA, 2007]. The major islands of Oʻahu, Maui, Kauai and Hawaiʻi are also designated as counties.

The City and County of Honolulu covers the entire island of Oʻahu (see Figure 3), approximately 600 square miles in size. Its resident population was 910,000 in 2006 [Department of Business, Economic Development and Tourism, 2006]. It rises from sea level to a high point of 4,020 feet

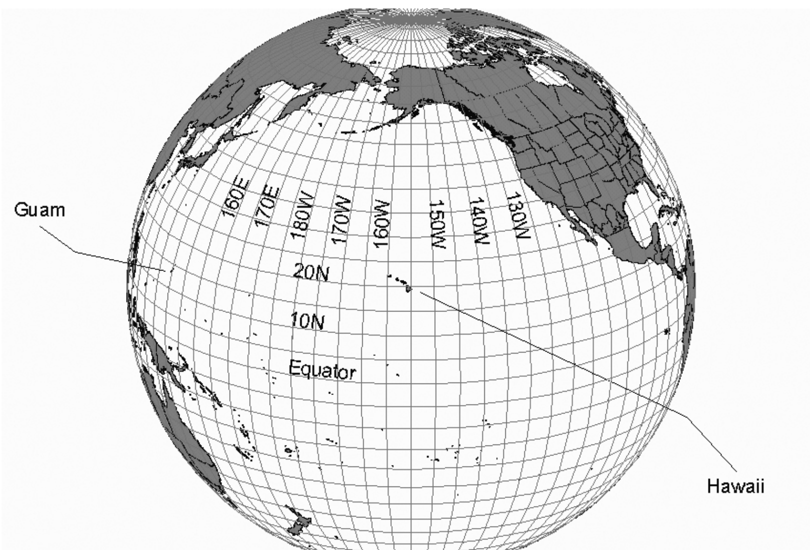

Figure 1: Hawaiʻi's location in the Pacific Ocean

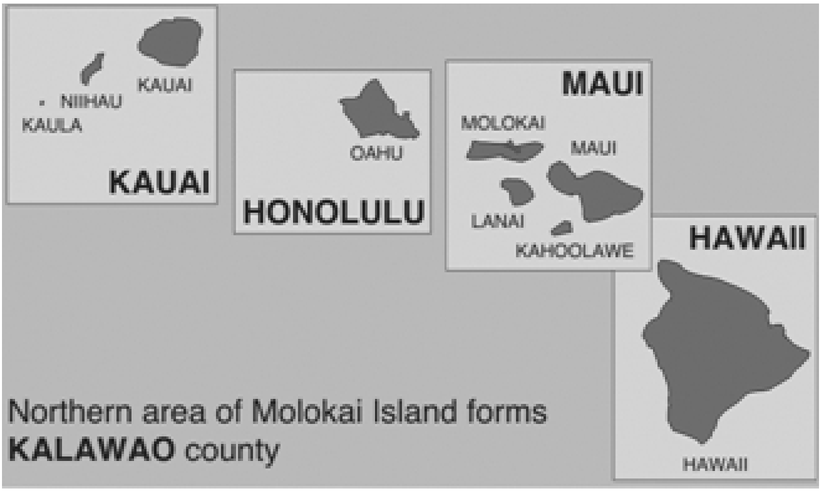

Figure 2: The Hawai'ian Islands

Figure 3: The island of O'ahu

on Mt. Kaala in the Waianae Range. The island is situated approximately 2000 miles, or 5 shipping days, from the continental United States. Housing 80 % of the State's population, O'ahu measured from its farthest points

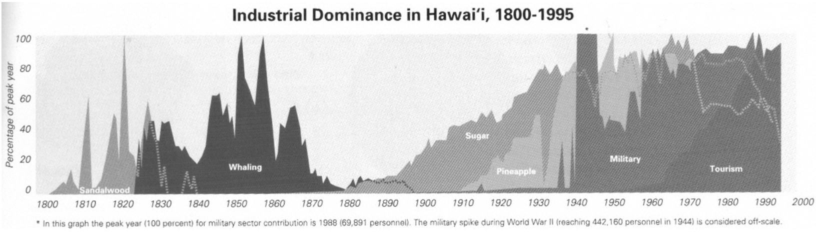

Figure 4: Predominant industries in Hawai'i 1800–1995

is 44 miles long by 30 miles wide. The 112 mile coastline holds the two largest harbors in the state, Honolulu and Pearl [FEMA, 2007, p. 17].

The other designated counties and main islands consist of Maui, Kauai and the Big Island. Hawai'i's economy is centered around tourism, the dominant source of export earnings (see Figure 4) [Department of Geography, 1998, p. 239]. The neighbor islands have more prominent agricultural and tourism sectors than O'ahu because O'ahu attracts other businesses such as financial and health services, as well as defense. The former importance of plantation agriculture and defense diminished over the last decades due to stagnation in agricultural output and prices and the end of the Cold War, while a growth of tourism in general persisted [Department of Geography, 1998].

The State is heavily dependent on resource imports: 89 % of Hawai'i's primary energy depends on imported petroleum [FEMA, 2007]. Hawai'i's small market size inhibits the exploitation of manufacturing economies of scale, resulting in an overdependence on imported merchandise [Department of Geography, 1998].

1.1 Background on State of Hawai'i and O'ahu

The term hurricane has its origin in the indigenous religions of past civilizations. The Mayan storm god was named *Hunraken*. A god considered evil by the Taino people of the Caribbean was called *Huracan.* Hurricanes are products of a tropical ocean of 28 degree Celsius or more and a warm, moist atmosphere [U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, 2006]. Hurricanes develop from tropical depressions with sustained winds up to 38 mph to tropical storms with sustained winds of 39 to 73 mph before becoming hurricanes with winds of 74 mph or more. The Saffir-Simpson Scale categorizes hurricanes depend-

Hurricane Category	Central Pressure (Mm of mercury at 32 degrees F)	Sustained winds mph	Peak Gust (over land) mph	Approximate Storm Surge Height (ft)	Damage Potential Indications
Tropical Storm	979-1007	40-73 mph		2-3 ft	**Some.** Minor damage to buildings of light material. Moderate damage to banana trees, papaya trees, and most fleshy crops. Large dead limbs, ripe coconuts, many dead palm fronds, some green leaves, and small branches blown from trees.
1	980-992	74-95 mph	82-108 mph	4-5 ft	**Significant.** Corrugated metal and plywood stripped from poorly constructed or termite-infested structures, may become airborne. Some damage to wood roofs. Major damage to banana trees, papaya trees and flesh crops. Some palm fronds tron from the crowns of most types of palm trees, many ripe coconuts blown from coconut palms. Some damage to poorly constructed signs. Wooden power poles tilt, some rotten power poles break, termite-weakened poles begin to snap. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage tron from moorings.
2	965-979	96-110 mph	108-130 mph	6-8 ft	**Moderate.** Considerable damage to structures made of light materials. Moderate damage to houses. Exposed banana trees and papaya trees totally destroyed, 10%-20% defoliation of trees and shrubbery. Many palm fronds crimped and bent through the crown of coconut palms and several green fronds ripped from palm trees; some trees blown down. Weakened power poles snap. Considerable damage to piers; marinas flooded. Small craft in unprotected anchorages torn from moorings. Ecavuation from some shoreline residences and low-lying areas required.
3	945-964	111-131 mph	130-156 mph	9-12 ft	**Extensive.** Extensive damage to houses and small buildings; weakly constructed and termite-weakened houses heavily damaged or destroyed; buildings made of light materials destroyed; extensive damage to wooden structures. Major damage to shrubbery and trees; up to 50% of palm fronds bent or blown off; numerous ripe and many green coconuts blonw off coconut palms; crowns blown off of palm trees; up to 10% of coconut palms blown down; 30-50% defoliation of many trees and shrubs. Large trees blown down. Many wooden power poles broken or blown down; many secondary power lines downed. Air is full of light projectiles and debris; poorly constructed signs blown down. Serious coastal flooding; larger structures near coast damaged by battering waves and floating debris.
4	920-944	131-155 mph	156-191 mph	13-18 ft	**Extreme.** Extreme structural damage; even well-built structures heavily damaged or destroyed; extensive damage to non-concrete cailure of many roof structures, window frames and doors, especially unprotected, non-reinforced ones; well-built wooden and metal structures severely damaged or destroyed. Shrubs and trees 50%-90% defoliated; up to 75% of palm fronds bent, twisted or blown off. Many crowns stipped from palm trees; numerous green and virtually all ripe coconuts blown from trees; severe damage to sugar cane; large trees blown down; bark stipped from trees; most standing trees are void of all but the largest branches (severely pruned), with remaining branches stubby in appearance; trunks and branches are sandblasted. Most wood poles downed/snapped; secondary and primary power lines downed. Air is full of large projectiles and debris. All signs blown down. Major damage to lower floors of structures due to flooding and battering by waves and floating debris. Major erosion of beaches.
5	< 920	>155 mph	> 191	> 18 ft	**Catastrophic.** Building failures; extensive or total destruction to non-concrete residences and industrial buildings; devastating damage to roofs of buildings; total failure of non-concrete reinforced roofs. Severe damage to virutally all wooden poles; all secondary power lines and most primary power lines downed. Small buildings overturned or blown away.

Table 2: Saffir-Simpson Hurricane Scale Ranges with additional Hawai'i damage indications

ing on their maximum sustained wind speeds (intensity), but other characteristics must be considered as well to estimate damage potential and extent as outlined by the State Civil Defense (see Table 2) [State Civil Defense, 2005]).

Overall, hurricanes pose a Variety of threats. The damange potential of a hurricane depends on strength (size of storm), storm life, moving speed and path [The World Meteorological Organization, 1997]. Additionally, it is influenced by the rainfall intensity during the storm. A 'dry' hurricane

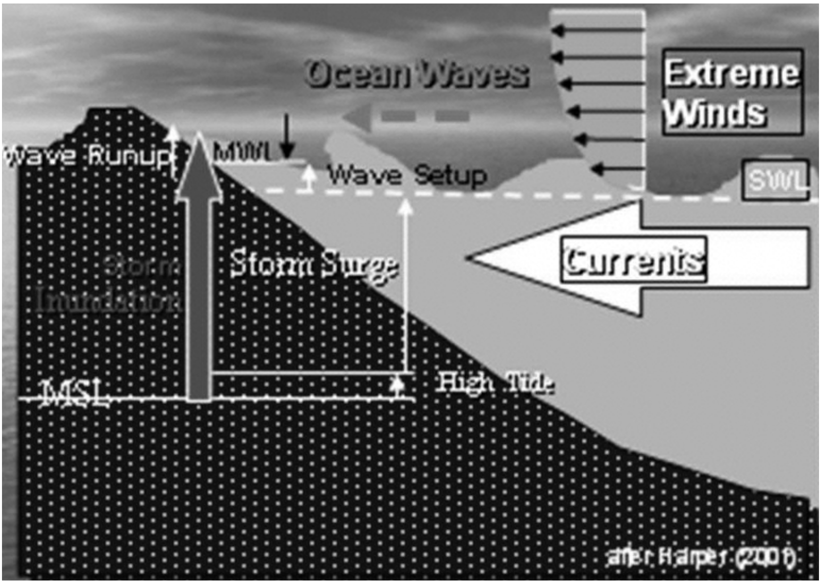

Figure 5: Storm inundation including wave run-up and setup

event does not cause rainfall-related damage such as landslides or flooding. Further threat factors are storm inundation and related surge, astronomical tide, wave setup and wave run-up; high winds and possible magnification by terrain and possible tornados; and heavy rains and associated flash flooding, which can also be terrain enhanced [Browning, 2007b]. Wind gusts within a hurricane may exceed the sustained winds by as much as 50 % [FEMA, n.d.]. Due to underwater topography around Hawai‘i, such as depth and slope steepness, and the large wave setup and wave run up effect (see Figure 5), surf and storm inundation can vary widely. Wind waves associated with a major hurricane may reach 30 feet or more as seen during Hurricane ‘Iniki in Kauai 1992 with high water marks from storm inundation up to 27 foot on the south shore, Poipe, but the storm surge only measured 6 to 9 foot. On O‘ahu, it caused 15 to 20 foot surf with a three to four foot storm inundation. During hurricane Katrina, the cause of the storm inundation was mainly the storm surge due to the size of the hurricane. [Browning, 2007a]. Hurricane Katrina’s maximum storm inundation was 27.8 ft but the National Hurricane Center at Miami speculated that this level was likely exacerbated by extremely large waves offshore. One buoy measured the largest wave ever documented by the National Data Buoy Center at 55 ft. Those uncertainties pose a vulnerability to decision makers in disaster management due to the wide range of damage potential.

1.2 Background on hurricanes

Figure 6 shows the tracks of all Central Pacific hurricanes from 1949 to 1997 [Businger, 1998]. The shading from red to blue is important because 80°F is the minimum Sea Surface Temperature (SST) for hurricane formation. The climatology of hurricane tracks over the central Pacific shows a mean track passing to the south of the Hawai'ian Islands and a maximum hurricane occurrence during the late summer when the ocean surface is warmest (Figure 7) [Businger, 1998]. Hawai'i's hurricane season prevails from June 1st to November 30th, with the highest probability of occurrence in August [Browning, 2007b].

Those are important considerations because the climatic phenomenons of El Niño, La Niña and La Madre that seem to become more and more influencial in the region due to global warming [IPCC, 2007] will influence the hurricane paths, their strength and life time. A warmer climate correlates with an increased frequency and intensity of ENSO events [Mack-

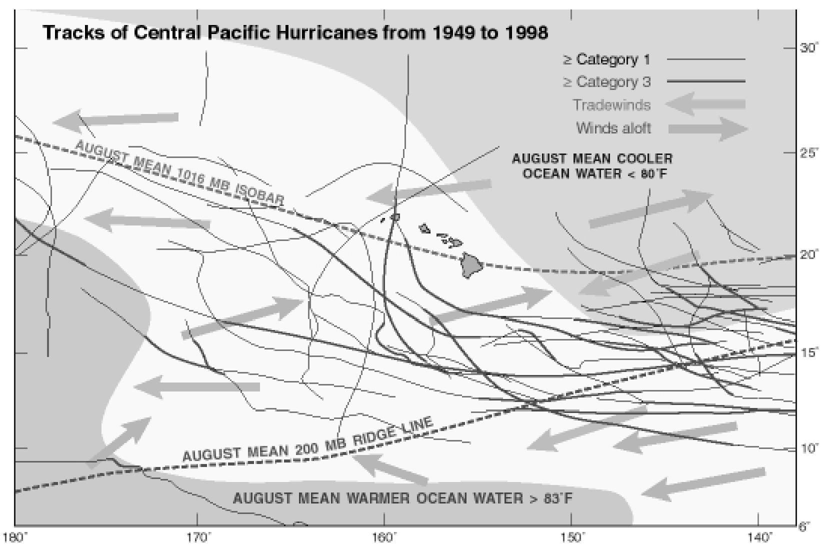

Figure 6: Tracks of Central Pacific Hurricanes from 1949 to 1997

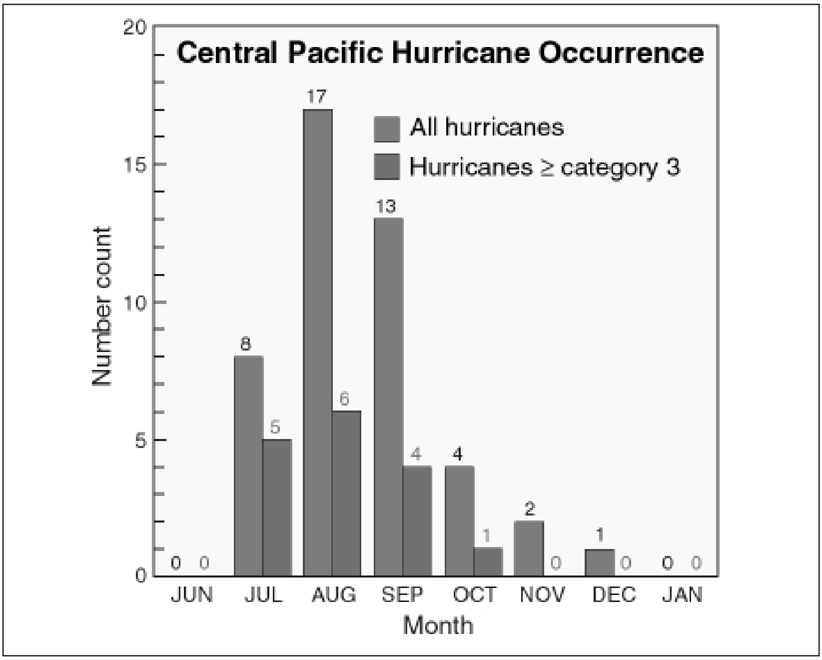

Figure 7: Central Pacific Hurricane Occurrence

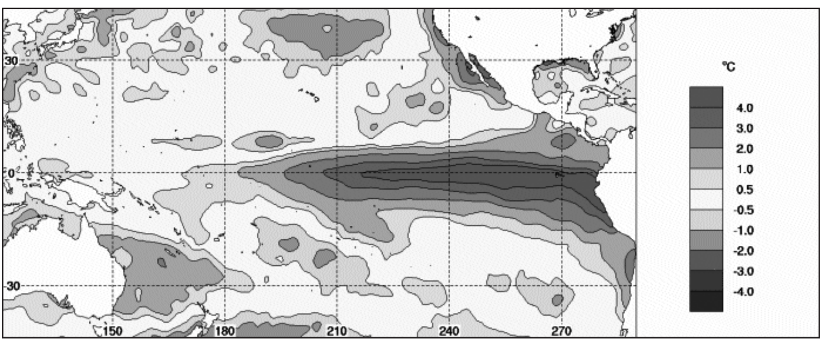

Figure 8: Departures from average ocean surface temperatures in December 1997 at the height of the 1997/98 El Niño

enzie, 2003]. Figure 8 shows the warm SSTs, which developed during the El Niño 1997/98 [Bureau of Meteorology, 2008] and Table 3 suggests that in ENSO years the probability of hurricane development is enhanced in the Pacific (see Table 3) [University of Hawai'i at Mānoa , 1993, p. 53]. Meteorological observations conclude more specifically that during El Nino conditions with warmer waters on the West coast of Mexico more intense and more numbers of hurricanes develop that could potentially threaten Hawai‘i [Browning, 2007a].

Year 19..	70	71	72	73	74	75	76	77	78	79	80	81
Storms	5	5	7*	2	3	1	4*	0	7	0	2	2
Year 19..	82	83	84	85	86	87	88	89	90	91	92	
Storms	10*	6	5	8	7*	4	5	4	4	3	11*	

Table 3: Frequency of hurricane events and correlation with ENSO years
** denotes ENSO year*

Further, a warming atmosphere contributes to sea level rise through expansion of seawater and melting ice on land. These factors further increase the

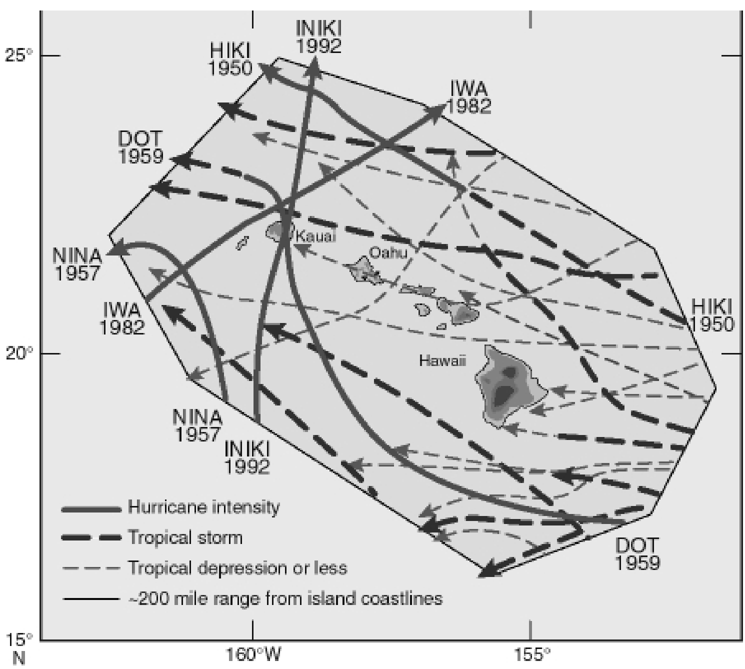

Figure 9: Diagram capturing all tracks of tropical cyclones passing within 3 degree Latitude of the islands between 1950 and 1992. Major hurricanes are named.

vulnerability of Hawai'i's coastlines and enhance the damage potential of hurricanes in Hawai'i. The effects in the Hawai'ian Islands result in worsening of coastal erosion, beach will narrow or be lost, coastal properties and roads will be overtopped more frequently, some lands will become completely submerged and coastal lands will become more vulnerable to coastal hazards including tsunamis, storm surge and high waves.

All major islands in the Hawai'ian Island chain were struck by strong wind storms since the beginning of history. Until 1950 no official data was collected about tropical cyclones approaching Hawai'i. It is only since 1969 that there is geostationary satellites available monitoring storm development in the Pacific. Documents identified storms before that time period, but no exact data on storm intensity and other relevant data are available. From 1832 to 1949, 19 tropical cyclones were identified from scattered written records and ship reports [Shaw, 1981]. Data on hurricane history for the Hawai'ian Islands do not allow the calculation of a statistically significant frequency of tropical storms and hurricanes, but nonetheless show that the islands are at risk. 'Hurricane threats will be frequent and actual strikes will be rare' (see Figure 9) [Businger, 1998][University of Hawai'i, 1993,

Name	**Year**	**Peak winds**	**Winds at landfall**	**Remarks**
Nina	1957		No landfall	Close approach, record Honolulu wind
'Iwa	1982	92 mph	No landfall	Eye Northwest of Kauai
Fefa	1991	105 mph	< 30 mph	Rain producer
Fico	1978	115 mph	No landfall	South of South point
Uleki	1988	120 mph	No landfall	Threatened recurvature
Fabio	1988	125 mph	No landfall	Heavy rains from remote range
Estelle	1986	130 mph	No landfall	Surf damage Hawaii, Maui, rains on Oahu
Susan	1978	138 mph	No landfall	Greatest threat for Hilo
'Iniki	1992	145 mph	130 mph	Direct hit on Kauai
Dot	1959	165 mph	81 mph	Eye over Kauai

Table 4: History of hurricanes in Hawai'i

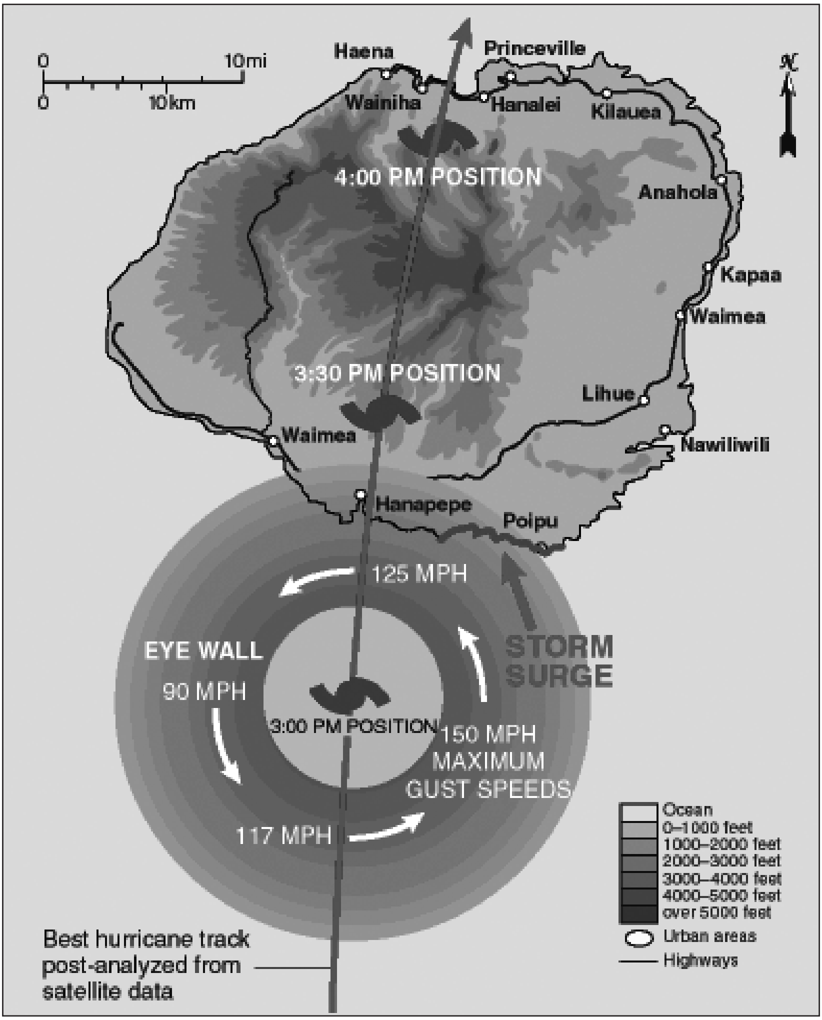

Figure 10: Track of Hurricane 'Iniki 1992

pp. 2]). The hurricane risk for a strong hit or near miss on O'ahu lies at about 1–3 %. This probability seems low, but risk is mathematically constituted by the probability of an event times the magnitude of the consequences of the event. Consequently, the severity of the impacts needs to be considered. As various vulnerability analyses show [Federal Emergency Management Agency, 2007; Reissberg, 2010], those impacts would be catastrophic. Only considering the minimal probability is mis-leading for responsible disaster

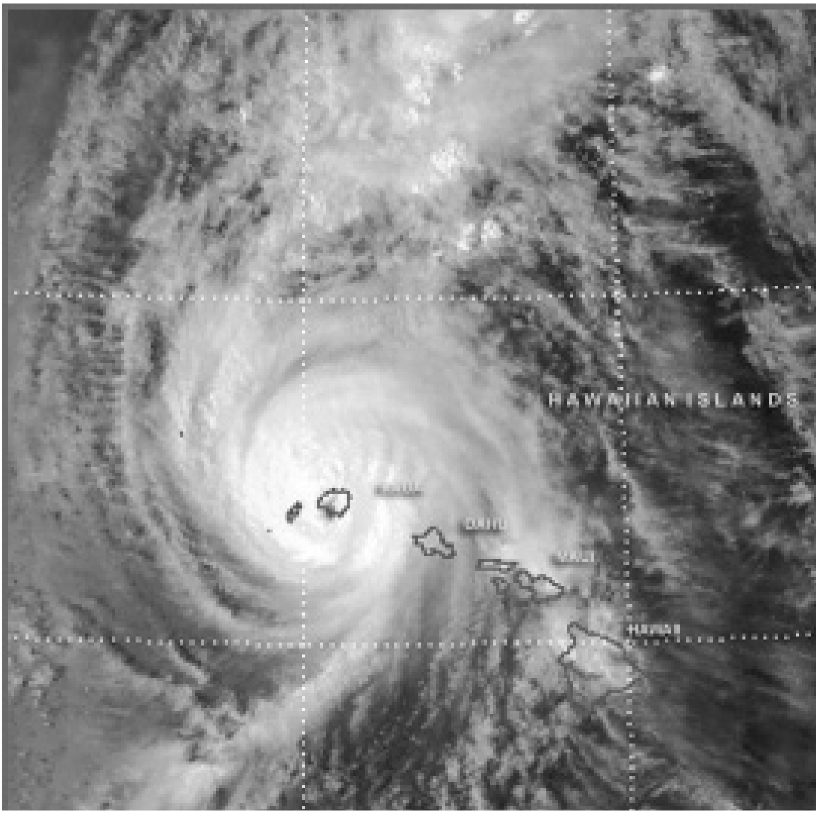

Figure 11: High resolution infrared image of Hurricane ʻIniki

managers as well as politicians. But of course, emphasizing the low probability of High-Impact-Low-Probability (HILP) events comes in handy if long-term expensive measures are not favourable to politicians who want to be reelected, for example.

Kauai received the brunt of Hurricane ʻIwa, which struck on 23 November 1982 and produced an estimated $234 million in damage. Hurricane ʻIniki in 1992 was the most costly disaster in Hawaiʻi, ever [Businger, 1998]. Table 4 shows that hurricane Dot was the strongest hurricane in terms of peak winds, but ʻIniki made landfall with the highest wind speed (130mph) [University of Hawaiʻi at Mānoa , 1993, p. 3]. It is important to note that a hurricane does not have to be a direct hit to cause great damage [FEMA, n.d., p. 1].

By any measure except loss of life, Hurricane 'Iniki, which hit Kauai on Sept. 11, 1992, was by far the worst natural disaster in recorded Hawai'i history [Starbulletin, 2002c]. Figure 10 shows the hurricane track crossing over the island of Kauai [Businger, 1998]. It caused over $1.6 billion in losses to residential property, visitor accommodations, public utilities, public buildings, and agriculture on Kauai. Six months after the storm the unemployment rate was still over 16 %. Kauai County lost an estimated $14 million in property tax revenue during 1993 and 1994. Property losses from 'Iniki also precipitated a statewide property insurance crisis, the bankruptcy of one insurance company, and the cancellation of over 40,000 property insurance policies [University of Hawai'i at Mānoa , 1996]. Figure 11 shows the hurricane making landfall on Kauai at 3:15 PM HST on 11 September 1992. The image was taken by a NOAA polar orbiting satellite about 500 miles above the Earth [Businger, 1998].

O'ahu is much more vulnerable than Kauai and costs will be enourmous. It cannot expect resource support from the other Hawai'ian Islands due to their dependency on O'ahu's resources and the fact that they will be impacted to some degree as well. Because of the technical condition of their harbors, containerships are offloaded on O'ahu and resources are barged to the other islands [FEMA, 2007]. During hurricane 'Iwa (1982) and 'Iniki

Figure 12: Aerial photograph of debris line on Kauai after Hurricane 'Iniki 1992

Figure 13: Category 4 destruction on Kauai

Figure 14: Flying debris during Hurricane 'Iniki 1992