

Impacts of Global Climate Change on Hawaii and Implications for Mitigation and Management

University of Hawaii at Manoa
Department of Urban and Regional Planning
Professor Dr. Makena Coffman

Adam Ayers, Kawika Burgess, Willow Hetrick, Brandi Kokubun, Shem Lawlor, Elsj
Manginsela, Erin Marquez, Brianna McDowell, Austin Shelton, Kristen Shon

*Authors listed in alphabetical order

Introduction

When addressing the impacts of climate change for Hawaii, there are several issues that should be addressed by all levels of governance in order to effectively plan and prepare for the future. The primary impacts of climate change are sea level rise and warming temperatures. These factors can have numerous detrimental effects on Hawai'i through breaches in infrastructure such as saltwater backing up storm drains, placing sewer lines at risk, saltwater flooding roads and highways, severe weather; wetland loss or alteration in structure and function, and salt water inundation of some aquifers, agriculture, and ecosystems.

This paper presents several key issues that need to be addressed in order to better prepare the state for the impacts of global climate change. Because there is no current national policy to address these issues, it is up to state and local governments to develop policy and management plans that can mitigate, manage, and plan for these impacts. We have outlined three major issues including sea level rise, severe weather impacts, and impacts to wetlands as major issues that must be addressed when planning for Hawai'i's future and climate change.

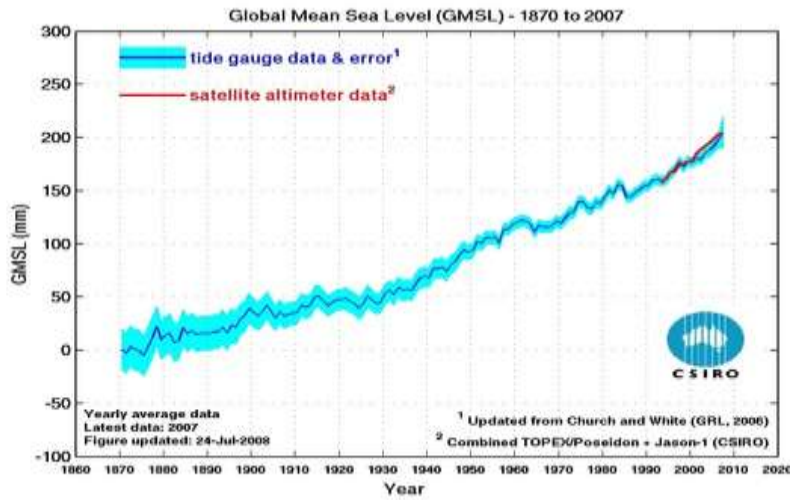
I. Sea Level Rise and Oahu

There is ample scientific evidence that the world's oceans are rising. Average global sea levels are about 200 mm (8 inches) higher today than they were in 1870 (White, 2008). Most of the rise in sea level is due to thermal expansion (water increasing in volume as it warms) but increased melting of ice sheets in the world's polar regions are also increasing the mass of water in the world's oceans.

There is some uncertainty as to exactly how quickly the oceans will rise in the future due in part to the great difficulty in modeling how quickly polar ice sheets melt. Scientific predictions vary from 18 to 59 cm of sea level rise by the year 2100 over 2000 sea levels (IPCC, 2007).

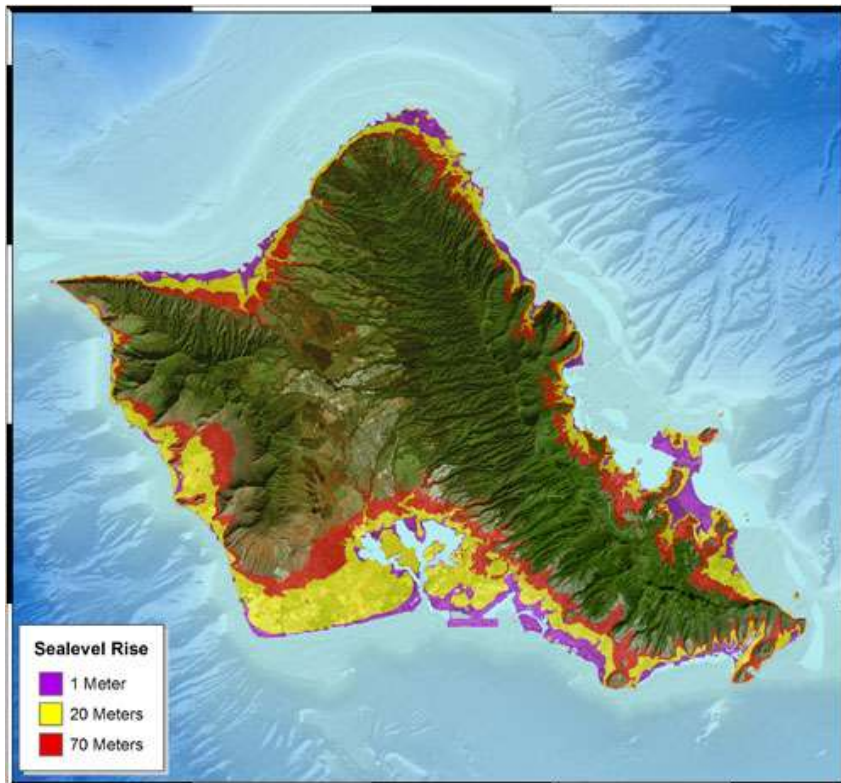
What will be the effect on Hawaii's islands as sea levels continue to rise? With a change in sea level, there are many areas on the island of Oahu that will be greatly affected (Figure 1).

Figure 1. Global mean sea level from 1870 to 2007. Available satellite data correspond and agree with tide gauge data, allowing scientists to use remote sensing to track the increase in sea level.



The purple areas on the map are those locations which will be under water if the sea level increased by one meter. Much of Honolulu International Airport's runways, Sand Island, Mapunapuna, Downtown, Kaka`ako and Waikiki would be under water. So also would parts of Hawaii Kai, Ewa Beach, Haleiwa, Laie, and Kailua. This will put tremendous strain on these coastal areas of Oahu. Beaches would be lost, sewers would be inundated, streets would be submerged and homes would be ruined.

Figure 2. Estimates of one meter, 20 meter and 70 meter sea level rise on Oahu.



Sea level rise is due to a number of causes, some of which may exert a more regional influence than others. These include Edalin Michael "Sea Level Rise"
<http://www.wunderground.com/climate/SeaLevelRise.asp>

Thermal expansion

As seawater becomes warmer it expands. Heat in the upper layer of the ocean is released quickly into the atmosphere. However, heat absorbed by the deeper layers of the ocean will take much longer to be released and therefore, be stored in the ocean much longer and have significant impacts on future ocean warming. An increase in freshwater inputs from mountain glaciers, ice sheets, ice caps, and sea ice, as well as other atmospheric and hydrologic cycles due to rising global surface and ocean temperatures

Physical forces

Subsidence and lifting are associated with tectonic activity and the extraction of water and resources such as gas and oil. These types of forces don't actually change the volume of the ocean, only the relative sea level. However, these changes do affect movement over land, as well as estimates from satellite altimetry. For example, in Scandinavia's Gulf of Bothnia, the weight of glaciers had caused the land beneath it to compress and sink. Now that glaciers are melting and the pressure has been released, the region is lifting at a rate of as much as 11 mm per year. This rebound makes it seem like sea level is dropping even though it is actually rising by 2.1 mm per year Milne et al. (2001) "Space-Geodetic Constraints on Glacial Isostatic Adjustment in Fennoscandia" *Science* 291(5512):2381-2385. .

Ocean current variations

Large, regional ocean currents which move large quantities of water from one location to another also affect relative sea level without changing the actual volume of the ocean. For example, el Niño moves water from one side of the Pacific to the other every three or four years. These large-scale variations also affect the relative sea level of certain areas. In normal conditions, trade winds blow across the Pacific toward the west. According to [NOAA](#), the trade winds push warm surface water to the west Pacific, so the sea level is roughly 1/2 meter higher in Indonesia than it is in Ecuador. During el Niño years, this warm water is pushed over to the eastern Pacific. Atmospheric pressure influences sea level by impacting the surface itself. This also only affects relative sea level as the water pushed out of one place will move to another.

II. Severe Weather Conditions in Hawaii

Tropical Cyclones (Hurricanes)

While tropical cyclones are generally a rare occurrence, there are roughly 80 per year worldwide. The limited occurrence of tropical cyclones is due to the fact that there are six factors that need to come together in order to produce a tropical cyclone:

1. Warm waters (80° F or more)
2. Low variation of winds with height
3. Latitude high enough for spin
4. Deep moist atmospheric layer
5. Instability to allow thunderstorms to develop
6. A pre-existing disturbance

While the occurrence of tropical cyclones is rare, the impacts of tropical cyclones on populated areas can be devastating. A category 3 storm will generate winds of 111 to 130 mph, and a category 5 will generate winds over 156 mph. (Schroeder, Thomas. 2008. *The Hurricane Future*)

Heavy Rains

In the spring of 2006, Oahu was given a preview of disasters which may happen due to sea level rise as a result of global climate change. Rain poured down on Honolulu and other parts of Oahu for 40 days and 40 nights. Sewer lines ruptured throughout the island. The most notable break was in Waikiki. In order to prevent raw sewage backup into Waikiki streets and hotels, the Honolulu mayor ordered that the sewage be diverted into the Ala Wai canal. An estimated 48 million gallons flowed through the canal and out to the ocean (Dingeman 2006).

The most notorious event of the 2006 spills was the infection and death of a 34-year old man who fell into the contaminated waters of the Ala Wai Boat Harbor. It is believed, but not proven, that he died from a bacterial infection that led to septic shock and organ failures throughout his body (KHNL 2006).

Honolulu's water tables are extremely close to the land surface. There is a great possibility that with a slight increase in sea level, the water will push up through the ground surface destroying roads and breaking sewage lines. Transportation would be greatly affected, and human health and safety would be jeopardized. Damaged roads will lead to increases in traffic congestion as vehicles travel on roads at higher elevations. Sewer spills will lead to serious sanitation problems in housing areas. Raw sewage may seep into drinking water supplies. Sewage leakage into the ocean will increase nutrient levels and create anoxic zones which will lead to fish die-offs and coral bleaching. It is estimated that at the current rate of sewage spills, 5,500 people nationwide get sick each year from direct exposures near beaches (Wheeler 2008).

The impacts of Climate Change on Tropical Cyclones

Recent studies have indicated that there has been an increased duration of intense tropical cyclones in the Atlantic and Northwest Pacific, as well as increased frequencies in category 3-5 storms in all basins globally. Sea level is also rising at a rate of 3.75 mm/year globally. (Emmanuel, Kerry. 2007. *What We Know About Climate Change*). While there has been little change in sea level in Hawaii to date, sea level is likely to rise in the next 50 years.

As a result of increased frequency and intensity of tropical cyclones, as well as the threat of sea level rise, Hawaii is increasingly susceptible to tropical cyclones. One of the major breeding

grounds of tropical cyclones is located in the eastern Pacific Ocean off the coast of Mexico and Central America. The Central Pacific averages about 4.4 tropical cyclones per year. The tropical cyclone season is from June 1 through November 30. There is currently a 1 out of 15 chance of hurricane winds somewhere in Hawaii every year. As sea levels rise, and global sea temperatures increase, Hawaii could be more susceptible to the triple threat of tropical cyclones; high waves and storm surges, high winds, as well as heavy rains and flash flooding. (Central Pacific Hurricane Center)

Hurricane Iniki - The Third Most Destructive in US

In United States history, Hurricane Iniki is the third most destructive hurricane which hit the Hawaiian islands in this century. Forming during the El Niño of 1991-1994, Iniki was one of eleven Central Pacific tropical cyclones during the 1992 season. At the time it was the costliest hurricane in US history costing \$1.8 billion dollars (1992 dollars) and causing six deaths. To this day, it still remains one of the most costliest occurring within the eastern Pacific.

The Central Pacific Hurricane Center (CPHC) failed to issue tropical cyclone warnings and watches for the hurricane more than 24 hours in advance. It is remarkable that despite the lack of early warning, only six deaths were attributable to the storm. Damage was greatest on Kaua'i, where the hurricane destroyed over 1,400 houses and severely damaged over 5,000. Though not directly in the path of the hurricane's core, O'ahu still experienced moderate damage from wind and storm surge.

In the months after the storm, many insurance companies left Hawai'i. To combat this, State Governor John D. Waihee III enacted the Hurricane Relief Fund in 1993 to help unprotected Hawai'i residents. The fund was never needed for another Hawai'i hurricane, and it was stopped in 2000 when insurance companies returned to the island. Folk legend states that Hurricane Iniki blew apart many chicken coops, some possibly used to house fighting chickens; this caused a dramatic increase in the numbers of wild chickens roaming Kaua'i.

The name Iniki was retired due to this storm in 1993, and was replaced with Iolana in the Central Pacific storm list. Because that list is rotated through regardless of year, Iolana has not been used for any storm and is not likely to be used for decades due to the relative rarity of storm formation in the Central Pacific.

Evacuation plans/suggestions

In examining Honolulu's hurricane evacuation plan, there is no mention of any specific methods that address how vulnerable populations will be evacuated. Shelters are identified and preparation reminder lists are posted, but there is no mention of how the elderly, disabled, and those below the poverty line will be transported to shelters, or who may take care of them once they arrive.

When looking for best practices to emulate, the government preparation and response to Hurricane Gustav should be examined. In advance of Category Four Hurricane Gustav, all levels of government were eager to ensure that the mistakes made before, during, and following the landfall of Hurricane Katrina were not repeated. Residents with no access to personal transportation were bused, ferried, and even flown to areas outside of the storm's impacts. The state of Texas provided a C-130 aircraft to help fly residents with special needs out of state to receive care and assistance. In total, 90% of southern Louisiana (1.9 million people) was evacuated. Although Gustav did not make landfall with its forecasted intensity, the evacuation exercise shows how collaboration between all levels of government can ensure another atrocity like Katrina is averted.

The City and County of Honolulu should emulate this type of planning and response in their evacuation plan. Since the island of Oahu has such a large military presence, military buildings, planes and resources could be employed to help shelter citizens or even fly them to another island or the mainland in advance of the storm. Agreements could also be put in place to commandeer the various Superferry boats to transport people off the island of Oahu. City buses could also be used to evacuate low-lying areas and vulnerable populations to storm shelters. Additionally, storm shelters must be adequately staffed and structurally sound to protect citizens. Plans must be made ahead of time along with a public information campaign to make citizens aware of the various government evacuation options available to them before a hurricane makes landfall, especially those that are most vulnerable to the storm's effects.

Disaster preparedness

Preparing for disaster is an important precautionary measure when and if a disaster were to occur. Not knowing what to do is the worst thing that can happen, and may result in deadly situations. Acting promptly and efficiently can give you and your family the ample time, food, and money you need in order to survive.

Here are some disaster plans for Hawaii that can help you prepare for the unexpected. There are four simple steps to preparedness.

- 1) Get informed. Contact Hawaii's emergency management office or Hawaii's Red Cross chapter to gather information to create a plan. Ask about specific hazards that threaten your community and about your risk from those hazards.
- 2) Make a plan. Meet with your family members, choose an "out-of-town" contact, decide where everyone should meet, discuss escape routes and safe plans, and complete a family communication plan.
- 3) Assemble a disaster supplies kit. This should contain a three-day supply of nonperishable food and manual can opener, three-day supply of water, portable (battery-powered) radio or television with extra batteries, flashlight, first aid kit and manual, sanitation and hygiene items, matches, extra clothing, blankets, kitchen accessories and cooking utensils, photocopies of identification and credit cards, cash and coins, prescription medications, eye glasses, contact lens solution, hearing aid batteries, items for infants, tools, pet supplies, map of local area, and any other needs that are unique to your family.

4) Maintain your plan. Review the plan every six months. Conduct fire and emergency evacuation drills on a regular basis. Restock food supplies for expiration dates and discard or replace stored water and food every six months. Test the indicator on your fire extinguisher and replace every ten years.

You also want to know where the shelters are in your neighborhood. There are also many shelters on O'ahu, as well as the neighbor islands that families can go to in the mist of a disaster. Many of the local schools are used as shelters, but the problem with that is many of the shelters may not be able to hold the capacity it demands.

Vulnerable populations in the City and County of Honolulu

According to the IPCC, vulnerability refers to a “function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system” (IPCC, 2007). Therefore vulnerability cause by climate change will affect people differently in different places. Studies have proven that climate change-related hazards can affect people’s lives differently based on their age (Tol et al., 2004 and Bunyavanich et al., 2003), disabilities, and level of income (Adger and Kelly, 1999; Handmer et al., 1999). Children, senior citizens, people with disabilities, and poor people are more vulnerable than other groups that do not share these attributes. To increase their adaptive capacity and enhance their resilience, government can play a role to provide disaster preparedness plan and warning systems as well as evacuation procedures (IPCC, 2007).

In 2007, the total number of vulnerable people in the County of Honolulu is 373,652, or 41.26% (Table 1.) Considering that this number is more than two fifths of total population of the City and County of Honolulu, state government agencies must take these groups more seriously in helping them face climate change-related hazards. The government agencies (federal, state, and county) as institutions, in collaboration with non-government agencies, have formulated a pre-disaster plan to address their needs for special assistance.

Table 1. Number and percentages of vulnerable people by group type in the City and County of Honolulu for 2007 (U.S. Census Bureau, 2007 American Community Survey)

Type	Number	Percent
Children	63,646	7.00%
Senior Citizens	134,155	14.80%
Disabled	107,025	13.40%
Poor	68,826	7.60%
Total Population	905,601	100%
Total vulnerable people	373,652	42.80%

As Hawaii’s state government agencies have recognized the needs of these vulnerable groups, they provided an emergency preparedness plan for disabilities (physical, learning, seeing, and hearing) in a document titled “The State of Hawaii 2008: Interagency Action Plan on Emergency Preparedness for Persons with Disabilities”. It can be accessed on The Hawaii State Department

of Health website (<http://www.state.hi.us/health/dcab/emergencyprep/index.htm>), and a guideline for the disabilities and senior citizens can be accessed on the Red Cross website (http://www.redcross.org/services/disaster/0,1082,0603_,00.html).

According to Peter J.S. Hirai, the Deputy Director of Department of Emergency Management in City and County of Honolulu, the government assumes that children have adult caregivers. So emergency preparedness messages are targeted towards adults, while for the poor people including the homeless, the government will give them equal attention in evacuation assistance and provide shelters if necessary (personal communication over the phone and email on November 26, 2008).

III. The Roles of Wetlands in Climate Change Planning

“Wetlands are broadly defined as a variety of shallow water bodies and high groundwater environments that are characterized by permanent or temporary inundation, soils with hydric properties, and plants and animals that have adapted to life in saturated conditions” (Bergkamp and Orlando 1999). Wetlands include, for example, floodplains and riparian areas along rivers and lakes, upland areas that are covered with peatlands, tundra areas, and coastal areas affected by the daily sea level fluctuations, such as sea grass beds, mangroves, and tidal salt and freshwater marshes (Matthews 1993).

Wetlands have been ranked as one of the Earth’s most valuable ecosystems and are often referred to as “nature’s kidneys”. Wetlands provide habitat, reduce runoff, treat water, and increase groundwater recharge. Wetlands also play a large role as a greenhouse gas source and sink. There has been a dramatic loss of wetlands from the conversion of land to agriculture and urban development, as well as invasion of non-native species and pollution. In addition, inland and coastal wetlands are faced with numerous detrimental consequences caused by climate change’s affects on the natural hydrological cycle, warming temperatures, and sea level rise. Through conservation and mitigation efforts, these valuable areas can contribute not only to preserving biodiversity and increasing water quality, but also to decreasing the detrimental effects of global warming. It is essential that wetlands become part of the planning process for reducing the impacts of climate change.

The Current State of the World’s Wetlands

Global estimates of wetlands range from 7-9 million km², or 4-6% of the Earth's surface (Maltby and Turner, 1983; Aselman and Crutzen 1989). Of this, 56% occurs in tropical or subtropical regions (Mitsch and Gosselink 2007). An alarming amount of the original wetlands have been lost due to population growth and the demands that go along with it such as agriculture, infrastructure, and water demand. It is estimated that there has been at least a 50% loss of the world's original wetlands (Dahl 1990). In areas such as Europe, New Zealand and Iraq, losses exceed 90% (Moser et al. 1996). Global climate change and the demand for biofuels pose new challenges to wetlands.

Wetland Functions and Values

A wetland can provide numerous functions that present economic, social, and environmental values. An estimated \$15.5 trillion in ecosystem services is provided by wetlands per year (Bergkamp and Orlando 1999). These wetland functions and values are dependent upon site-specific environmental and socio-economic factors. In general, a healthy wetland provides wildlife habitat, water cleansing and storage, and biogeochemical transformations. Ascribed to these functions are recreational, educational, medicinal, agricultural, cultural, public safety, and global climate change values.

Due their wide range of ecological niches, wetlands are highly diverse. Over 10,000 fish species, 4,000 amphibians, and numerous waterfowl inhabit wetlands globally (Bergkamp and Orlando 1999). Wetlands employ activities of microbes, media, and plants to treat water. This action can significantly reduce total suspended solids, nutrients, metals, organics, and pathogens. Wetlands have been found to retain up to 100% of the metals present in water (Kadlec and Knight 1996). Nutrients are processed through bacterial denitrification and plant uptake. Vegetation stabilizes soil, preventing erosion, and trapping sediments, as well as other pollutants that settle within the wetland rather than nearby waterbodies. Wetlands are also effective at slowing water velocity, decreasing runoff momentum and increasing infiltration by allowing more time for settling (Kadlec and Knight 1996; Lehner et al. 1999).

Wetland diversity gives rise to numerous resources for direct human consumption including: water for drinking; food such as fish, cranberries, and rice; reeds and timber for construction; and peat and fuelwood for fires. Fishing, hunting, water sports, and aesthetic and spiritual opportunities are also offered by wetlands (Bergkamp and Orlando 1999). Wetlands lessen the impact of extreme weather events by serving as a natural buffer zone against wind, wave, and current energy, reducing the effects of tropical storm surges and hurricane impacts. They also act to limit salt water intrusion in freshwater systems and decrease erosional forces associated with rising sea levels (Twilley 2007).

Wetlands: A Greenhouse Source and Sink

Wetlands cover 3-6% of the world's land surface, and contain 10-20% of the global terrestrial carbon. This is three times greater a carbon sink than forests (GACGC 1998). The conversion of wetlands to other land uses, such as biofuel production, has contributed to the release of large amounts of stored carbon (WI 2008). Depending on the size and type of wetland, mineralization from drained wetlands can generate from 2-40 t C ha⁻¹ yr⁻¹ (Bergkamp and Orlando 1999). In South-east Asia, carbon emissions from wetland conversion exceeds fossil fuel contributions of greenhouse gases from major polluting countries (WI 2008). In addition, due to the anoxic conditions and high primary productivity of wetlands and rice fields, 15-40% of the total global source of methane is produced (Kusler 2006; Bergkamp and Orlando 1999)

Climate change factors that will affect wetlands

Sea-level rise, warming temperatures, and an alteration of the hydrological cycle are expected to impact wetland services. Water availability and quality are expected to shift the geographical distribution of wetlands and alter their functions. In turn, drinking water, food production and other wetland services are more vulnerable (Kusler 2006; Bergkamp and Orlando 1999).

Current predictions estimate an increase of 2 degrees Celsius globally (Bergkamp and Orlando 1999). Water temperature regulates oxygen and carbonate solubility, viral pestilence, pH and conductivity and photosynthesis and respiration rates of aquatic organisms (IPCC 2007). These effects challenge the adaptive capabilities of sensitive species.

Wetlands are highly dependent on water levels. Flooding and rising sea-levels will contribute to wetland loss or the migration of wetlands inland. Aquatic communities will shift depending on their tolerance to changing salinity, light penetration, and water depth. Sea-level rise may also contribute to increased storm surges and tidal ranges, increasing coastal erosion, causing property loss or damage, as well as habitat denudation and alteration (Twilley 2007). Sea levels are expected to rise between 0.18 and 0.59 m within the century (IPCC 2007). The U.S. Environmental Protection Agency (EPA) has estimated that a 0.6 m rise in sea level could eliminate 17-43% of the United State's wetlands (EPA 1989).

Shifts in the hydrological cycle will alter precipitation, evapotranspiration, runoff, and groundwater recharge and flow. Precipitation is expected to vary, decreasing in some areas, while increasing in others. Extended periods of drought can lead to desiccation of wetlands (Twilley 2007). Intense rainfall, on the other hand, will bring sediments to, or erode sediments from wetlands (Kusler 2006). Soil accretion from storms and increased precipitation are likely to shift wetland type or increase the development of new wetlands in some areas (Kusler 2006; Twilley 2007). Aquatic species spawning, migration, composition, and food chain support are likely to be impacted from changes in the frequency, duration, and timing of hydroperiods and nutrient fluxes (Crance 1988).

Under natural conditions, wetlands are capable of adapting to increasing salinity and sea-level rise through inland migration. Adaptation will greatly depend on species dispersal and migratory abilities. Human alteration of wetland hydrology and biogeochemical cycling will make these adaptations difficult (Twilley 2007). Many coastal areas are fragmented by human land uses such as transportation, residential, and industrial areas. Coastal barriers and reservoirs also limit the ability of wetlands to migrate.

Wetland Planning and Policy Implementations

Wetlands are a valuable resource and should be part of climate change planning and policy. Wetlands provide many important functions in urban and natural areas and are highly valued for the services they provide. If current activities continue, sea level rise will eventually threaten most coastal ecosystems in the United States. It is urgent to implement a policy, not because there is an impending loss of wetlands but because we may miss the opportunities to inexpensively prevent an eventual catastrophic loss if we do not act soon. Many wetlands could be saved through a gradual abandonment of coastal lowlands. A complete abandonment is highly unrealistic due to existing property owners and developments in place. It is necessary to decide the level of wetland protection that is desirable, keeping in mind that plan and policy implantations may not work in all areas; they must be tailored or allowed to change depending in the location. Several management and policy measures can be applied to increase resiliency and decrease degradation of wetlands and suggestions for policymakers, urban, land-use, and environmental planners, and managers. Although state and local governments often serve as proving grounds for the new strategies, national legislation is necessary. It is Legislation would need to be like the Coastal Zone Management Act (which encourages sound planning) or the

Clean Air Act (which sets absolute limits to environmental degradation). But regardless of the level of federal involvement, there needs to be a national goal.

It is necessary to increase conservation and mitigation, with priority in preservation of natural wetlands. If the existing wetlands can be preserved, the natural ecosystem balance will also be preserved and allow for a continuation of wetland services. By delineating boundaries around wetlands, succession can occur as sea levels rises. Planners and policymakers must be aware of existing and potential wetlands, keeping in mind that destruction or change of the current state can be detrimental to local communities.

Where development has already occurred, it is important to plan to link fragmented wetlands to provide corridors for plant and animal migration, and maintain water and sediment flow. Allowing for this exchange will preserve already existing wetlands, and allow for new ones to form in areas that would benefit. Setbacks and land purchases must be enacted before an area is developed, and where areas are already developed, once the land is vacant, they setbacks must be in place.

All of these suggestions can be a reality by planners and policymakers by aiming to develop partnerships with land conservation agencies. Programs that purchase land and preserve it will benefit the local and national community immensely. Legislation must be in place to implement protection services, and the knowledge of these services and opportunities must be effectively communicated to the public. Raising public awareness and landowner's involvement will prove to be effective in any plan and policy implementation. Involving federal, state, and local governments in land management will help develop legislative strategies to provide authority for planning and land use regulation. By provide decision support tools for improving habitat restoration programs, cooperation between agencies will be easier to reach and practice in the long run. New and innovative ideas must be created and practiced in order to successfully change regulations along with our changing planet. Such ideas could be the use of tax breaks or payments for conservation easements. It is also necessary to work alongside scientists to develop and design criteria used to prioritize projects, while at the same time seek funding for projects that plan for and address sea level rise in their design. A bridge between science, planning and policy will support wetland protection and restoration. If the United States government were to undertake a national study of the costs, benefits, and profitability of success for various options for protecting the nation's natural shorelines, our nation would be one step closer to effectively managing our declining wetlands. Although it may seem difficult to implement all of these suggestions, it is important to note that it is not easier to accept a world in which these ecosystems are lost as we invest ever-increasing sums to hold back a rising sea.

Conclusions

Although there are uncertainties that exist concerning the impact of climate change on wetlands and the role of wetlands in climate change, there is enough scientific knowledge to suggest that wetland functions are of great importance to society, including long-term carbon sequestration. Potential impacts on wetlands and their functions as carbon reservoirs should be factored into discussions by scientists, planners, and policy makers that are assessing the broader range of possible climate change impacts, when modeling climate change, and when developing

realistic international measures for carbon debits and credits. A comprehensive management strategy that encompasses a variety of options for protecting and restoring wetlands is necessary to better achieve other existing wetland management goals and to reduce and compensate for possible climate change impacts.

While it is unclear what impact climate change will have on extreme weather events in Hawaii, increases in both global atmospheric and ocean surface temperatures suggest an increase in frequency and intensity in hurricanes is possible. With the threat of increased severe weather events, evacuation plans must be amended to include partnerships with military and private business and shore up any gaps not filled by city, county, and state governments. Securing such agreements will help to ensure that all citizens are taken care of, especially vulnerable populations. However, the government cannot manage all aspects of disaster preparedness. It is the personal responsibility of all citizens to stay informed, make a disaster plan and keep it updated, and create a disaster supply kit well ahead of a storm's landfall. Following these recommendations should help the City and County of Honolulu to become more resilient to severe weather risks posed by climate change and sea level rise today and into the future.

References

- Adger, W. N. and Kelly, P. M. 1999. Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change*, **4**:253-266
- Aselmann and P.J. Crutzen. 1989. Global distribution of natural freshwater wetlands and rice paddies, their net primary productivity, seasonality and possible methane emissions. *Journal of Atmospheric Chemistry*, **8**(4): 307-358.
- Bergkamp, G. and Orlando, B. 1999. Wetlands and Climate change, Exploring Collaboration between the Convention on Wetlands (Ramsar, Iran 1971) and the United Nations Framework Convention on Climate Change, *Background paper, IUCN - The World Conservation Union*.
- Bunyavanich, S., C. Landrigan, C., McMichael, A.J., and Epstein, P.R. 2003: The impact of climate change on child health. *Ambulatory Pediatrics*, **3**: 44–52.
- Crance, J.H. 1988. Relationships between palustrine wetlands of forested riparian floodplains and fishery resources: a review. *U.S. Fish and Wildlife Services*, **88**(32).
- Dahl, T.E. 1990. Status and Trends of Wetlands in the Conterminous United States 1998 to 2004. *U.S. Fish and Wildlife Service*. Fisheries and Habitat Conservation. Washington, D.C.
- Dingeman, R. Raw sewage spill largest in 20 years. Honolulu Advertiser. April 1, 2006.
- EPA, 1989. The Potential Effects of Global Climate Change on the United States. Report to Congress. Washington, D.C. *U.S. Environmental Protection Agency*. EPA 230-05-89-052.
- GACGC, 1998. The accounting of biological sinks and sources under the Kyoto Protocol: A step forwards or backwards for Global Environmental Protection? *German Advisory Council on Global Change, Special Report*, Bremerhaven.
- Handmer, J. W., S. Dovers and T. E. Downing. 1999. Societal vulnerability to climate change and variability. *Mitigation and Adaptation Strategies for Global Change*, **4**: 267-281.
- IPCC, 2007. Working Group II Report "Impacts, Adaptation and Vulnerability". *Intergovernmental Panel on Climate Change Fourth Assessment Report*. Retrieved on November 25, 2008 from <http://www.ipcc.ch/ipccreports/ar4-wg2.htm>.
- Kadlec, R.H., and R.L. Knight. Treatment Wetlands. 1996. Lewis Publishers: New York.
- KHNL. Man who fell into polluted Ala Wai dies. KHNL News 8. April 7, 2008.
- Kusler, J. 2006. Wetland, Climate Change and Carbon Sequestering. Association of State Wetland Managers.

- Lehner, P., Clark, G. P. A., Cameron, D. M., Frank, A. G. 1999. Stormwater Strategies Community Responses to Runoff Pollution. *Natural Resources Defense Council*. Retrieved October 20, 2008, from <http://www.nrdc.org/water/pollution/storm/stoinx.asp>.
- Maltby, E. and R.E. Turner. 1983. *Wetlands of the World*. Geographical Magazine, **55**(1): 12-17.
- Matthews, G.V.T. 1993. The Ramsar Convention on Wetlands: Its History and Development (Ramsar Convention Bureau). *International Wildlife Law*, 183–207.
- Mitsch and Gosselink. 2007. *Wetlands, Fourth Edition*. John Wiley and Sons, Hoboken, New Jersey, USA.
- Moser, M. C. Prentice, and S. Frazier. 1996. A Global Overview of Wetland Loss and Degradation. *Wetlands International*. Retrieved November 22, 2008, from http://www.ramsar.org/about/about_wetland_loss.htm.
- Twilley, R.R. 2007. *Coastal Wetlands and Global Climate Change: Gulf Coast Wetland Sustainability in a Changing Climate*. Arlington, VA: Pew Center on Global Climate Change.
- Wheeler L, Smith G. Pipeline of trouble: Aging sewer systems pose threat to health. USA Today. May 8, 2008.
- WI 2008. *Wetlands for water and life*. Wetlands International. Retrieved November 28, 2008, from <http://www.wetlands.org/Whatwedo/Projects/WetlandsandBiofuels/tabid/1253/Default.aspx>.