

Drivers and sediment dynamics in Maunalua Bay, O‘ahu, Hawai‘i.

A case study prepared for Mālama Maunalua and the Maunalua community.



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Introduction

Maunalua Bay is located on the southeastern shore of O‘ahu, Hawai‘i between the two points of Kūpikopiko and Kawaihoa. Including eight miles of shoreline and over six square miles of ocean waters, the bay was historically a productive source of sustenance to residents before the 1960’s. The bay is characterized by its coral reef and seagrass bed habitat, home to many species of fish including surgeonfish, parrotfish, goatfish, squid and eels. An occasional Hawaiian Monk Seal can be spotted as well as endangered Hawaiian water birds including the *Ae‘o* (Hawaiian Stilt) and the *Alae‘ula* (Hawaiian moorhen) (Mālama Maunalua, 2009).

Maunalua Bay has a rich history of biological and cultural significance dating back to times of the beginning of Native Hawaiian residency. Kuapā, a fish pond that still currently resides in the watershed of Maunalua Bay, was part of a system that fed the native residents. In 2009, the bay is housed to over 60,000 residents (Atkinson, 2007). There is an additional attraction to the bay for O‘ahu residents and visitors to enjoy fishing, boating, diving, parasailing, windsurfing, jet skiing, and surfing.

The increased use and population within the Maunalua Bay Watershed adds pressures to the system that have altered the natural environment. As a result of urban development, population increase, increased fishing pressure, the bay has been declared as an impaired water body by Department of Health under the Clean Water Act (CWA) Section 303(d) (Mālama Maunalua, 2009).

In the Natural Resources and Environmental Management program at the University of Hawai‘i, our Economic Analysis of Natural Resources (NREM 601) graduate course is collaborating with the community-based non-profit organization Mālama Maunalua, to investigate the drivers behind the declining water quality of bay and provide potential solutions for restoration and mitigation. Mālama Maunalua has asked NREM 601 to adopt Maunalua Bay as a case study to research topics of concern including Water Quality, Sediment, Economy, and Invasive Algae Growth. Using a conceptual mapping tool named CMAP, we investigate the drivers and pressures in the bay, the state of the bay, and resolutions moving forward.

Challenge

Within the larger framework of the NREM 601 class, we will specifically address the sediment dynamics in Maunalua Bay, from mauka to makai. Our research question asks, “what are the sediment dynamics of Maunalua Bay?” Using CMAP, we illustrate connections between the main drivers influencing the sediment dynamics of Maunalua Bay.

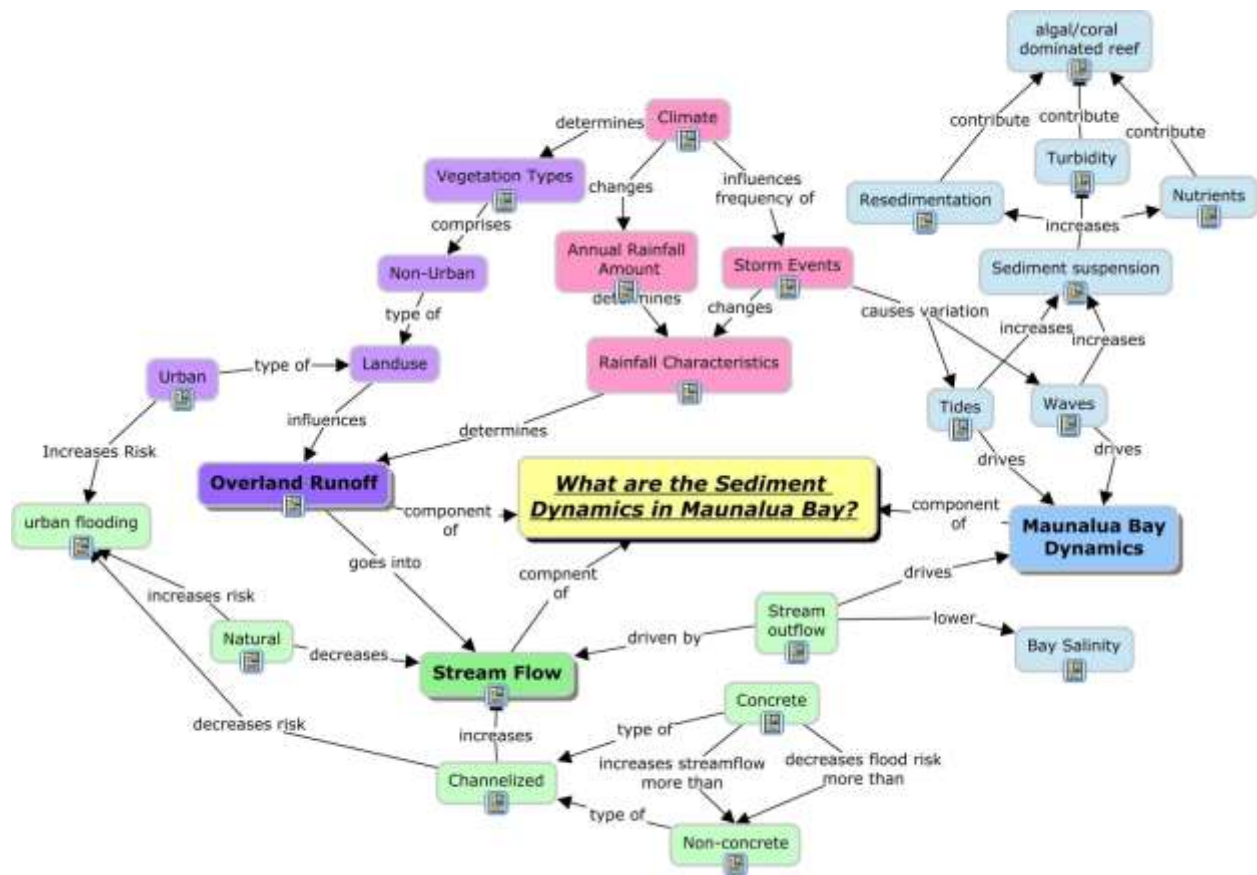
Malama Maunalua would like better science that accurately projects sediment input and transfer across the Bay. With this information, we can more appropriately target the biggest source of sediment input (by stream or watershed). In this knowledge domain, we have gathered the existing information to predict and measure sediment dynamics in Maunalua Bay.

Narrative

In the CMAP framework, runoff, stream morphology, and hydrodynamics are the main drivers that influence sediment dynamics in the Maunalua region. Climate affects the annual rainfall and influences storm events the amount of rain then determines the strength of the vector for overland runoff. The land use around the stream (urban vs. non-urban) will be a strong factor

in what flows with the water (I.E sediment, nutrients, pesticides). To protect urban areas from flooding, streams are often channelized which increases the water velocity in the stream and decreases the sediment retention rate. This increased flow can differ with concrete and non-concrete channelization. Once the sediment reaches the bay, the main dynamics that affect its movements are the streams, tides and waves. Storm events can cause variation in the tides and waves which increases the amount of suspended sediment. This suspended sediment increases turbidity, re-sedimentation and nutrients which are stressors that influence a phase shift from coral to algal dominated reef.

CMAP



Methods

Individual knowledge domain were created by each group member for their sub-topic under the main topic of drivers and sediment dynamics in Maunalua Bay. Each individual knowledge domain includes a specialized research question and hypothesis to assess a different contributing factor to sediment loading dynamics in Maunalua Bay. Additionally, each group member outlined a planned approach for water quality sampling, literature review, and how to include the use of the InVEST sediment model to support their hypothesis and investigate their

research question. A Connectivity Map (CMAP) illustrates the interconnectedness of each sub-topic and how they correlate to the bigger picture of sediment dynamics in Maunalua Bay.

Knowledge Domains

Climate Knowledge Domain by Brendan Martin

Introduction

Sediment dynamics influencing Maunalua Bay are driven by rainfall events that cause soil erosion and result in sediment transport to the bay. To better understand how this system will respond to climate change, I intend to investigate the rainfall characteristics associated with different climate scenarios, and the resulting effect on sediment transport. This information will require fundamental knowledge on both soil and rainfall characteristics, and how they influence the erosion and transport of sediment.

Research Questions

The principal question is how will different future rainfall scenarios affect erosion and sediment transport to Maunalua Bay from the surrounding watersheds? Precipitation events serve as the primary driver of sediment transport to Maunalua Bay, and a major factor in land erosion. Climate change is expected to alter the amount, frequency, and intensity of precipitation events in Hawaii. Although, rainfall projections vary greatly depending on scale and methodology employed, therefore various rainfall scenarios will be investigated. Research questions include 1) can we successfully model future rainfall variables: amount, frequency, and intensity, 2) What rainfall variable has the greatest effect on the amount of sediment transported to the bay, 3) What are the best/worst combinations of potential future rainfall variables for sediment transport to the bay?

Hypothesis

We predict that the rainfall intensity, rather than annual rainfall, will have a greater effect on erosion and sediment transport to the bay. However, the amount of annual rainfall is expected to increase erosion and sediment transport to a lesser degree compared to rainfall intensity. Rainfall frequency will only have a significant effect on erosion when describing high-intensity events.

Approach

Investigating the role of climate change in the process of sediment erosion and transport involves the understanding the erosion process (including soil, rainfall, topography, and land cover characteristics), factors influencing Hawaii's climate, and future rainfall predictions (which incorporates past trends, future projections, and projection methods). This information will be collected through a thorough literature review.

This literature review serves as the precursor to the analysis of sediment dynamics in Maunalua Bay using the InVEST sediment delivery model. Information from this review will provide information necessary for the validation of the model, and design of different potential rainfall scenarios for Hawaii.

Existing Evidence

Soil Properties and Erosion (Adapted from Holz et al. 2015)

The primary soil properties that determine soil erodibility include antecedent moisture, porosity, surface roughness, texture, and aggregation. Antecedent soil moisture is the most important property influencing erosion during storm events. Wetter soils saturate quicker, saturated soils produce more overland flow, and therefore more erosion potential. Soil porosity is the most important property influencing infiltration rates. Higher soil porosity results in higher infiltration rates, a higher infiltration rate produces less overland flow, and therefore less erosion potential. Surface roughness (in the absence of vegetation) influences soil seal development, runoff, and erosion. Rougher surfaces delay sealing and erosion due to lower raindrop impact. Soil texture influences infiltration and runoff rates, shear strength, and aggregate stability. Large soil aggregates require more energy to transport.

Precipitation Characteristics and Erosion (Adapted from Holz et al. 2015)

Precipitation characteristics have a significant role in determining erosion rates. Precipitation is characterized by amount, duration, intensity, and sequence (order and timing of rainfalls). Rainfall intensity, defined as amount/duration, is the most important factor affecting erosion. Increased intensity results in higher kinetic energy of raindrops, this increases detachment and transport of soil. Increased rainfall duration results in increased erosion. This is due to the increased rainfall volume, resulting in soil saturation, which produces surface runoff and increased erosion and sediment transport. The sequence of rainfall events is important because it directly impacts soil moisture. Greater periods of time between rainfall events generally result in drier soils (slow saturation), while frequent rain events lead to more consistently moist soils (fast saturation).

Other Factors Influencing Erosion (Adapted from Holz et al. 2015)

Topographic characteristics and vegetative cover (including vegetative litter) are important factors influencing soil erosion. Increased slope steepness results in increased soil detachment rates and sediment transport capacity. Increased slope length results generally results in higher amounts of soil loss. This process is affected by seal development, rill development, and deposition. Vegetative cover provides raindrop interception, decreasing the erosion potential of raindrop splashes. Vegetative cover increases surface roughness with stems, rooting, and litter, these effects slow overland runoff

Introduction to Precipitation in Hawaii

Rainfall is an essential component to life in the Hawaiian Islands, the two main precipitation delivery systems are trade winds and kona storms. Rainfall in Hawai‘i varies dramatically both temporally and spatially based on trade winds, topography, mid-latitude weather systems, storms and cyclones, ENSO and PDO phases and much more (Schroeder, 1993). These factors combined with Hawaii’s small geographic area present a challenge to accurately predict future rainfall. Global climate models are often too geographically broad to resolve specific regions such as Hawai‘i. Climate scientists simulate regional changes by adapting global models to smaller scales (i.e., “downscaling”), however most are cautious about the accuracy of results. Downscaling climate models can bring the risk of enhancing any inherent weakness or errors of the parent model but they can also help resolve uncertainty in regions with complex topography, such as Hawai‘I (UH Seagrant, 2014). These problems, however, do not make regional simulations insignificant, as long as their limitations are understood. Within the Hawaiian Islands trends and projections vary from island to island, and even valley to valley. The overarching past trend across the islands has been a decrease in total rainfall. The projections show a potential increase in frequency of extreme rain events. These projections have implications for stormwater infrastructure, sustainable yield from aquifers, and runoff into coastal waters (UH Seagrant, 2014).

Precipitation Trends/Observations in Hawaii

Past rainfall trends in Hawaii have indicated a decrease in annual rainfall, and an increase in rainfall intensity (accompanied with a decrease in the frequency of high-intensity events. It is important to note that that site selection and time span vary across studies presented here, and therefore must be assessed cautiously. With regards to annual rainfall, Chu, 1995 and Chu and Chen, 2005 reported that Hawaii’s total annual average rainfall has decreased over the last century. Oki, 2004, Bassiouni and Oki, 2012, and Giambelluca et al, 1991 reported that streamflow records show a decline in base flow over the last century by 20- 70%, depending on the watershed, suggesting a decrease in groundwater level. Chu et al., 2012 reported that Hawai‘i has experienced longer droughts in recent years, as all the populated islands show an increasing trend in length of dry periods during 1980-2011, as compared with 1950 -1970. Collins et al., 2010, Tokinaga et al., 2012, and Garza et al., 2012 reported that prevailing northeasterly trade winds, which drive orographic precipitation on windward coasts, have decreased in frequency since 1973 in Hawaii. With regard to rainfall intensity, Groisman et al., 2004, reported from 1958 and 2007, the amount of rain falling in the very heaviest downpours (defined as the heaviest 1% of all events) has increased approximately 12% in Hawai‘i. Elison Timm et al., 2011, and Chu et al., 2010 reported the number of high intensity rain events has decreased by 27% while the frequency of low intensity rain events has increased.

Precipitation Projections in Hawaii

Precipitation projections for the Hawaii estimate varied responses for annual rainfall, that most likely depend on the scale and Rainfall Intensity is projected to increase. With regards to annual rainfall, Keener et al., 2013 reported that coarse models indicate that the southerly main

Hawaiian islands (Hawai'i and Maui) may become wetter towards the end of the 21st century while those in the north (Kaua'i and O'ahu) become slightly drier. Timm et al., 2014 applied a statistical downscaling method and found that the most likely scenario for Hawai'i by the late 21st century is a 5%-10% reduction of the wet-season precipitation and a 5% increase during the dry season, as a result of changes in the wind field. Zang et al., 2016, found that rainfall is projected to change up to 25% at many locations. The currently wet windward sides of the major islands will have more clouds and receive more rainfall, while the currently dry leeward sides will generally have even less clouds and rainfall. Lauer et al., 2013, and Takahashi et al., 2011, reported that summer dry months will become wetter while winter wet months become drier in Hawai'i over open ocean environments. With regards to rainfall intensity, Zang et al., 2016 reported that extreme rainfall events are expected to increase significantly. Norton et al., 2011, reported that for the southern shoreline of O'ahu, the frequency of heavy rainfall is projected to increase through 2040, with those heavy rainfall events becoming less extreme.

Climate Model Downscaling

Global Climate Models (GCMs) are the primary tool employed by researchers to investigate global climate change, they provide reasonable accuracy of climatic simulations at large scales (i.e., global, hemisphere, continental) (Hewitson & Crane, 1996). Impact studies require a spatial scale much finer than provided by GCMs. Many impact applications require the equivalent of point climate observations and are highly sensitive to fine-scale climate variations that are parameterized in coarse-scale models. This is especially true for regions of complex topography, coastal or island locations, and locations with a highly heterogeneous land cover (Wilby et al, 2004).

Downscaling, or the adjustment of GCMs for local predictions, provides finer spatial resolution information for climate impact assessments. Dynamic and statistical downscaling are the two primary methods of large scale model downscaling. (Pielke & Wilby, 2012). Dynamical downscaling (as defined by NCAR, 2017) requires running high-resolution climate models on a regional sub-domain, using observational data or lower-resolution climate model output as a boundary condition. These models use physical principles to reproduce local climates, but are computationally intensive. Statistical downscaling (as defined by NCAR, 2017) is a two-step process consisting of 1) the development of statistical relationships between local climate variables and large-scale predictors, and 2) the application of such relationships to the output of global climate model experiments to simulate local climate characteristics in the future.

Conclusion

Of the main factors influencing erosion (rainfall, soil, topography, vegetation), climate change is expected to primarily alter rainfall characteristics (more research is needed to investigate the effect of different rainfall scenarios on vegetation). The most important rainfall characteristics affecting erosion are rainfall intensity, duration (i.e, amount), and sequence. Therefore, rainfall amount is important, but more so how it coincides with intensity and sequence. An increased frequency and intensity in storm events (resulting in a greater total

amount) would most likely have a larger effect on erosion rates than the same amount of rainfall distributed evenly through a time period.

The projection of future rainfall in Hawaii is a complicated endeavor, and has resulted in very different outcomes depending on the complexity, geographic scale, downscaling method, and time frame of the model used. Trends from combined past observations and future projections indicate a decrease in annual (i.e., total) rainfall and an increase in storm frequency and intensity.

Using the InVEST sediment delivery model, researchers can analyze which rainfall variable has the greatest influence on the amount of sediment transported in the Maunalua Bay system. This would provide information to resource managers that would prioritize watershed restoration efforts.

Storm Events by Carmen Antaky

Introduction

To expand our knowledge domain on sediments in Maunalua Bay, I investigated how storm events affect sediment input and flow within our system. Tropical storms in Maunalua Bay are classified as high rainfall events, which increase the amount of water entering the Maunalua Bay watershed. Sediment is then picked up and carried by the water which flows into the bay. Additionally, storms bring large waves and strong winds within the Bay which affects the movement of sediment. In this knowledge domain, I will expand on the direct impacts of storms on Maunalua Bay.

Research Questions

My research questions include (1) How do storm events change sediment dynamics in Maunalua Bay? (2) How often will storm events occur in the future? (4) How long do post-storm event sediment conditions last? (5) How does stream morphology affect the transport of sediment into the Bay post-storm event?

Hypothesis

Based on previous literature and studies done in Maunalua Bay, I predict that storm events will increase the velocity and amount of sediment being deposited in the Bay. I also hypothesize that storm events will increase in the future due to climate change. Post-storm sediment loads will persist in the Bay days after the storm event, causing long lasting effects to coral health. Additionally, channelized concrete streams will have greater and faster transport of sediment than non-concreted streams into Maunalua Bay after a storm event.

Approach

To answer my research questions of storm events on sediment dynamics in Maunalua Bay, there must be an understanding of how much sediment in the Bay under normal conditions versus post-storm conditions and then measure long the post-storm conditions persist. Additionally, to quantify the impact of stream morphology, natural versus channelized, a

measurement of sediment (suspended and deposited) and flow rate in Bay by each stream outlet (channelized and non-channelized) could be collected pre and post storm events. Also, to determine future intensity of storm events, I reviewed expert climate change predictions from resources given by International Panel of Climate Change.

Methodology will include a literature review and field validation. To assess sediment loads in the Bay, water samples for baseline turbidity and suspended solids could be taken under normal weather conditions. Then following a post-storm event, water samples for post-storm turbidity, suspended solids, and nutrient levels could be taken. After, water samples could be processed by in the lab for nutrient levels, for example at the SOEST lab at University of Hawaii at Manoa. For flow rate, flow rate measurements could be taken with flow probe (digital water velocity meter) under normal weather conditions by each stream outlet in Maunalua Bay. Then after a post-storm event, flow measurement could be taken again in same locations. For additionally calibration, data could be gathered from the closest USGS streamflow gauge and NOAA rain gauge to Maunalua Bay.

Existing Evidence

Climate Change

Climate change will play a focal role in the future storm patterns Maunalua Bay and will increase intensities of tropical storms more so than seasonal flux. Climate change experts at the International Panel of Climate Change predict that many of the impacts of climate change are likely to manifest themselves through extreme weather (IPCC, 2013). It is expected that the intensity of precipitation and winds associated with tropical storms will increase on average, so it is important to understand how storms will alter the sediment patterns in Maunalua Bay (IPCC, 2013).

Sediment in Bay Post Storm

Previous studies have tied increased turbidity and suspended solids, elements of sediment load, to post-storm conditions in the Bay (Storlazzi et al., 2008; Wolanski et al., 2009). Increased runoff due to high rainfall and resuspension of sediment from large waves occurs in the Bay after storm events (Storlazzi, 2008). It has been found that high sediment post-storm values remained in sites within the Bay for up to 10 days (Wolanski, 2009). Although, it has been seen that turbidity decreases quickly to pre-event levels due fast current speeds and rapid settling of the sand-sized particles (Storlazzi 2008).

Streamflow Post Storm

Channelization occurs in all streams flowing in the Maunalua Bay, with only Wailupe stream without concrete. Channelization inhibits groundwater recharge and as a result peak flows in the streams are increased, enabling the sediment plumes to spread further in Maunalua Bay (Wolanski, 2009). Additionally, streamflow in channelized streams increases during and after storm events (Wolanski et al., 2009). Documented in a previous storm event, about 20 tons of fine sediment was discharged into Maunalua Bay through the dredged channel from a combined contribution of the Kuliouou, Kamilo Nui, and Kamilo Uki channelized streams (Wolanski, 2009). Data from other channelized watersheds in Oahu Island suggest that these hardened streams have the potential to degrade coral reefs from increasing nutrient load into the system (Wolanski, 2009).

Conclusion

An unnatural increased amount of sediment load into Maunalua Bay from storm events intensified by channelized streams and climate change may have a large and negative impact on Maunalua Bay's watershed and health. Additionally, Maunalua Bay is plagued by invasive algae. Increased runoff, enriched with nutrients, could sustain the algae growing over the dead corals, further collapsing living corals and preventing recruitment of new coral while increasing invasive algal communities (Wolanski, 2009). It is important to address post-storm sediment dynamics in Maunalua Bay and find solutions to lessen its devastating effects. Solutions may include working to lower anthropogenic climate change and de-channelize the watershed to reduce the speed and amount of sediments being deposited into the Bay after storm events.

Stream Morphology by Tanya Harrison

Introduction

I will investigate stream morphology and how that affects sediment discharge into Maunalua Bay. Stream morphology describes the shape of a stream as a function of a variety of factors such as stream bed materials (gravel, concrete, etc.), sinuosity, steepness, and riparian vegetation. Urban streams are generally channelized to protect the built environment, which changes the flow characteristics of the stream. I will also look at the effects of the urbanization on stream morphology, and possible ways to reduce sediment discharge into the bay.

Research Questions

How does stream morphology contribute to sedimentation? What is the effect of urbanization on stream morphology? What can be done to reduce sediment discharge into the bay?

Hypothesis

Channelized streams discharge more sediment than natural streams. Removal of riparian vegetation and large woody debris, channelization, and replacing natural uneven surfaces with concrete all simplify the stream channel structure and increase rates and amount of sedimentation. Increasing roughness of channelized streams can decrease streamflow velocity and reduce sediment discharge in the bay.

Approach

To learn how much sediment going into Maunalua Bay is due to channelization, I'd want to find a reference reach (Rosgen 1998). This would be a stream channel similar to a stream flowing into Maunalua Bay, but un-channelized. It would be used as a template for comparison to sediment discharge from the channelized streams flowing into the bay.

An extensive literature review was also done to learn more about the processes that contribute to streamflow velocity, causes of channelization, work done in other channelized

streams to reduce sedimentation, and other methods that may reduce high flow events that carry sediment.

Existing Evidence

Stream morphology

The best definition I found of stream morphology: “Stream morphology is directly influenced by eight major variables including channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size.” (Rosgen, 1994). Roughness of the stream bed decreases flow velocity. Vegetation contribution to velocity is lessened as channel steepness increases. Greater sinuosity of a stream can slow velocity and ultimately how much sediment can be carried (Chin 1992), (Rosgen, 1994).

Streams are dynamic systems that if left alone, change naturally. This includes movement of debris within the channel, movement of the channel itself, and flooding, which spreads sediments across the landscape (Cockerill 2014). Runoff into streams is affected by a number of factors, including rainfall directly on the stream, rainfall on land within the watershed, groundwater discharge from the water table, and water from bank storage. Stream beds absorb some water at high flow, which is slowly discharged over time (Oki 2003).

Removal of riparian vegetation and channelization have increased sediment loads in most Oahu streams. Replacing vegetation with impermeable surfaces such as roads prevent water from absorbing into the ground, increasing runoff into streams, which affect stream flow velocity (MacKenzie 2008).

Urban flooding

Due to small, steep watersheds, Hawaii streams tend to be naturally flashy – streamflow can rise rapidly to flood stage, especially with intense rains over a short period of time. These floods have resulted in loss of property and lives (Oki 2003). Most rainfall on undeveloped land is absorbed into the soil. But rainfall on developed land falls on impermeable surfaces and flows directly into the stream. Streams in developed areas have much higher and more frequent high stream flows than streams in undeveloped areas, allowing for large pulses of sediment discharge (Roesner, 2001). This urbanization increases flood risk (Asakawa 2004).

Streams are channelized to protect the built environment from these floods. Channelized streams are confined to its banks, instream debris are removed, and riparian vegetation usually removed. Channelized streams may have natural stream beds, which allow for water absorption, or concrete, which allows peak flows to move at maximum speed. (Roesner, 2001). Channelization decreases flood risk in urban areas (Asakawa 2004). Although these channelized streams protect urban areas from flooding, they allow high stream flows that can cause large sediment discharges, which can smother aquatic habitat. These streams are usually designed and controlled by government agencies that don't have a biological focus (Roesner, 2001).

Restoring channelized streams

Roughening a channelized stream bed can slow velocity and decrease sediment transport. One study used large meandricly arranged fabric ropes to create “a network of micro-dams which slowed the flow of water and reduced transport of soil along the slope.” (Broda 2017). The added roughness to the streams was small, but could be compared to the natural bed of a channelized stream. Large woody debris could be added to a stream to slow velocity, but increases flood risk (Larson 2011). Wetland construction at the mouth of streams are not recommended, as chemicals can bioaccumulate, and it can be overrun by flood waters. Prevention of contaminants and excess runoff into the stream itself is recommended (Helfield 1997), (Cockerill 2014).

Urban stream restoration generally focuses on small areas while ignoring wider ecological issues at hand. Resulting projects can look good to the public and provide a false sense of optimism (Cockerill 2014).

Conclusion

It appears that once a stream is channelized in an urban environment there is little that can be done to effectively reduce sediment discharge during peak flow events. Increasing roughness of stream channels may slow streamflow and trap some sediment, but time, cost, and labor commitments would be high.

There is also a direct correlation between natural stream flow and flooding. The valleys above Maunaloa are urbanized to the stream’s edge. Citizens have made a value judgement that their lives and property are more important than maintaining natural stream flow. I would recommend focusing on reducing excess runoff from entering streams during storm events to reduce sediment discharge. Prevention of further channelization is also important – I’d recommend that the last natural channelized stream in the Maunaloa Bay watershed not be encased in concrete.

Reflections

I was surprised to find a self-enforcing system loop - as urbanization continues in the Maunaloa Bay watershed, stream channelization is needed to protect the built environment from flooding. Flood prevention needs a smooth and open channel to move flood water downstream as fast as possible, exactly what we don’t want if we wish to reduce sediment discharge to the bay. Increasing roughness and adding obstacles to the streams to reduce stream flow would increase flood risk (Roesner 2001).

This loop can be described as the system trap Shifting The Burden. Trying to reduce in-stream flow velocity through stream “restoration” projects such as increasing stream bed roughness along or creating a small wetland near the mouth only treats symptoms of sediment discharge and not the cause –change in land use from undeveloped to urban and the subsequent need to protect property from flooding. The trap of concentrating only on the stream and not the big picture is found in many stream restoration projects. (Cockerill 2014). The way out of this

trap is to not go in. Instead, I would recommend focusing on the symptom, which is excessive runoff during storm events caused by land use changes.

Land use Knowledge Domain by Blaire J. Langston

Introduction

Land use change over time has had significant variation within O'ahu surrounding Maunalua Bay. From early settlement and indigenous cropping systems to a complete renovation of the watershed into an urbanized landscape, Maunalua Bay has gone from one extreme to the other over a relatively short period of time. As a result, the water quality of the bay has been impacted by increased sediment loads transferred at an intensity that the ecosystem can not properly process through natural cycles. The increased sediment loads due to land use have changed the dynamics of the bay, smothering coral and carrying with them a host of pollutants via storm runoff. Here we look at how land use has changed over time within the Maunalua Bay watershed, and how this affects sediment dynamics in the bay. Overall, sedimentation in the bay due to land use change is part of a larger cycle within sediment dynamics in Maunalua Bay, and is closely connected to and influenced by climate, channelization and stream morphology, and storm events.

Research Question

How does land use change affect sediment dynamics in Maunalua Bay?

Hypothesis

Developed areas contribute larger amounts of sediment to Maunalua Bay compared to undeveloped areas.

Planned Approach

To understand how land use affects Maunalua Bay a thorough literature review was conducted to summarize existing knowledge. According to current literature, it is difficult to connect land use change to water quality. Here we have a definitive time frame where urbanization increased. Using the Invest model, I will compare scenarios of sedimentation before and after the 1960's. This comparison will address my research question by looking at three scenarios: using the Invest model to compare a non-urban land use scenario inspired by a traditional agricultural landscape before settlement, and an urban landscape created in the 1960's to accommodate population increase. A third scenario can be compared by examining current water quality data to examine impact of land use over time, in this case of fifty years.

Existing Knowledge

Effects of Land use on Water

Factors that influence water quality include precipitation, river discharge, geology, soil, topography, and vegetation cover (Meybeck et al. 1989). Different types of land use and human influence can play a large role in the natural influences that affect water quality. This includes urbanization, removal of natural vegetative areas, stream impounding, agriculture, development. As a result, urbanization involves increasing the amount of impervious surfaces surrounding a waterbody. Urbanization can directly affect runoff by exacerbating erosion through construction, increasing the amount of runoff volume and intensity that enters a body of water, and increasing the amount of pollutants, including sediments that enter a body of water. In Maunalua Bay, urban areas include residential areas, shopping centers, marinas, golf courses, parking lots, channelized streams and major roads..

Urbanization can affect water quality in a multitude of ways. First, through clear cutting or removing vegetative areas hydrologic and sediment transport are affected (Brooke, et al. 2009). The United States Geological Survey explains that land use change including the conversion of forested land to agricultural land affect the intensity of floods and sediment loads. However, a percentage as small as five percent of urban land use increased will have a dominating impact on water quality compared to agriculture.

Vegetation and riparian zones can reduce runoff intensity and reduce pollutant loads into Maunalua Bay. Forested and vegetated areas allow for runoff to filter through to ground water before reaching the bay. In this process, pollutants present in runoff including petroleum, nutrients, chemicals, and sediment can be recycled through plant uptake before reaching the bay. Human alteration breaks this cycle, creating a reinforcing feedback loop without a balance.

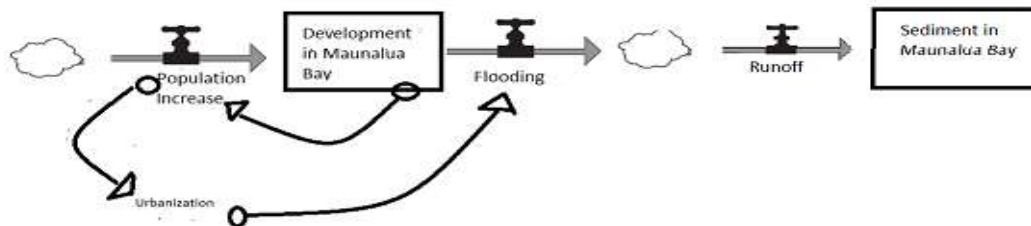
Land Use Change in Maunalua Bay

Historically, land use in Maunalua Bay was reported as being used for Polynesian agricultural practices (Atkinson 2007). Moving ahead, the population increased significantly between 1959 to 1999 from 2,005 people to over 27,000 residents (Atkinson 2007). Development now extends from the beachfront to the top of the watershed. Niu fish pond was filled in for housing as well as Kuapā pond which was transformed into a boating marina for developments in Hawai'i Kai. The surrounding coastal plains of the bay were also urbanized. To accommodate the population increase and mitigate flooding, streams were channelized and lined with concrete. Kuliouou stream which once drained into Paiko Lagoon, was redirected to flow directly into Maunalua Bay. It was reported that after urbanization sedimentation increased in Maunalua Bay (Wolanski 2009).

Conclusion

Maunalua Bay has become a system trap, “Shifting the Burden” (Meadows 2008) regarding sedimentation and land use. The increased urbanization increases runoff that carries sediment to the bay (see figure below). Also, with increased urbanization in general, the modification of streams to mitigate flooding increases the amount of impervious and urbanized landscape in Maunalua Bay watershed. Urbanization and stream channelization decrease the amount of time water spends flowing through the watershed and increase the amount of sediment

carried with it. There is no loop to close the increased sedimentation rate because all natural routes of removal have been modified. This is driven by the increase in development in Maunalua Bay which creates a need for flood control, which created a need for mitigation, or channelizing streams, which increased urbanization, which increases flooding again. As a result, runoff intensity is increased, along with the sedimentation rate into Maunalua Bay.



In order to assist Mālama Maunalua in their goals to restore the bay, I propose they will have to make a strong argument that land use affects the water quality of the bay. Existing proof collected in this knowledge domain will support additional findings ran in the Invest model. The results will link the degradation of the bay directly to the land use change. Conclusively, the sediment group will provide this information with suggestions and solutions to address the issue behind land use change and increased sedimentation in Maunalua Bay.

Maunalua Bay Dynamics Knowledge Domain by Courtney Payne

Research Question

How does a bay process sediment and how does this affect benthic cover?

Hypothesis

I hypothesize that the strongest factor affecting sedimentation in the bay will be the ebb flow as conceptually, a bay that has a strong ebb flow will have a higher tolerance of stream inputs than one that is more stagnant. A strong outward flow could keep the sediment suspended in the water column and leave quicker than a slow outward flow that retains the sediment. I also hypothesize that high sediment levels will cause a phase shift from a coral to algal dominated reef as sediment will increase turbidity and smother coral.

Existing knowledge

We have discussed how stream dynamics affect sediment, but what happens to this sediment once it reaches the bay? In a general bay or estuarine system, the strongest effects are tides, waves and rivers/streams (Bell et al., 2000). Tides or prevailing currents provide a steady source of momentum for sediments into and out of the system (Bell et al., 2000). Waves, on the other hand, are less predictable than tides and can have large variations with seasons or storm events (Bell et al., 2000). The waves re-suspend bed sediment which can then be transferred via the prevailing currents (Bell et al., 2000). Turbidity is often used as a measure for the amount of sediment in a water system, but this only measures the suspended particles; traps are needed to measure sedimentation rates (Emerson, 1991)

When sediment is suspended in the water column through tides and waves, the turbidity increases and decreases the amount of light available to the benthos (Fabricius, 2005) Sediment

enters from the stream but to move out of the water column and become sedimentation, the critical shear stress must be greater than the wave/current shear stress (Storlazzi et al., 2008).

Sediment inputs affect corals directly through sedimentation and indirectly as a vector for other contaminants. If the sedimentation occurs near a coral reef, then the particles can smother the corals. Heavy sedimentation on corals negatively affects their abundance, growth rates, recruitment, and net productivity (Rogers, 1990). Corals are able to reject the sediment through tissue swelling, polyp movement and mucus production, but these actions increase energy expenditure and stress levels (Weber et al., 2006). Stressed corals are weak to defend against other stressors like temperature or salinity flux and can lead to coral bleaching and phase shifts. There are many compounding factors that can lead to a phase shift from a coral to algal dominated reef including major perturbations and chronic stressors (McManus and Polsenberg, 2004). Depending on length of exposure decreased light availability, sedimentation and excess nutrients can increase these chronic stressors and facilitate a phase shift (McManus and Polsenberg, 2004). Not only is the sediment itself detrimental, but also what accompanies the sediment; inorganic and particulate material has been argued to be the most important contaminant on a regional and national scale (Fabricius, 2005).

In 2008 the effect of these factors on sediment dynamics were analyzed through an USGS initiative and provide a useful baseline for our current study (Storlazzi et al., 2008). This study found that the bay had an overall low turbidity with the highest after storm events (Storlazzi et al., 2008). The suspended sediments decreased quickly to pre-storm levels after the event which as hypothesized to be due to the fast current speeds (Storlazzi et al., 2008). Storlazzi et al. found that the shallow areas off the north central and northwestern coasts had generally lower salinity and higher turbidity (2008). Wave heights ranged from .48 to 4.07m while the tides were typical for the coast and changed with about 6 hour intervals (Storlazzi et al., 2008). Majority of sediment type was sand with a mean of 4.6% being gravel (Storlazzi et al., 2008). The salinity in the bay was ranged from 19.64 to 35.21 PSU (Storlazzi et al., 2008).

Conclusion

After this knowledge domain, I conclude that neither hypotheses were accurate. I hypothesized that the ebb flow would be the strongest factor in the bay, but research shows that there are three main driving factors. This hypothesis was further refuted with the Maunalua case study that found turbidity and salinity were good predictors for large sediment deposits. My second hypothesis that sediment inputs would be a cause for a reef phase shift was also not correct; sediment can be a stressor that will limit a coral's immunity to other stressors but is not enough on its own to create a phase shift.

Resolution

From the synthesis of our individual knowledge domains, we were able to identify the main system animals and create an integrated conceptual map portraying the interwoven drivers of sediment dynamics in Maunalua Bay. Climatic patterns, such as storm events, determines the amount of rainfall that carries sediment from land into streams, which flows and alters the ecosystem dynamics in the bay. Future directions include limiting the input and increasing the output of sediment into the Bay. Instead of solely focusing on downstream activities like implementing rain gardens or engineered sediment removal in the bay, the system must be considered as a whole. Future research could address how to slow down or reduce the positive

feedbacks associated with urbanization perpetuating channelization and impervious surfaces. Furthermore, effective solutions to reduce the negative impact of climate change and shifting social values to ecosystem health and water quality while designing flood control, should be investigated to alleviate the traps within our system.

We define our system of sediment within the bay as a one-stock system with reinforcing and balancing loops (Meadows, 2008). Sediment, the main stock in our system, is brought into the bay through runoff facilitated by rainfall and channelization. Sediment then leaves the bay through natural processes including waves, currents, and tides, classified as a balancing loop. A reinforcing loop occurs in urbanization as it increases flooding, leading to stream channelization, which results in less sediment retention in streams. Within the bay, a reinforcing loop occurs with coral/algal reef phase shifts as a stable phase will perpetuate itself until a threshold is reached. Climatic events, such as storm events, amplify the loops within the system. For example, tropical storms increase wave activity which carries sediments out of the bay. Although, the increased rainfall from the storm accelerates the amount of sediment running into the bay and reinforces the need of urbanized flood control. This lowers the ability of sediment retention within the stream, halting natural balancing loops within the system. Most natural balancing loops to remove or prevent sediment entering the bay have been completely altered by human activity and urbanization. Overall, this makes our system very one-sided, as more sediment is being input into the Bay than can naturally be removed. Additionally, invasive algae perpetuates sediment within the bay, leading to increased eutrophication, poor water quality, and reduction of native species.

One trap within the system is defined as, “Shifting the burden to the inventor.” (Meadows, 2008). Naturally occurring vegetation and soil absorbs rain which is lost with urbanization causing increased overland flow over the concrete surfaces and flood streams. To prevent this flooding, channelization has been chosen as the main solution. Channelization has also caused its own problem of increasing stream velocity and reducing sediment retention. The solution to a problem has created another problem, if the initial problem of losing the water absorption ecosystem service was solved then the channelization would not be as critical.

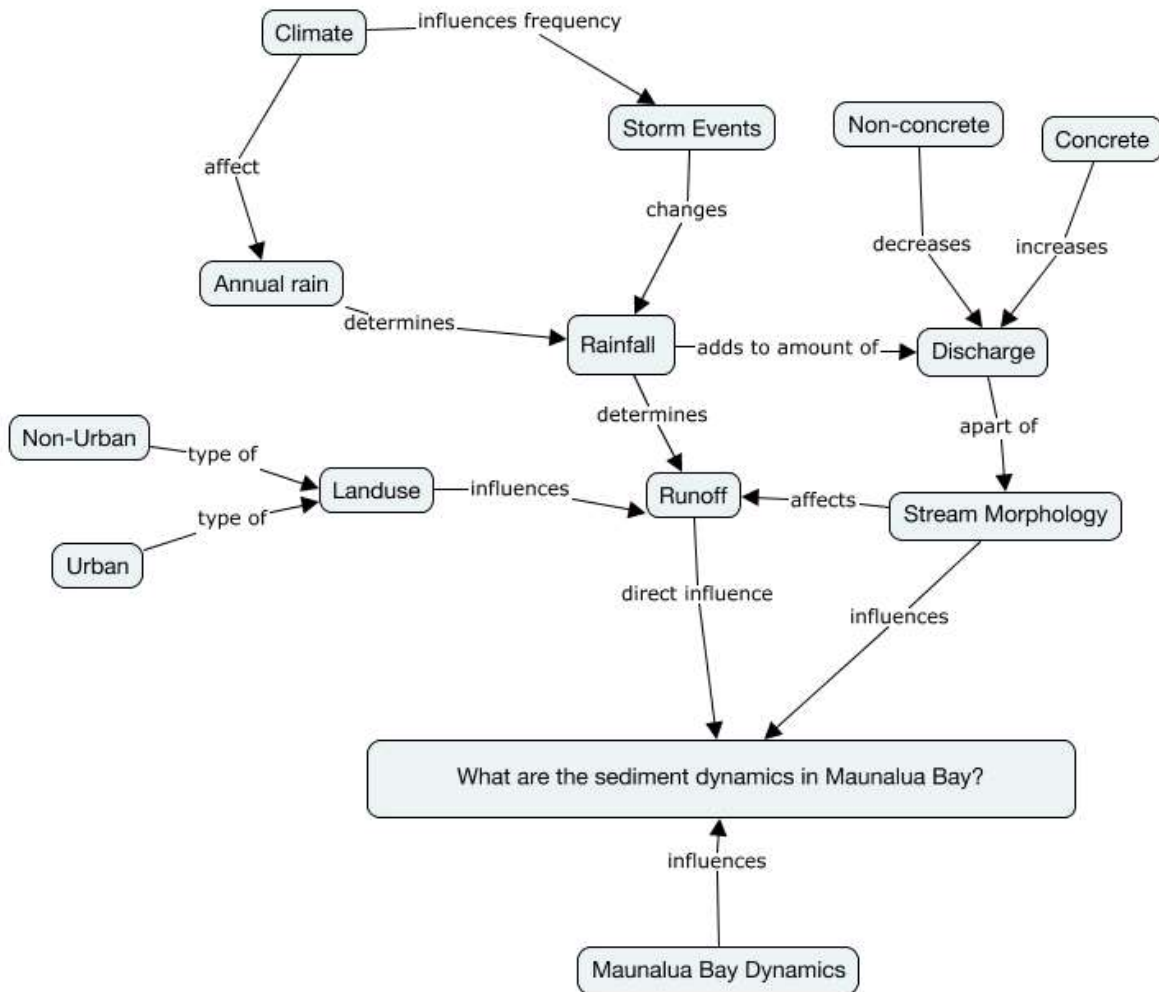
Appendix

CMAP Progression

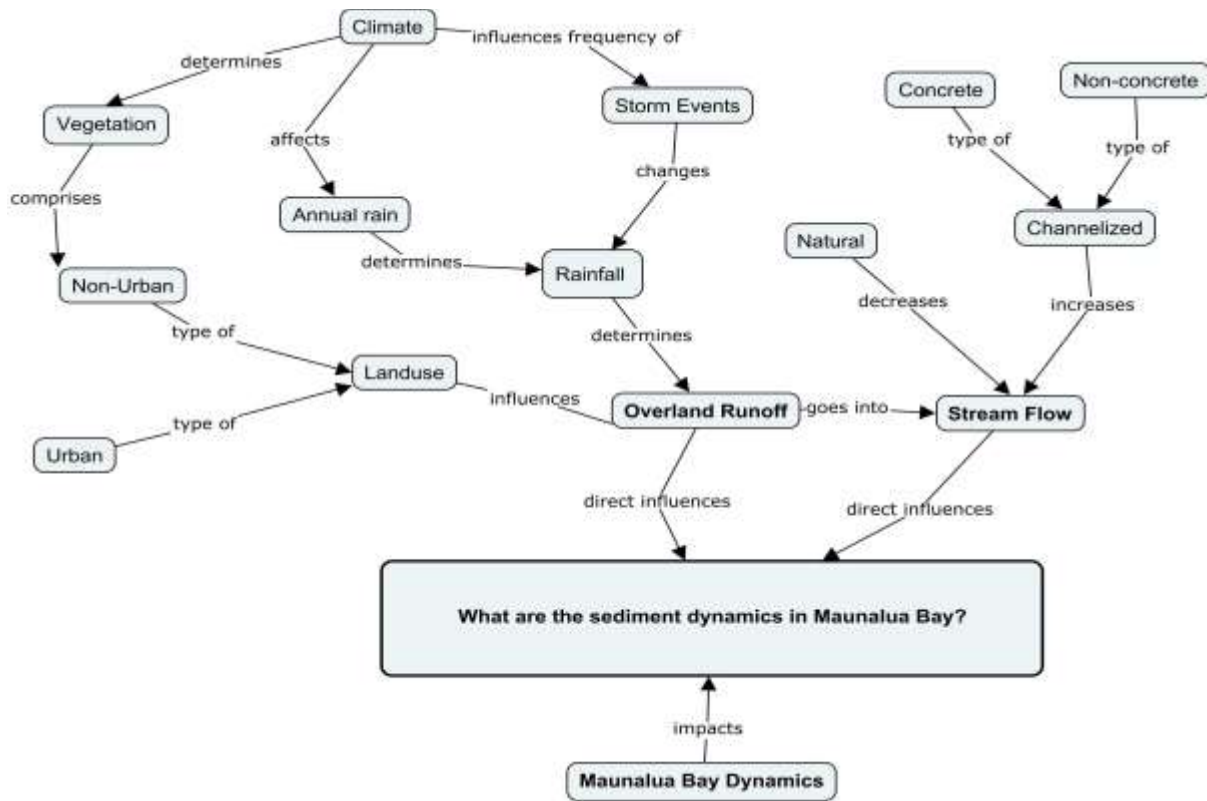
We first thought of the main drivers that impact sediment dynamics in the stream and in the bay which we decided were runoff, stream dynamics, and bay dynamics. These three components were the backbone of all our CMAP drafts. From the main drivers, we discussed how these drivers were fueled. This created secondary drivers: stream morphology, land use, climate, storm events and bay dynamics. Each group member choose a secondary driver to perform their knowledge domain on and found the important inputs that would affect the main and secondary drivers. The largest change in CMAP's can be seen between CMAP 2 and the final CMAP as the addition of bay dynamics provided the linear loop and connected the system. Additionally, complexity was added in our CMAP revisions through added connections between focal drivers. Climate and non-urban land use are related as natural occurring vegetated

landscape is determined by climatic variables such as rainfall, humidity, and temperature. Also, stream morphology and channelization are linked to urbanization through flood control. From diving deeper into our domain of knowledge surrounding sediment dynamics in Maunalua Bay, we were able to draw connections and integrate loops throughout system into a final polished CMAP product.

CMAP 1



CMAP 2



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