Evy Braum, Tanya Torres, Rodrigo Rivero-Castro, Aviv Suan, Darcy Yogi
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Sediment Transport Modeling in Maunalua Bay

Final Project Report

Background

Maunalua Bay provides an abundance of ecosystem goods and services that are critical to human wellbeing such as seascape aesthetics, food for sustenance, and recreation for both residents and tourists. However, a rise in human population and urban development sprawled across the Maunalua watersheds eventually leading to the decline in the health of Maunalua bay affecting the above benefits (Mālama Maunalua, 2009). Urban expansion has increased impervious surfaces, replacing the natural landscape and fundamentally altering how the land and water interact. These surfaces such as roads, housing developments and parking lots do not allow runoff to infiltrate into the ground and instead carry nonpoint source pollution directly into the bay. Impervious surfaces coupled with intense rainfall events create pulse stress events of large volumes of fresh water, nutrients, and pollutants into the bay devastating the function of the coral reef ecosystems (De Carlo et al., 2007; Delwyn, 2003; Wolanski et al., 2009).

Heavy sediment and nutrient influxes are associated with lower reef biodiversity, stunted coral growth, and macroalgae phase shifts that turn a previously thriving coral reef ecosystem into a algae dominated environment (Rogers, 1990; Wolanski et al., 2009; Brasher & Wolff, 2004). In Maunalua Bay, increased fertilizer use and wastewater production exacerbate the above impacts further degrading coral reef ecosystems (Rabalais, et al., 2010; Wolanski et al., 2009). Furthermore, future climate change projections suggest increased storm intensity and frequency (Trenberth, 2011) which will amplify sediment erosion and transport into Maunalua Bay (Klein, 1979). Therefore, watershed management agencies need to prepare for both the current weather patterns as well as extreme changes in our climate.

Sediment flow dynamics are not well studied for this region. For example, the amount of rain it takes to move sediments into the bay is unknown. Managers are also in need of tools to effectively locate accumulated sediments to prioritize their efforts. Mathematical modeling is an effective tool that has the ability to predict soil erosion and sediment transport dynamics over a large scale study area. Sediment transport models enable the user to estimate the spatial distribution of soil erosion rates and sediment movement loads from specific rainfall events. The results can inform management on where to concentrate their efforts to effectively mitigate the negative effects of heavy rainfall events.

Objectives

The project objective was to use a spatially explicit model to assess sediment dynamics of the Maunalua Bay watershed to: (i) restore marine biodiversity and resources to Maunalua Bay through a mauka to makai framework; and (ii) address explicit spatial areas of interest applicable to managers at Mālama Maunalua. Furthermore, our research questions were: (i) Where are the spatially explicit locations of large pooled sedimentation within a watershed? (ii) What is the quantitative tipping point of a precipitation event (e.g. 2 inches) to mobilize sediments in Maunalua Bay?

Methods

To simulate sediment dynamics, we decided to use NOAA's open-source Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT). This tool is capable of modeling water quality (sediment, pollutants, runoff) considering watershed changes in climate, land cover, and rainfall events. The model uses the following geospatial layers to simulate potential water quality impacts of modelled precipitation and land use change events:

- Elevation
- Land Cover
- Rainfall
- Rainfall Erosivity Factor (R-Factor)
- Soil Erodibility (K-Factor)

The following table displays the source and descriptions for each data set required by the model. All of the data layers below can be freely accessed through our UH ScholarSpace.

Table 1: Input datasets for OpenNSPECT model

Dataset	**Description**	**Source**
Elevation	2007 Digital Elevation Model (DEM; 10m resolution)	National Oceanic Atmospheric Association (NOAA)
Land Cover	2011 C-CAP Land Cover of Oahu, Hawaii (2.4m resolution)	NOAA's Coastal Change Analysis Program (C-CAP)
Rainfall	Average annual rainfall from 1920-2012 (250 m resolution)	Rainfall Atlas of Hawaii University of Hawaiʻi at Mānoa, Geography Department
Rainfall Erosivity Factor (R-Factor)	Effects of raindrop impacts and reflects the amount and rate of runoff associated with the rain from 1975-1997. (30m resolution)	NOAA Office for Coastal Management
Soil Erodibility Coefficient (K-Factor)	2003 digital soil survey of geographic and attribute data developed by the National Cooperative Soil Survey	Soil Survey Geographic (SSURGO) database, USDA Natural Resource Conservation Service
Watershed Boundary	Raster .tif of Maunalua Bay watershed region	Nrem 601 Spring 2017 class

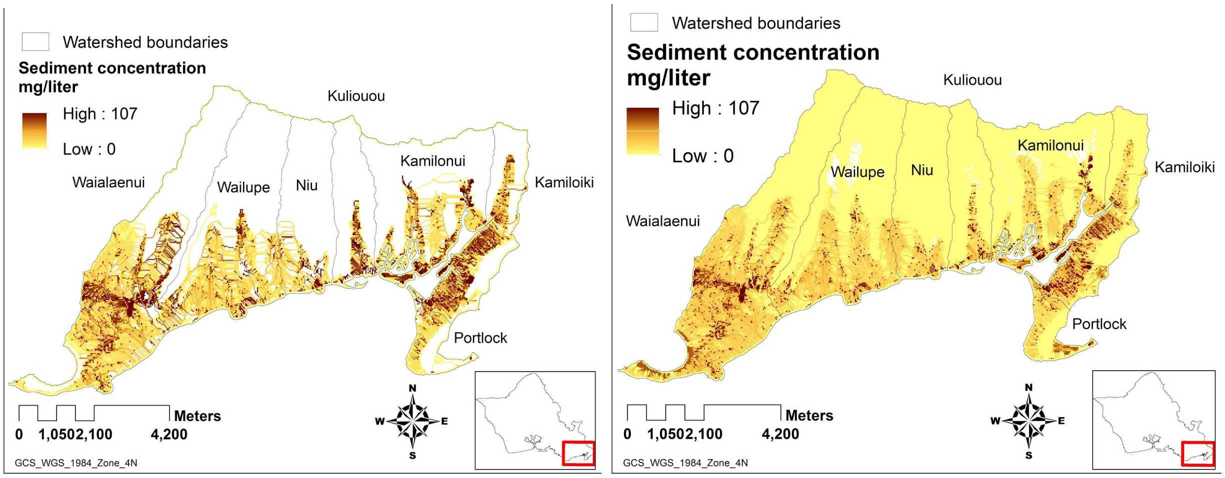
Outputs of the OpenNSPECT model are given as raster datasets of various attributes such as runoff volume (liters), accumulated sediments (kg), sediment concentration (mg/l), accumulated pollutants (kg), and pollutant concentration (mg/l). To answer our research questions, we would focus on the accumulated sediments and sediment concentration outputs. We predict that the sediment concentration output would give the best insight to locations of "pooled" sediments. To find the threshold at which sediments are mobilized in the watershed, we would run the model with different rain scenarios until the minimum amount for mobilization is reached.

When using model simulations it is standard to validate the accuracy of the model by comparing results to real world outcomes. Our initial plan for validation was to execute in-field validation by collecting water samples after various rain events in Maunalua Bay. Adjustments would then be made to more accurately attempt to answer our research questions.

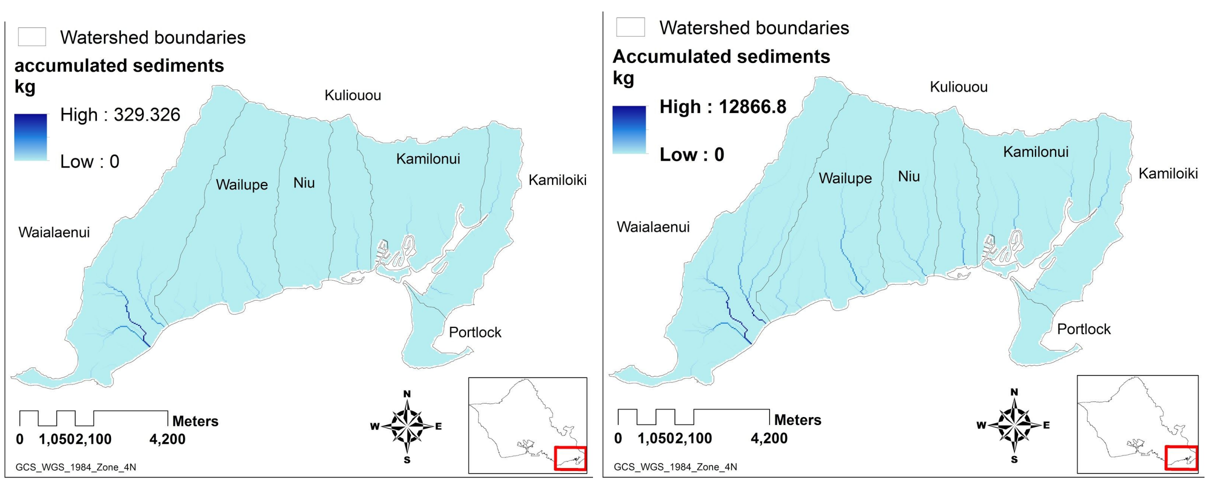
Results

After properly processing and parameterizing all the geospatial data, our model was able to simulate rain events and analyze the subsequent results. To understand the difference in sediment movement dynamics we started simulating a low rain event of 0.5 inches and a high rain event of 3 inches. We focused on two outputs that are pertinent to the health of Maunalua Bay and to the managers at Mālama Maunalua which are: 1) Sediment Concentration and 2) Sediment Accumulation.

Figures 1 & 2; Sediment Concentration After a Low (0.5 inch) and High (3 inch) Rain Event



Figures 3 & 4; Sediment Accumulation After a Low (0.5 inch) and High (3 inch) Rain Event



For the sediment concentration (Figure 1 & 2), we found some stark differences between the level of concentration in the study area between the rain scenarios. The high rain scenario had a wider spread of sediment concentration across, with the low rain scenario having large areas with no sediment concentration present. One interesting observation we had was that the low rain scenario had a higher concentration in certain locations, specifically the urban development areas in the majority of the watersheds which seemed counterintuitive to what we expected. A possible reason for this is that in the high rain scenario, the sediments could be washed into bay, since the amount of movement around the extent would be larger, while a low rain event pools sediments in limited areas and is not able to push them into the bay. The differences in sediment accumulation (Figure 3 & 4) is less surprising, with a clear relationship between the amount of rainfall and amount of accumulated sediments in each watershed.

Model Validation

In an effort to validate our model, we tried to establish a comparative sediment transport baseline for two out of the seven contributing Maunalua watersheds. In consultation with Dr. Yin-Phan Tsang from the UH Manoa Hydrology Lab, she relayed that in-field water sampling would present a high safety risk (especially during and after storm events) and a large time commitment (sampling everyday at the same time). Therefore, in-field validation was not in the scope of our project timeline and thus we relied on limited USGS stream gauge data. We gathered stream data from Wailupe (2008-2010) and Kuliouou (2009-2010) where the average values from these data sets can be found in **Table 2** (full raw data set available through UH Manoa ScholarSpace). Next, we needed daily rainfall data from the Maunalua Bay area to match up with our stream data period (2008-2010). The NOAA's National Climate Data Center had rainfall data that correctly matched up temporally with the stream gauges but not spatially. Given the spatial variability of rainfall within a watershed, we would need precipitation gauges overlayed with stream gauges because elevation can make a large difference in precipitation regimes.

Table 2: Average values from USGS stream gauge data

Stream	**Discharge, ft.^{3}/sec. (mn)**	**Suspended Sediment Discharge, ton/d (mm)**	**Rainfall, inches/day (Paiko rain gauge)**
Kuliouou	0.30	0.00	0.05
Wailupe	0.74	0.46	0.05

While our model was fully functional, using it to reach our objectives without proper validation would have been irresponsible. Therefore, we were not able to reach conclusive results. Our model does present some future opportunities to Malama Maunalua, as well as future students in this course. Properly validating the model would result in having a beneficial tool for the community that's capable of simulating movement of sediments as well as other materials after rain events. This final report functions as our culminating synthesis on pulse event sedimentation modelling for Maunalua Bay. The raw project and spatial data will be available through UH Mānoa ScholarSpace.

Limitations

Overall, we were able to successfully run our model, however there are a few recommendations that can be made to improve the model's accuracy. We utilized the provided *OpeNSPECT 1.2 Data Acquisition and Preprocessing Instructions* from the NOAA software website, however, properly running OpenNSPECT was a bigger challenge than expected. Many of the input data sources were outdated, non-existent, or not applicable to Hawaiʻi. For example, OpenNSPECT's spatial data inputs have multiple attributes (such as extent, cell size, data type) that all need to be in the same required format for it to work properly but many sources from this instruction did not provide the needed data. The process of finding the appropriate data took us longer than expected and we were not able to run the model successfully until the last week before final presentations. This allotted us a very limited time frame for data analysis.

Given problems with our model as well as questions we had about its use, we contacted the developer, David Enslinger, and joined the OpenNSPECT user group, efforts. However, we did not get any response by the developer or other users (last thread on user group from 2014). Nonetheless, our group was able to to successfully run the model, but we are unsure of our model validity. Therefore, before this data could be used for prioritization of sedimentation mitigation measures such as green infrastructure or upland restoration, we would recommend increased stream monitoring to validate our modeled understanding of sedimentation dynamics throughout the bay watershed.

Suggestions for the Future

Our main recommendation is to address data limitations which involve implementing long-term, auto-sampler monitoring programs that collect comprehensive, real-time stream data (stream discharge, sediment load, nutrient load). In an effort to validate our model with available data, we could only find two stream gauge datasets from between 2008-2010. Thus, we suggest the installation of more stream gauges and paired rain gauges within each contributing stream system. This will allow consistent and long-term data to optimize and validate future model outputs. This would also alleviate spatial disparities in data.

Future research would include validation of our model, with official stream gauges or in-field surveys to ground truth modeled “pooled” sediment areas. Finally, keeping up to date with available data layers is critical to simulate accurate sediment transport scenarios.

Conclusion

This project addresses the sediment and pollutant reduction priority of Mālama Maunalua (2009) through identifying priority areas of accumulated sediment. The maps produced can allow managers to better prioritize actions across the 28 square kilometer region that feeds into Maunalua Bay. With more time to dedicate to model optimization and validation, this model could provide novel and useful environmental data on water quality to Mālama Maunalua. This process can also be used to predict changes in water quality into the future with climate change or through proposed land use changes. This type of research is critical for watershed management planners; especially within island communities that rely on finite natural resources and whom maintain intimate relationships with their native landscapes.

References

Brasher, A. & Wolff, R. (2004). Relations between land use and organochlorine pesticides, PCBs, and semi-volatile organic compounds in streambed sediment and fish on the Island of Oahu, Hawaii. Arch. Environ. Contam. Toxicol. 46, 385-398.

De Carlo, E.H., Hoover, D.J., Young, C.W., Hoover, R.S., & Mackenzie, F.T. (2007). Impact of storm runoff from tropical watersheds coastal water quality and productivity. Applied Geochemistry 22: 1777-1797.

Delwyn, S.O. 2003. USGS fact sheet. Surface Water in Hawaii.

Klein, R.D. (1979). Urbanization and Stream Quality Impairment. Water Resources Bulletin 14: 948- 963.

Mālama Maunalua. (2009). Maunalua Bay Conservation Action Plan, A Community's Call to Action.

NOAA. (2017). Climate Data Online. Retrieved from https://www.ncdc.noaa.gov/cdo-web/.

Rabalais, N.N, Diaz R.J., Levin L.A., Turner, R.E., Gilbert, D. & Zhang, J. (2010). Dynamics and distribution of natural and human-caused hypoxia. Biogeosciences, 7:585-619.

Rogers, C.S. (1990). Responses of coral reefs and reef organisms to sedimentation. Mar Ecol Prog. Ser Oldend 62:185–202.

Trenberth, K. E. (2011). Changes in precipitation with climate change. Climate Research 47:123-138.

Wolanski, E., Martinez, J.A., & Richmond, R.H. (2009). Quantifying the impact of watershed urbanization on a coral reef: Maunalua Bay, Hawaii. Estuarine, Coastal and Shelf Science, 84(2), 259-268.