A Comparative Study of Passive versus Dynamic Sea-Level Rise Inundation Models for the Island of Kauai

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Introduction

- Sea level rising steadily since beginning of 20th Century at ~1.8mm/yr
  - Increased to 3.0mm/yr after 2000
  - Attributed to increase in anthropogenic CO$_2$
IPCC AR5 scenarios project 0.80 m rise from 1996-2100.

- 0.82 m projected for Hawaiian Islands, where sea level has risen at 0.15 cm/yr for last century
  - slower due to Pacific wind and circulation patterns
Ways to model sea-level rise: Bathtub vs Dynamic Models

1) GIS-based Passive “Bathtub” Models

Present

Future with Sea-level Rise

Mean Sea Level = +0.6 m above Mean Sea Level

2) Dynamic Model that Includes Wave-driven Set-up and Run-up

Present

Future with Sea-level Rise

Mean Sea Level = +0.5 m above Mean Sea Level

Mean Sea Level = +1.8 m above Mean Sea Level

Set-Up = Run-Up = Limit of Inundation

Set-Up = a rise in sea level above the mean sea level inshore of the initial point of wave-breaking produced by cross-shore gradients in momentum flux

Run-Up = maximum vertical extent that wave-driven swash reaches above the water level [mean sea level = set-up]
Study Site

**Kauai:** Northern most and oldest inhabited Hawaiian Island
- 5.7 million years old
- 75 km of sandy beaches, 71% classified as eroding
- Majority of residents live at or near sea level
- 3 locations chosen to represent different onshore and offshore conditions
Hanalei Bay
Summer, 2013
Kapa’a

Summer, 2012

Summer, 2014
Waimea
2012
Methods

• GIS based study
  – ArcGIS 10.1
• 3 m DEM
  – Referenced to LMSL and NAD83
• Four methods used to show inundation at 0.0, 0.5, 1.0, 1.5, and 2.0m of sea level rise
• Satellite images georectified for use in ArcMap
• Inundation maps created to compare methods and to show extent of inundation under different scenarios
Method 1 - Bathtub Model

- Treats sea level rise as a non-dynamic increase of a flat ocean surface (like a tub full of water)
- Shows any elevation less than each increment of sea-level rise
  - Raster Calculator
    → Conditional statement
    → Binary Raster
Method 2 - Include Tidal Data

- Shows low lying areas and impact of high tides
- Region specific tidal data from NOAA
  - Digital Coast Sea-Level Rise and Coastal Flooding Impacts
  - Tides and Currents database
- MHHW to show maximum inundation
  - Average MHHW value added to SL rise increment
- Map algebra
  - Conditional Statement
    → Binary Raster
Method 3- Tides and Wave Set-Up

- Set-up: increase in water levels near shore where waves are breaking
- Assumes that as sea level rises, the depth of the water column over the reefs increases too
- Following were added to SL increment and tides:
  - beach slope
  - shoaling factor (wave height in shallow water : wave height in deep water)
  - wave set-up
Method 4-
Tides + Wave Set-Up + Wave Run-Up

• Stockdon Equation:

\[
R_{2\%) = 1.1(0.35\beta_f(H_0L_0)^{1/2} + \left[H_0L_0(0.563\beta_f^2+0.004)\right]^{1/2})}
\]

- \(\beta_f\) = slope
- \(H_0\) = significant wave height
- \(L_0\) = wavelength
- \(R_{2\%) = 2\%\) exceedance run-up elevation

• Run-up values added to tidal, set-up, and sea level rise increments in Map Algebra to create binary rasters
Results - Hanalei Bay

Method #1

Method #2

Method #3

Method #4
Kapa’a

Method #1

Method #2

Method #3

Method #4
Waimea

Method #1

Method #2

Method #3

Method #4
• **Kapa’a** - least inundation
  – Greater wave run-up but steeper beach slope
  – Higher inland elevation

• **Waimea** - most inundation
  – Lowest wave run-up but lowest beach slope
  – Low inland elevation

• **Hanalei** - greatest wave run-up
  – Steeper beach slope and wider beach width
Discussion

- Limitations to all methods
- Can provide upper and lower bounds for inundation
- Passive models can be used to represent everyday conditions
- Dynamic models can be used to represent extreme conditions
Options for the Future

• **Option 1: Do nothing**
  – Popular reaction (wait and see, leave it for later)
  – Short sighted and can lead to future complications

• **Option 2: Continue to enforce setback laws**
  – Limits number of coastal protection structures, maintains public beach access, prevents new buildings from being built within 40 ft of shoreline
  – May need to be modified as sea level rises

• **Option 3: Build more protection structures**
  – Provides some protection to existing structures
  – May need to be rebuilt, can cause increased erosion on flanking sides, can impact public beach access
Conclusions

• Sea-level rise is no longer a what if question but rather a when question.
• Coastal communities need realistic models in order to plan for future inundation.
• Models should be region specific and dynamic.
• Assessing regional vulnerabilities can help in planning for future action.