Modeling Effects of Humans and Climate on Groundwater Resources of Hawaii's Volcanic-Rock Aquifers

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1. Abstract

The volcanic-rock aquifers of Kauai, Oahu, and Maui are stressed, leading to concerns related to the effects of groundwater withdrawals on saltwater intrusion and streamflow. A numerical modeling analysis using the most recently available data (for example, information on recharge, withdrawals, hydrogeologic framework, and conceptual models of groundwater flow) will substantially advance current understanding of groundwater flow and provide insight into the effects of human activity and climate change on Hawaii's water resources.

Three island-wide groundwater-flow models were constructed using MODFLOW 2005 coupled with the Seawater-Intrusion Package (SWI2), which simulates the transition between saltwater and freshwater in the aquifer as a sharp interface. This approach allowed relatively fast model run times without ignoring the freshwater-saltwater system at the regional scale. Model construction (FloPy$_3$), systematic parameter estimation (PEST), and analysis of results were streamlined using Python scripts.

Model simulations include pre-development (1870) and current (average of 2001-10) scenarios for each island. Additionally, scenarios for future withdrawals and climate change will be simulated for Oahu. We present our streamlined approach and example outputs of the model that will be used to estimate effects of human activity on the groundwater resource by quantifying decline in water levels, reduction in stream base flow, and rise of the freshwater-saltwater interface.

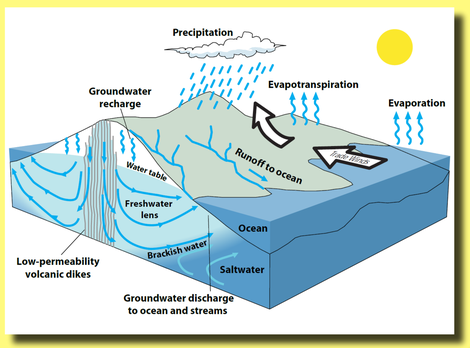
2. Motivation

Challenges

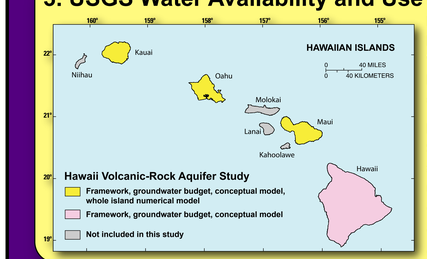
- Limited capacity of island aquifers to retain and store fresh groundwater
- Sharp contrasts in climate, geology, and hydrology

Scope

- Describe current condition of water resources in Hawaii volcanic aquifers
- Determine effects of human activities
- Evaluate responses to future stresses



3. USGS Water Availability and Use Science Program



Part I

Izuka, S.K., et al., in press, Volcanic aquifers of Hawai'i — Hydrogeology, water budgets, and conceptual models: USGS SIR 2015-5164

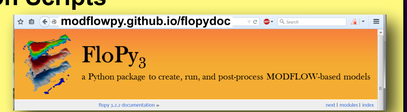
Part II

Simulate steady-state groundwater flow and freshwater-saltwater interface (MODFLOW / SWI2)

- 2001-10 average conditions
- Pre-development conditions
- Future scenarios (Oahu only)

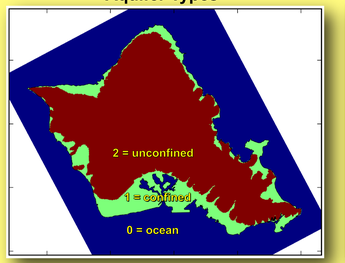
4. Modeling Using Python Scripts

- Instantaneous execution
- Readable files: easy to catch and correct errors
- Consistency: ensure individual modelers in a team use the same approach
- Reproducibility: a script is a record of the entire modeling or data-analysis process
- Python: free and open-source computer language



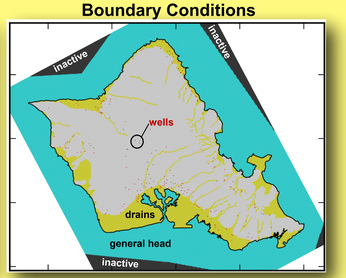
5. Input Grids

Aquifer Types



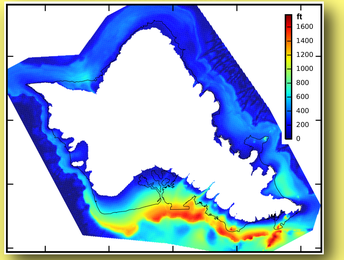
Intersect model grid with coastline and zero-ft contour of basalt → Integer grid

Boundary Conditions



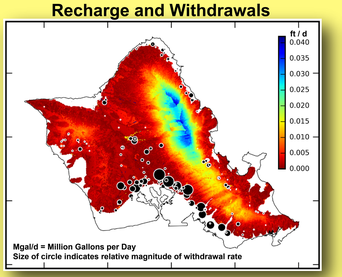
Apply integer grid of aquifer types to define boundary conditions on a cell-by-cell basis

Sediment Thickness



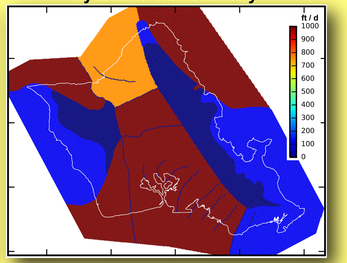
Subtract elevation of basalt from surface elevation → Caprock thickness

Recharge and Withdrawals



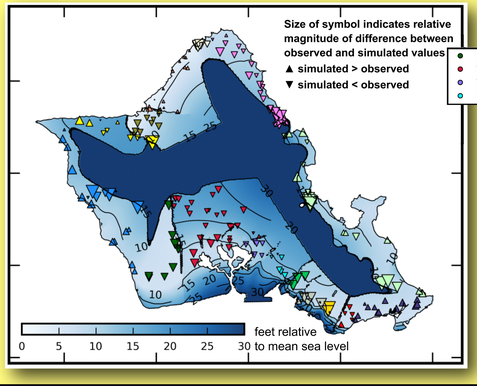
Total basalt recharge: 560 Mgal/d
Total basalt withdrawal: 197 Mgal/d

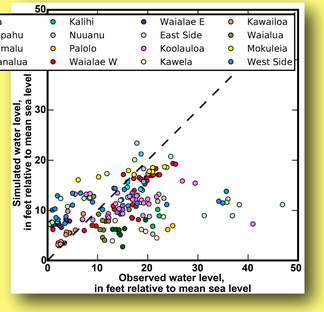
Hydraulic Conductivity



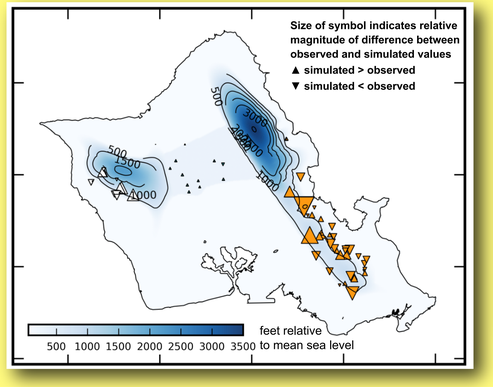
Apply integer grid of aquifer zones and boundaries to define hydraulic parameters

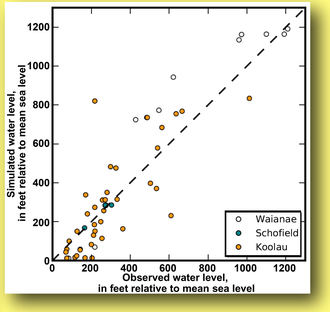
6. Examle Outputs 6a. Freshwater-Lens Water Levels



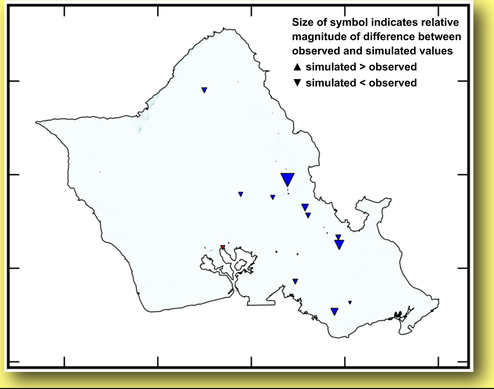


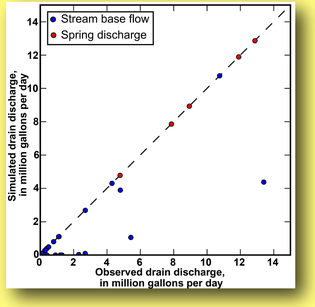
6b. Inland High Water Levels



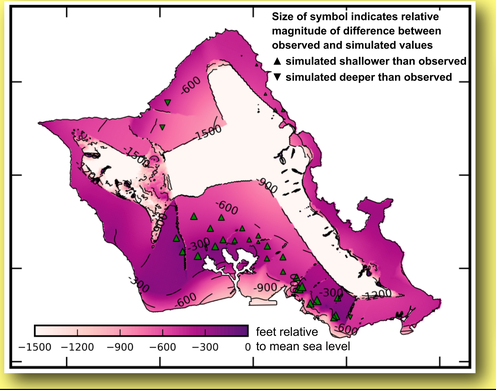


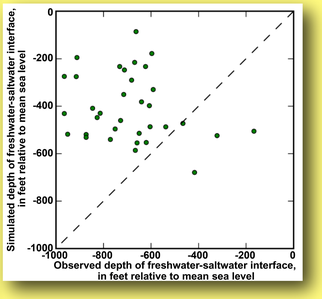
6c. Stream and Spring Discharge





6d. Depth of Freshwater-Saltwater Interface





7. Next Steps

- Calibrate numerical model
- Use systematic parameter estimation: PEST
- Run the calibrated model
  - with pre-development recharge and without withdrawals
  - future climate scenarios
- Assess changes in
  - water levels & discharge to streams and ocean
  - freshwater volume (freshwater-saltwater interface to water table)
- Compare results of Kauai, Oahu, and Maui