Improving Hawaii's *Groundwater Flow Models* in areas with elevated *Geothermal Resource potential*, including Red Hill

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Project Background

- Department of Energy – Geothermal Technologies Office
  Grant EE06729
- Team: Don Thomas, Garrett Ito, Neil Frazer, Steve Martel
  Robert Whittier, Erin Wallin, Nick Hinz, students
- Phase 1 (completed):
  (1) Identify, obtain, and compile existing geothermal relevant data across HI
  (2) Rank each dataset in terms of its ability to indicate qualities necessary for resource (subsurface Heat, Fluid, Permeability)
  (3) Develop geostatistical method to produce resource probability map for entire state
- Phase 2 (Feb 2016, through June 2017):
  - exploration in areas of interest, including groundwater.
Project Background

(1) **Identify, obtain, and compile** existing geothermal relevant data across HI.

(2) **Rank** each dataset in terms of **Heat, Fluid Permeability**

- **Heat**
  - Well Temp \( (9) \)
  - Cl/Mg ratio, Gravity \( (8) \)
  - Caldera \( (7) \)
  - Rift Zone, Resistivity, \( \text{SiO}_2 \) \( (6) \)
  - Vent, Dikes, Cl/SO\(_4\) \( (4-5) \)
  - Hawaiian Place Names \( (3) \)

- **Fluid**
  - Water table elevations \( (9-10) \)
  - Resistivity \( (9-10) \)
  - Recharge \( (9) \)

- **Permeability**
  - Rift Zone, Faults \( (8) \)
  - Calderas \( (8) \)
  - Geodetic Strain \( (8) \)
  - Seismicity \( (8) \)
  - Gravity \( (6) \)

Rely on accurate **Groundwater Flow Models** to be meaningful.
Hawaii’s Groundwater Flow Models

• Most existing models assume groundwater flow perpendicular to contour’s of water table elevation

(From Oki, 2005)

• Error:
  - Measurement uncertainty
  - Unknown subsurface structures
  - Lack of data (wells)

(From TEC, Inc; 2005)
Result: lack of confidence in groundwater flow models for most of state.
Improve Groundwater Flow Models

**Why?**
- Improve geothermal resource assessment
- Assist in water resource planning (e.g. usage)
- Source water protection (e.g. contamination)

**How?**
- **Isotopic tracers**
- More and improved water chemistry data
- Statistical methods to ID patterns

Example: West Hawaii study (Fackrell et al., in press)
West Hawaii Study

3 Volcanoes

Legend
- Study Area
- Hualalai
- Mauna Kea
- Mauna Loa
West Hawaii Study

5 Aquifers

2 Conceptual Models for Groundwater Flow
**Conceptual Model 1:** Groundwater flows within aquifer boundaries
- Groundwater from Mauna Loa flows around Hualalai

**Conceptual Model 2:** Groundwater flows from flanks of M. Loa to coast
- Hualalai and Mauna Loa water mix
Oxygen Isotopes

Predictable relationship between elevation of precipitation (recharge) & $\delta^{18}O$

“Light” Oxygen 16

“Heavy” Oxygen 18

- Can analyze isotopic ratios with great precision

- Isotopic composition expressed as $\delta^{18}O$
  - ratio of $(^{18}O/^{16}O)_{sample} : (^{18}O/^{16}O)_{seawater}$
  - $\delta^{18}O$ seawater $\sim 0$
  - Sample isotopically lighter than seawater has negative $\delta^{18}O$
• Light isotope $^{16}$O preferentially evaporates.
• Atmospheric $\delta^{18}$O $< 0$
• Heavy isotope $^{18}$O rains out first.
• $^{16}$O concentrates in clouds
Predictable relationship between precipitation elevation and $\delta^{18}$O.

Data for West Hawaii from USGS (Tillman, 2014)
**Known:**
- amount of recharge
- isotopic composition of recharge

**Model:** expected isotopic composition of groundwater collected along a given flow path (mixing line)

**Measure:** isotopic composition of groundwater collected at well
Results:
Conceptual Model 1

Measured values are lighter than model predicts

Inference: more high elevation water involved.
Results:
Conceptual Model 2

Better match between modeled and measured values.

Some modeled values slightly heavy.
Results favor conceptual model 2. Details warrant further scrutiny.
Phase 1 Results & Phase 2 Prospects
Phase 2 activities

(1) Water sampling campaign (10 locations)
- reliable chemistry data
- improve groundwater flow models

(2) Geophysical Surveys (2 locations)
- infer location, temp of groundwater
- infer presence of dense, impermeable structures

(3) Modeling
- crustal stresses (perm.)
- 3D

Team
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Thanks!
Oxygen and its Isotopes

- Dominant element (by mass) in water ($\text{H}_2\text{O}$)
- Two primary isotopes ($^{16}\text{O}$ and $^{18}\text{O}$)
- Can analyze isotopic ratios with great precision

<table>
<thead>
<tr>
<th>Oxygen 16</th>
<th>Oxygen 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 protons</td>
<td>8 protons</td>
</tr>
<tr>
<td>8 neutrons</td>
<td>10 neutrons</td>
</tr>
<tr>
<td>99.8%</td>
<td>0.20%</td>
</tr>
</tbody>
</table>

"Light" Oxygen

"Heavy" Oxygen

Add 2 neutrons

Isotopic composition expressed are the ratio of $^{18}\text{O}/^{16}\text{O}$ (sample):$^{18}\text{O}/^{16}\text{O}$ (seawater)

- $\delta^{18}\text{O}$ in parts per thousand (‰)
- $\delta^{18}\text{O}$ seawater $\sim 0$ ‰
- If sample water is isotopically lighter than seawater then $\delta^{18}\text{O}$ is negative
Groundwater Flow Model

Features common to both conceptual models
- No flow is allowed into or out of the south, east, and northeast model boundaries
- Recharge adds water to the model
- Water is either captured by wells or discharges at the coast

Conceptual Model 1

Groundwater flow is constrained to within aquifer boundaries
- Groundwater from Mauna Loa flows around Hualalai
- Hualalai and Mauna Loa water don’t mix
The Study Area

- West Hawaii Island
  - Three coalescing volcanoes
  - Five aquifers
    - Rift zones commonly form boundaries
    - Other boundaries along assumed flow lines
Results:
Conceptual Model 2
Unobstructed flow allowed from Mauna Loa to the coast
• Match between isotopic composition of the well water and that modeled improves
• Modeled is a little on the heavy side
• Examples
  • Hualalai Well
  • Komo Well (perched)
  • Waiaha Well
• Areas of significant difference
  • North Keauhou Aquifer
  • North Kiholo Aquifer
Too Light
Too Heavy
Within 1 °/oo
Modeled d18O Error (°/oo)

Conceptual Model 1

Most Negative Error
-3.08
Average Error
1.3
Most Positive Error
3.7
Points with +/- 1 °/oo
38%

Conceptual Model 2

Model simulates too much high elevation water
Model about right!
Model simulates too little high elevation water

Most Negative Error
-2.05
Average Error
1.0
Most Positive Error
3.8
Points with +/- 1 °/oo
63%
Conceptual Model 1

Results

Groundwater flow is constrained to within the aquifer boundaries

- Map shading show the isotopic composition of groundwater as a result of mixing along the flow paths
- Measured (well water) $\delta^{18}O$ tends to be lighter (lighter blue) than what the model predicts
- The model fails to properly simulate the contribution of high elevation recharge at the well intakes
- Examples
  - Hualalai Well
  - Note Komo Well (perched)
  - Waiaha Well