Merging Isotopic Chemistry With Numerical Modeling to Investigate Groundwater Flow Paths

R. Whittier[1], P. Eyre[2], J. Fackrell[3], and D. Thomas[3]

[1]Hawaii Dept. of Health, Safe Drinking Water Branch

[2]Commission on Water Resources Management

[3]University of Hawaii, School of Ocean and Earth Science and Technology

Commission on Water Resource Management

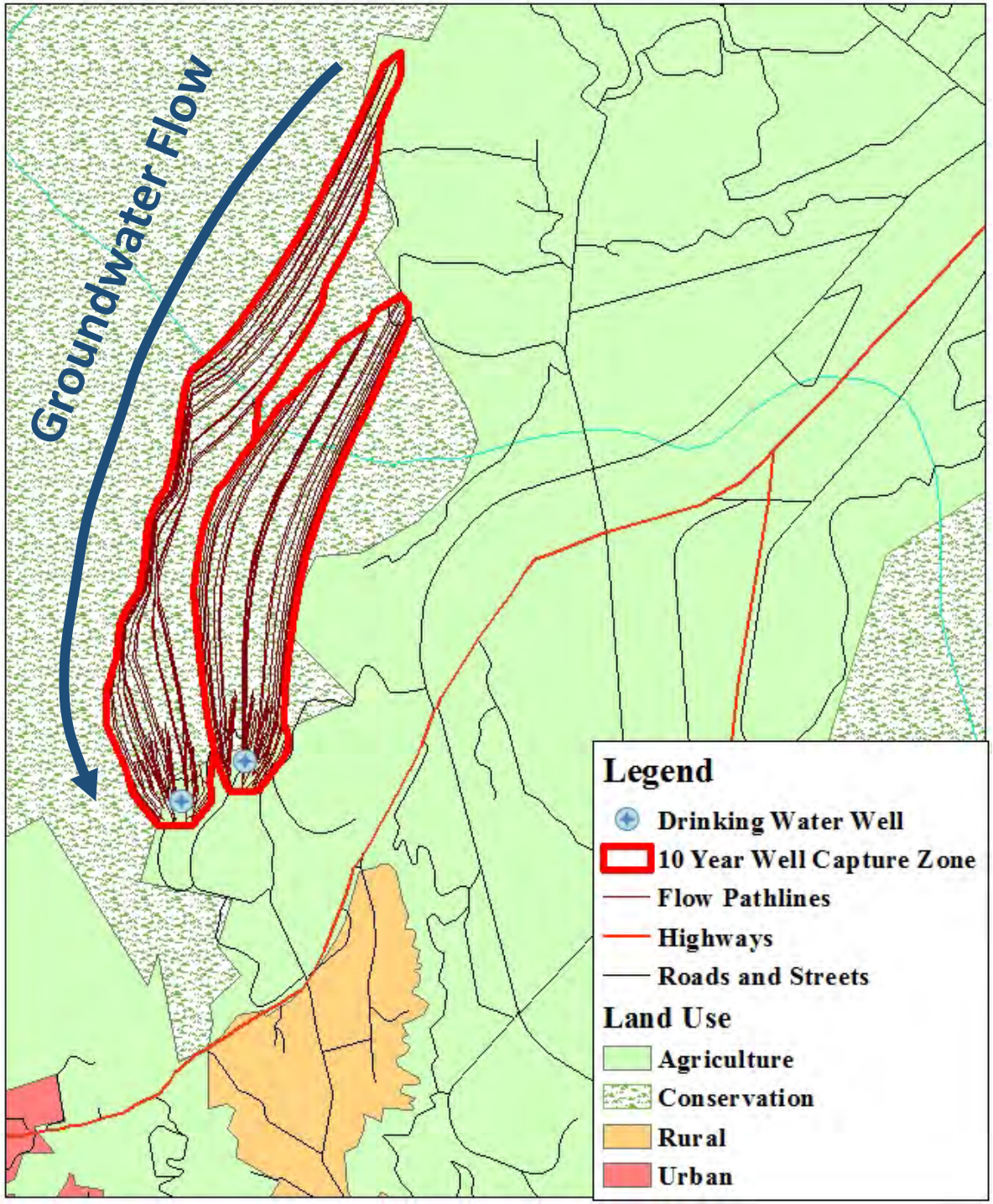
Kona, Hawai'i – May 20, 2015

Introduction

- An inter-agency collaboration to evaluate groundwater flow paths in west Hawaii
- University of Hawaii
  - Original concept of using an isotopic tracer
  - In-depth geochemical knowledge
  - Stable isotope analysis facilities
- Commission on Water Resources Management
  - Desires a review of assumed groundwater flow paths
  - In-depth hydrogeological knowledge
- Hawaii Dept. of Health
  - Needs validation of modeled captures zones for drinking water wells
  - Groundwater modeling expertise

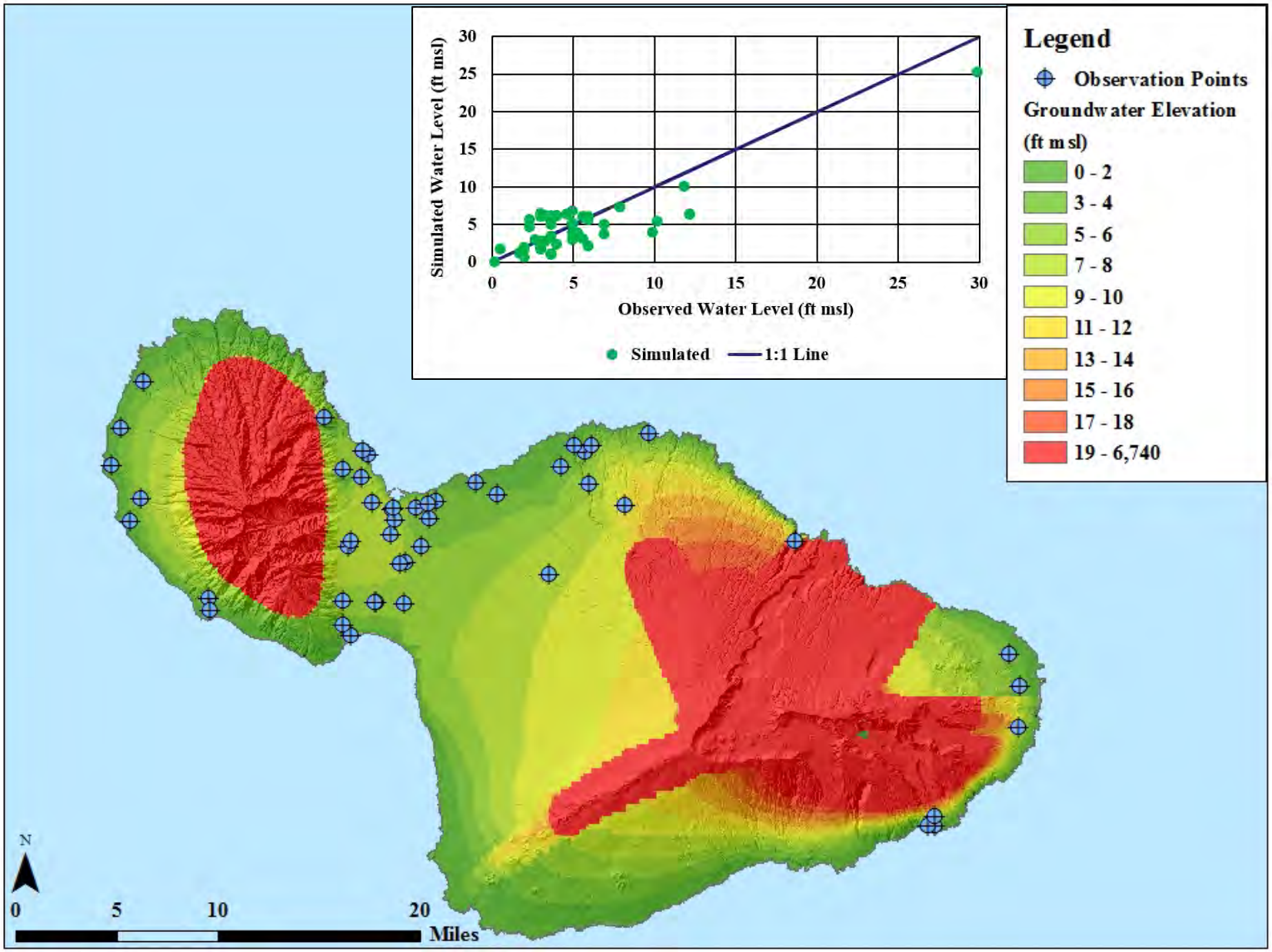
Specific Project Goals

- Test two conceptual models of groundwater flow in West Hawaii
- Investigate the utility of using isotopic tracers to understand groundwater flow paths
- Re-evaluate drinking water well capture zone delineations

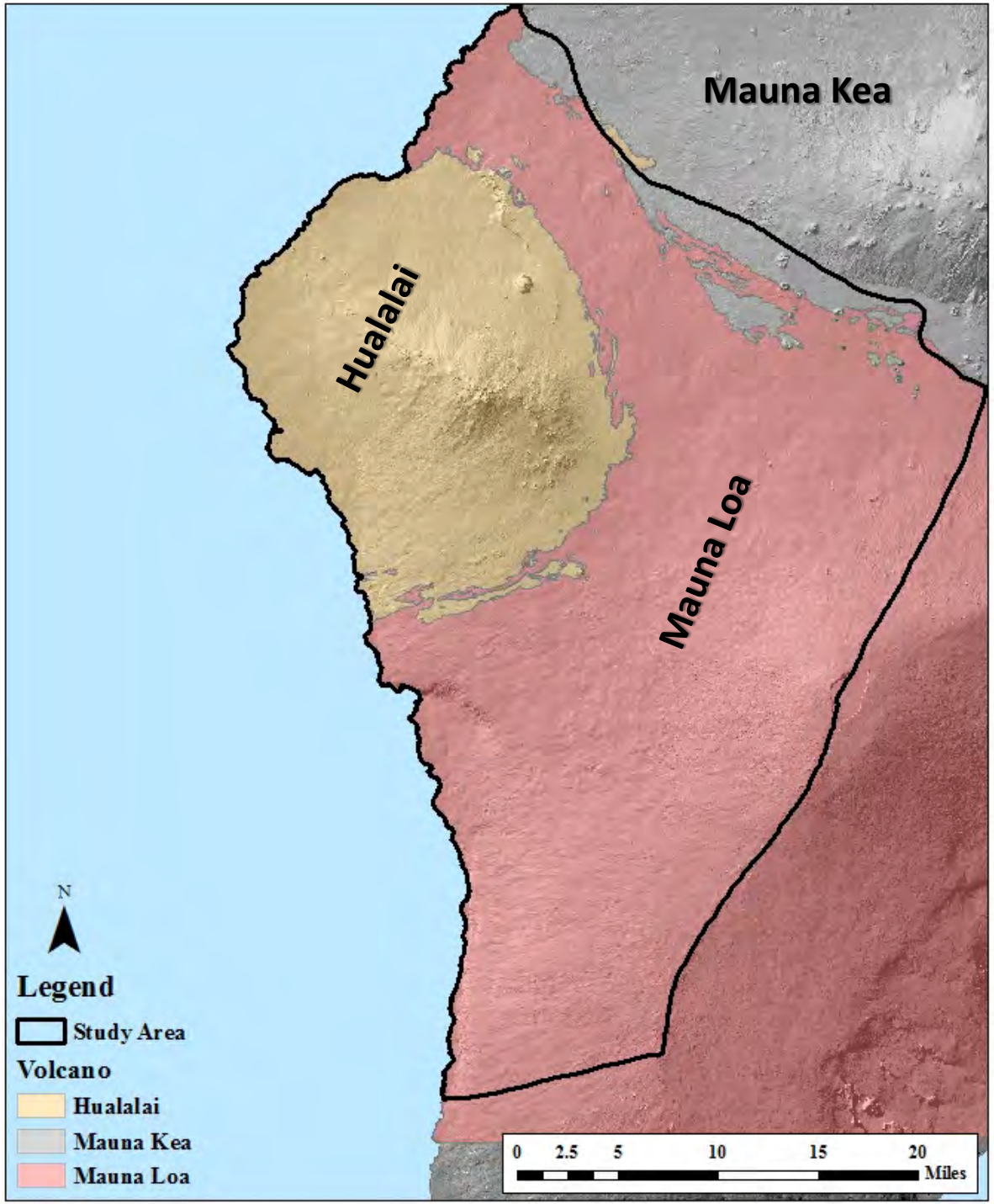


Drinking Well - Capture Zone Delineations

- Done as part of the Source Water Assessment Program
- Created using numerical models
  - MODFLOW to simulate groundwater flow paths
  - MODPATH particle tracking model to identify well capture zones
- Purpose is to identify contributing area for risk assessment and source water protection

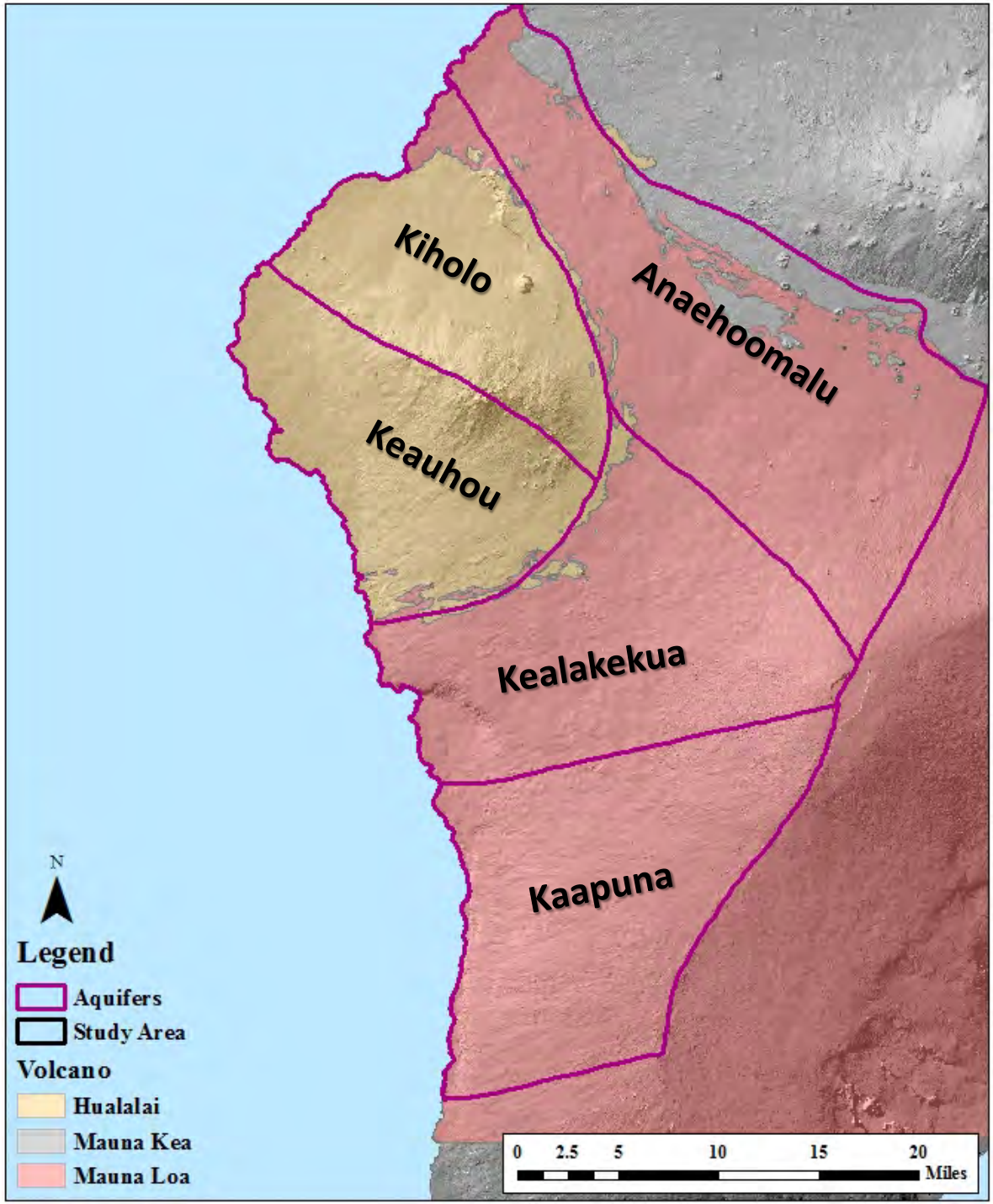


Model Validation



The Study Area

- West Hawaii Island
  - Three coalescing volcanoes



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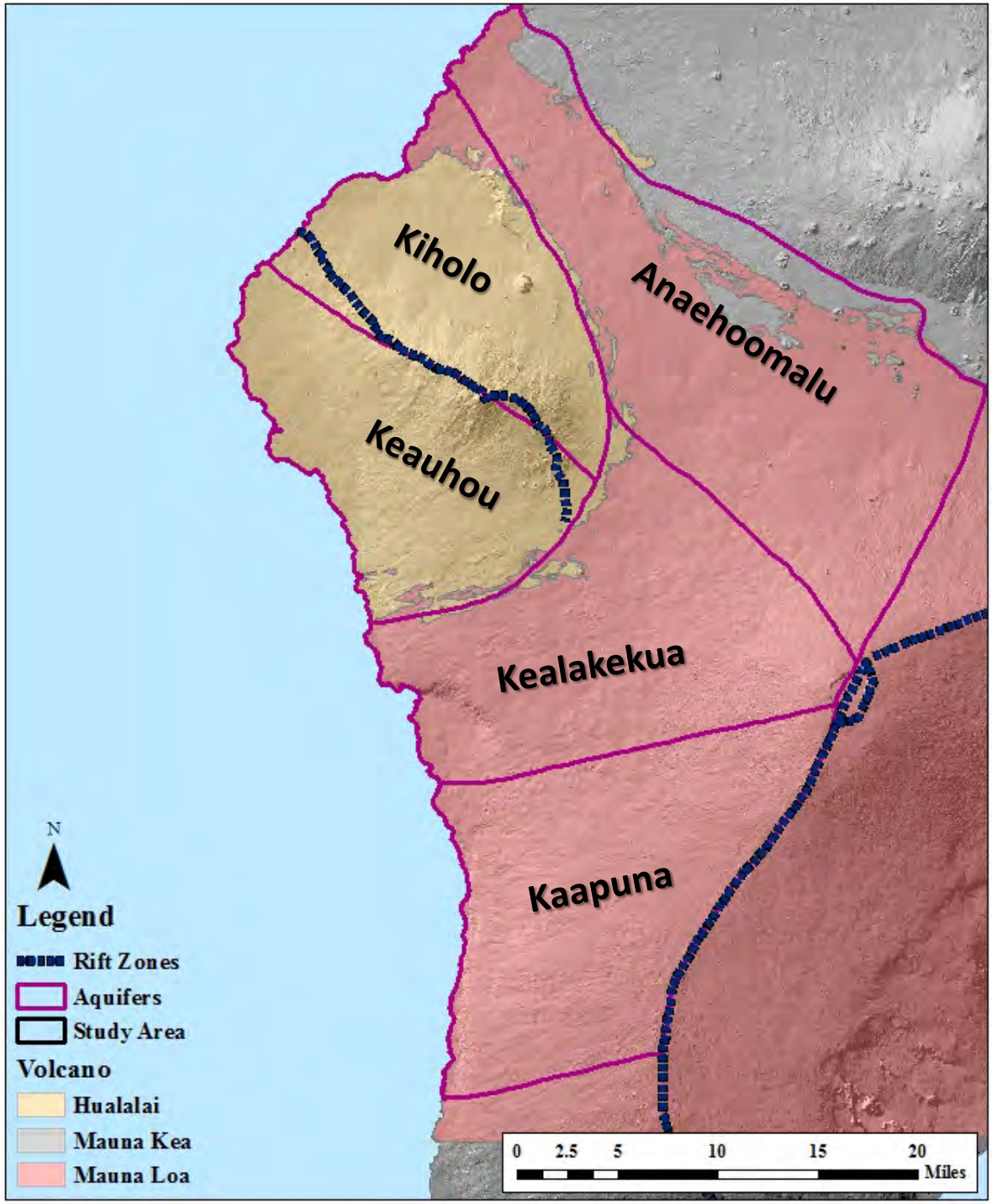

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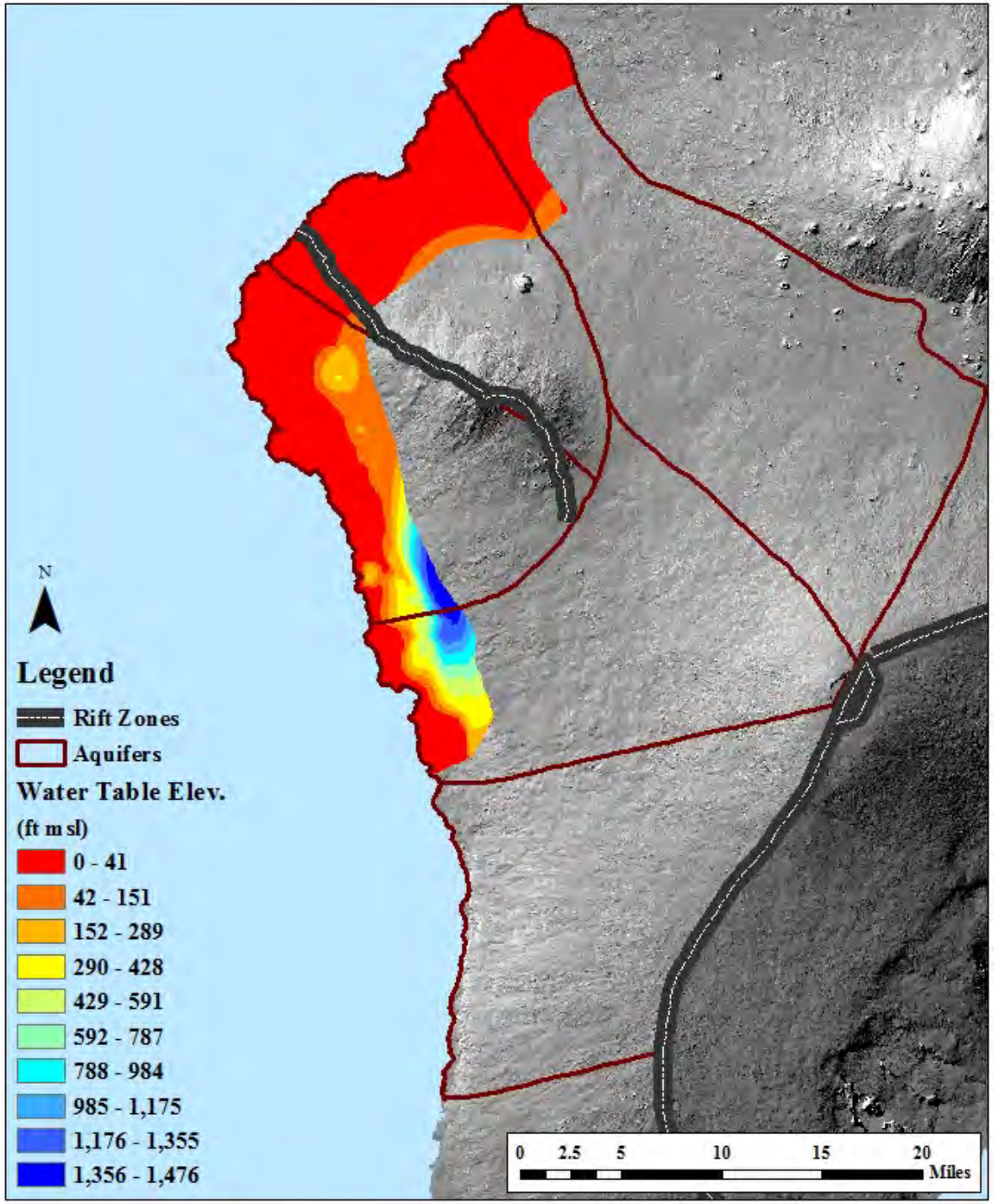
    - Rift zones commonly form boundaries
    - Other boundaries along assumed flow lines



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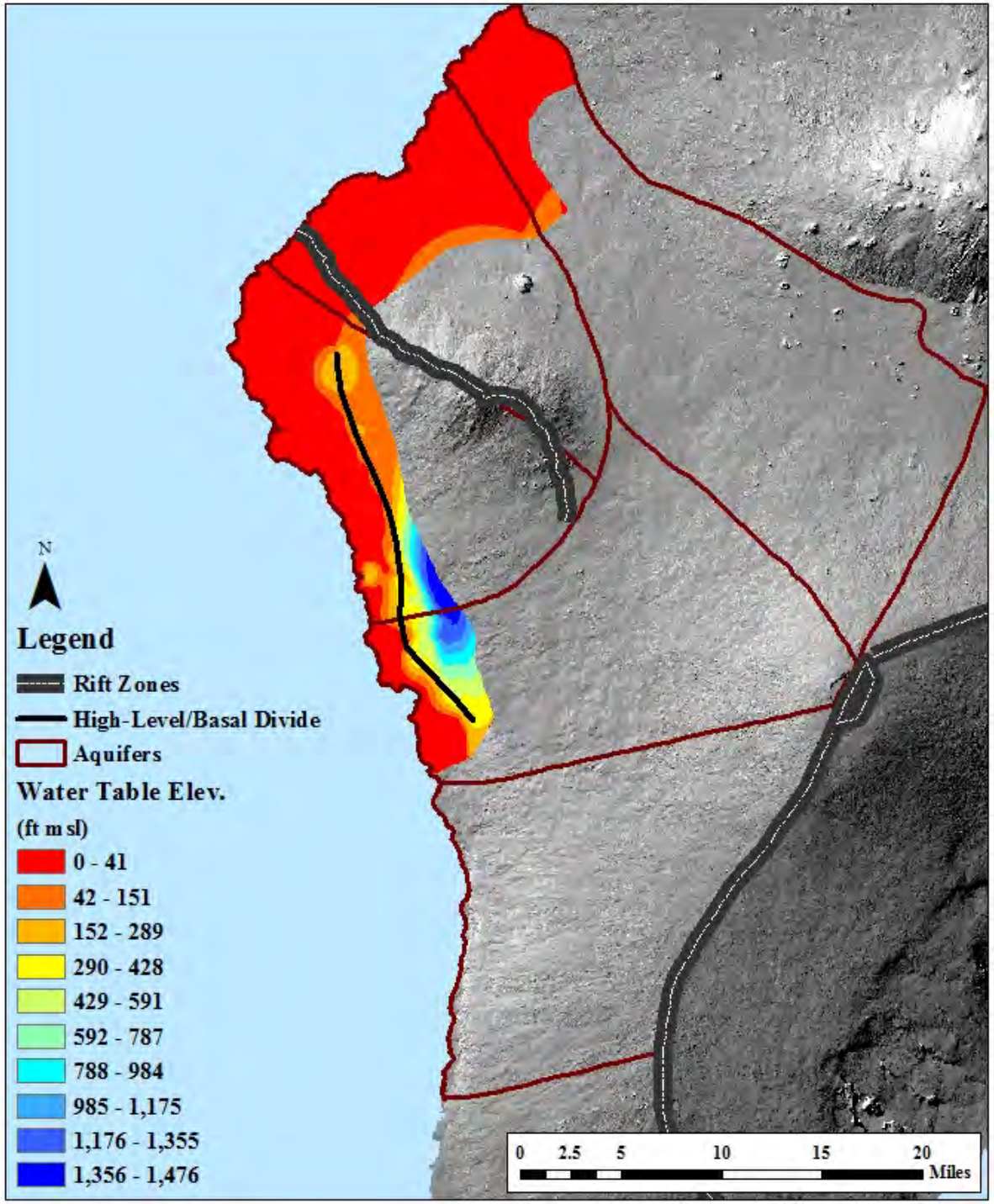
  - Groundwater Elevations



The Study Area

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    - Basal < 10 ft msl
    - High level > 40 ft msl

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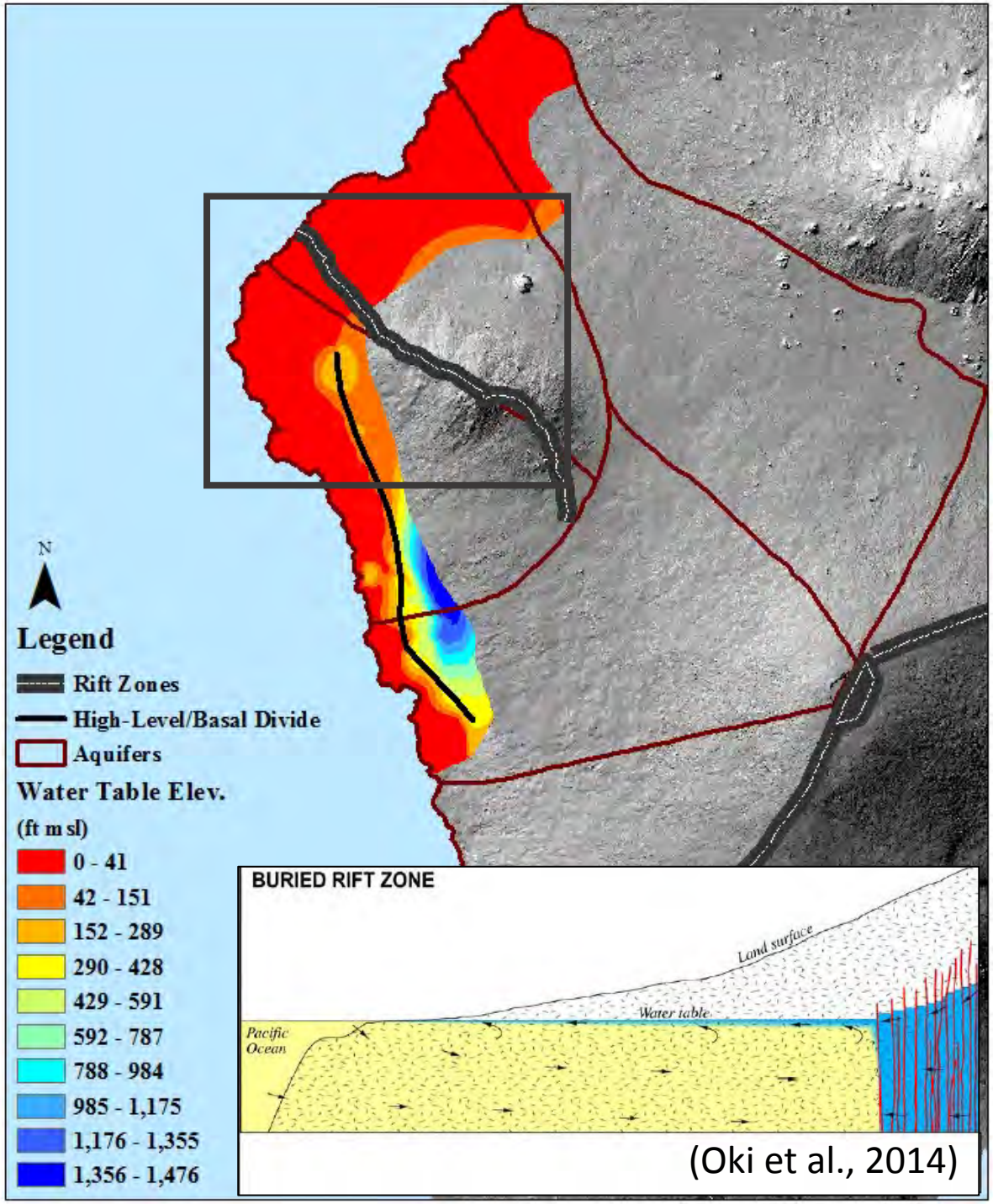
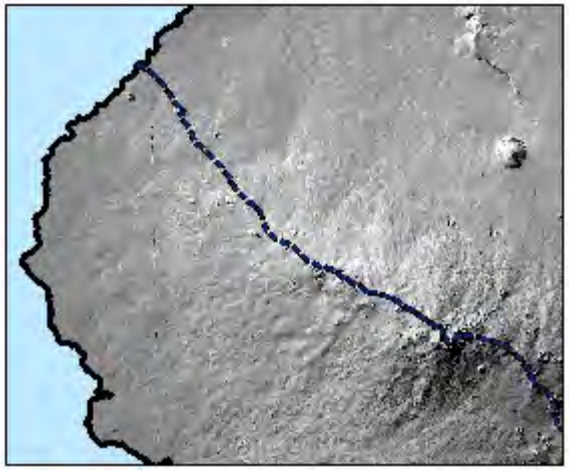
  - What causes the high level water?
    - Buried rift zone



(Oki et al., 2014)



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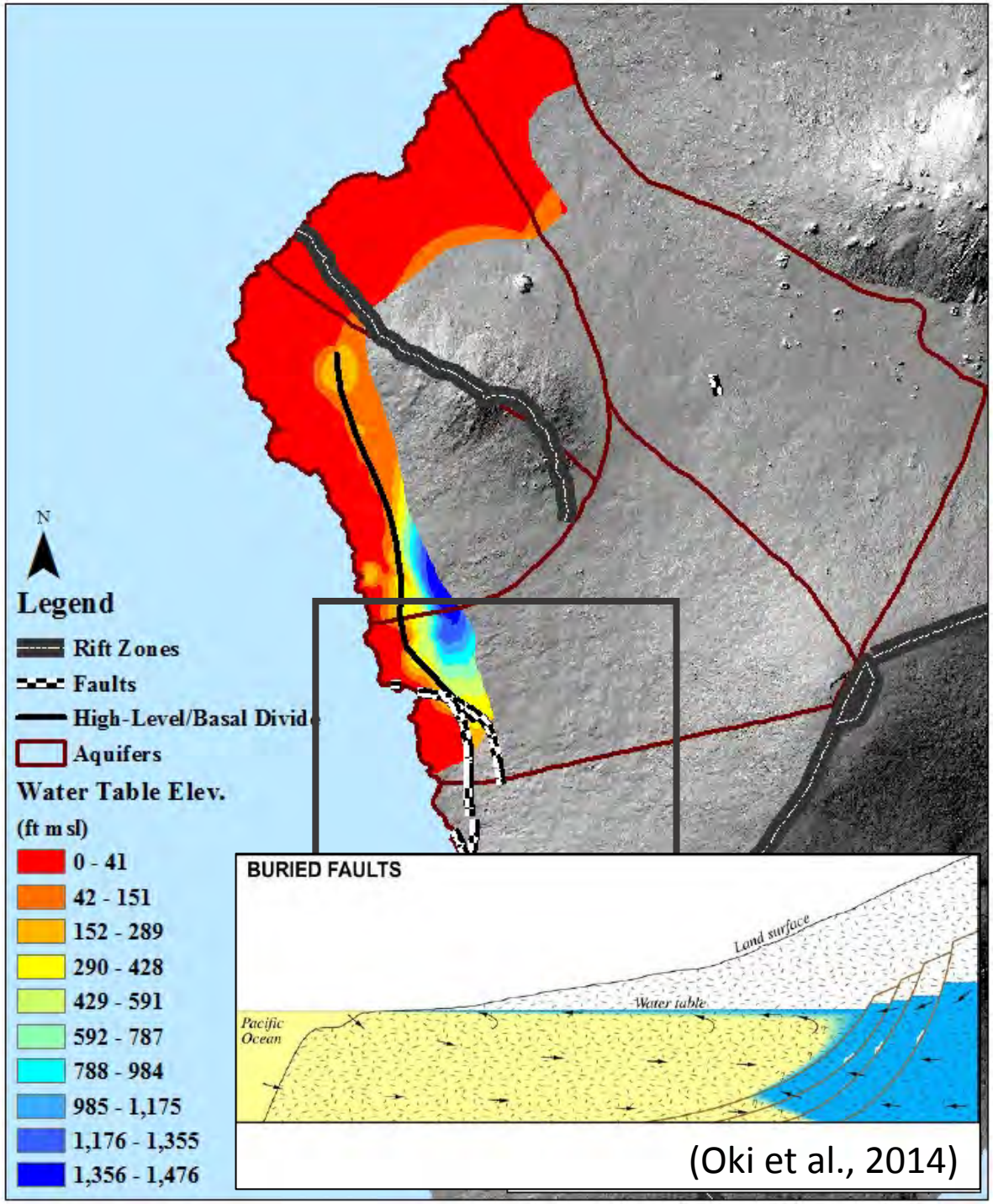

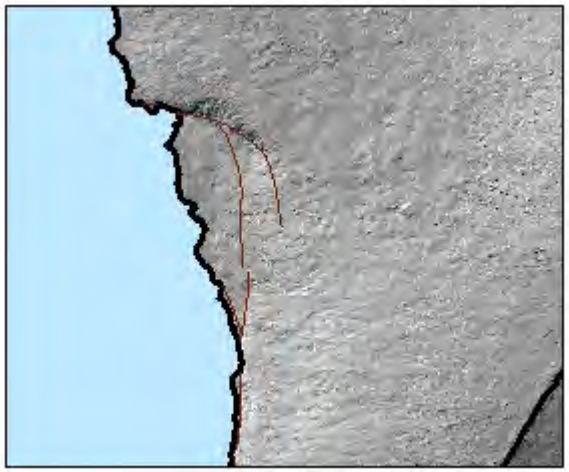

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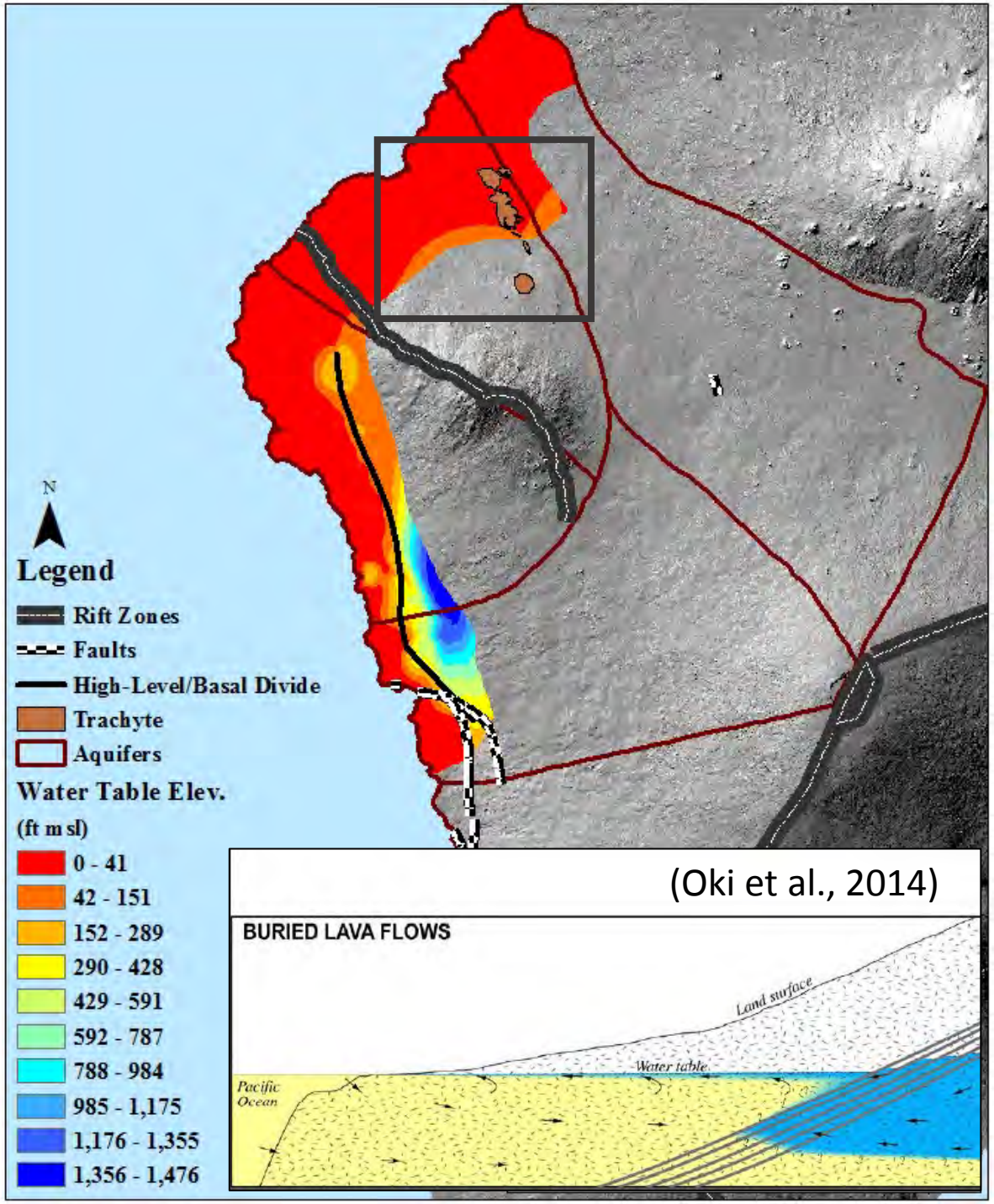
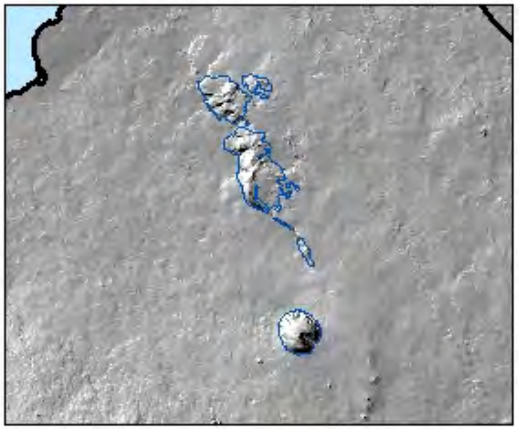
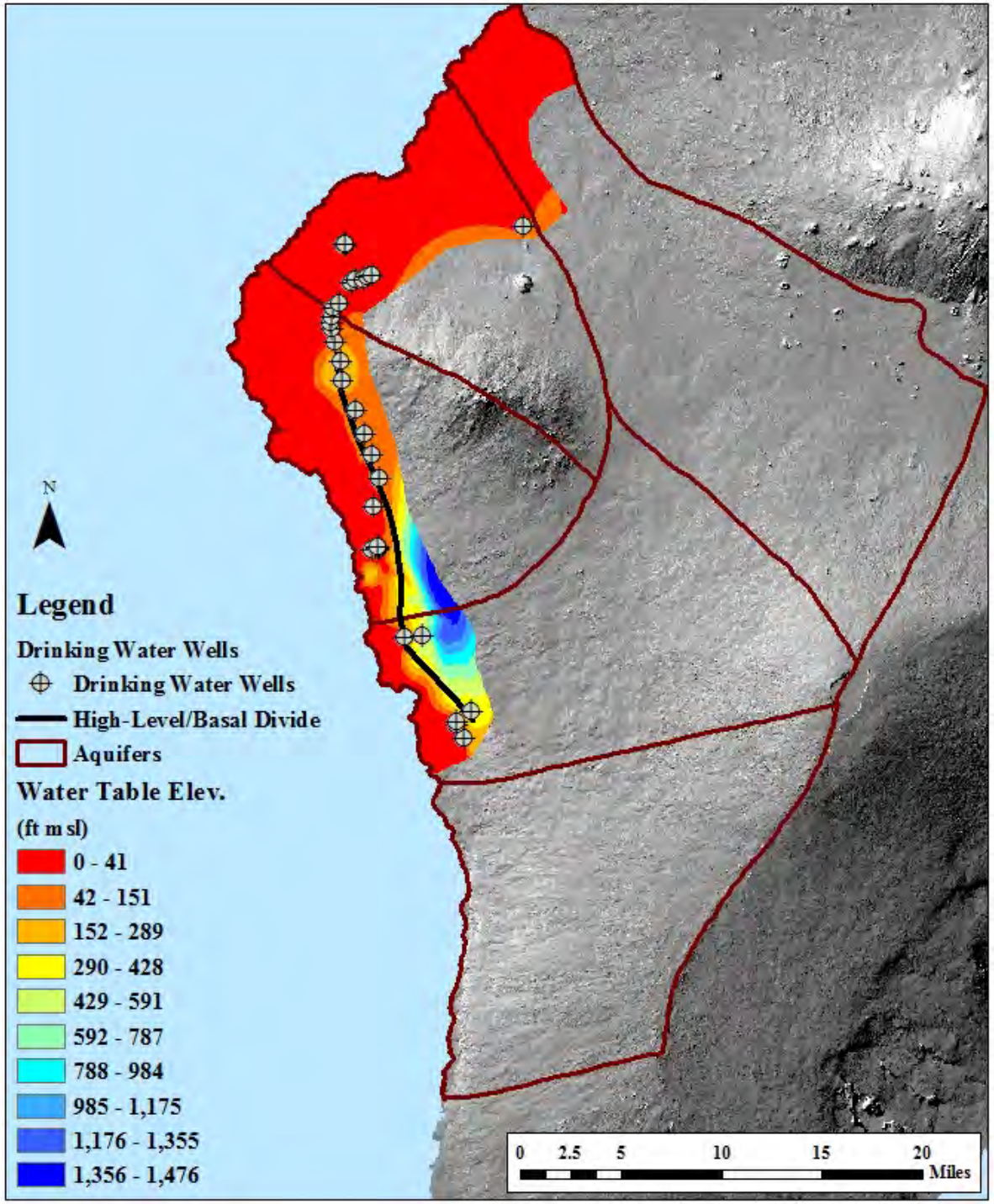
    - Buried dense lava flows

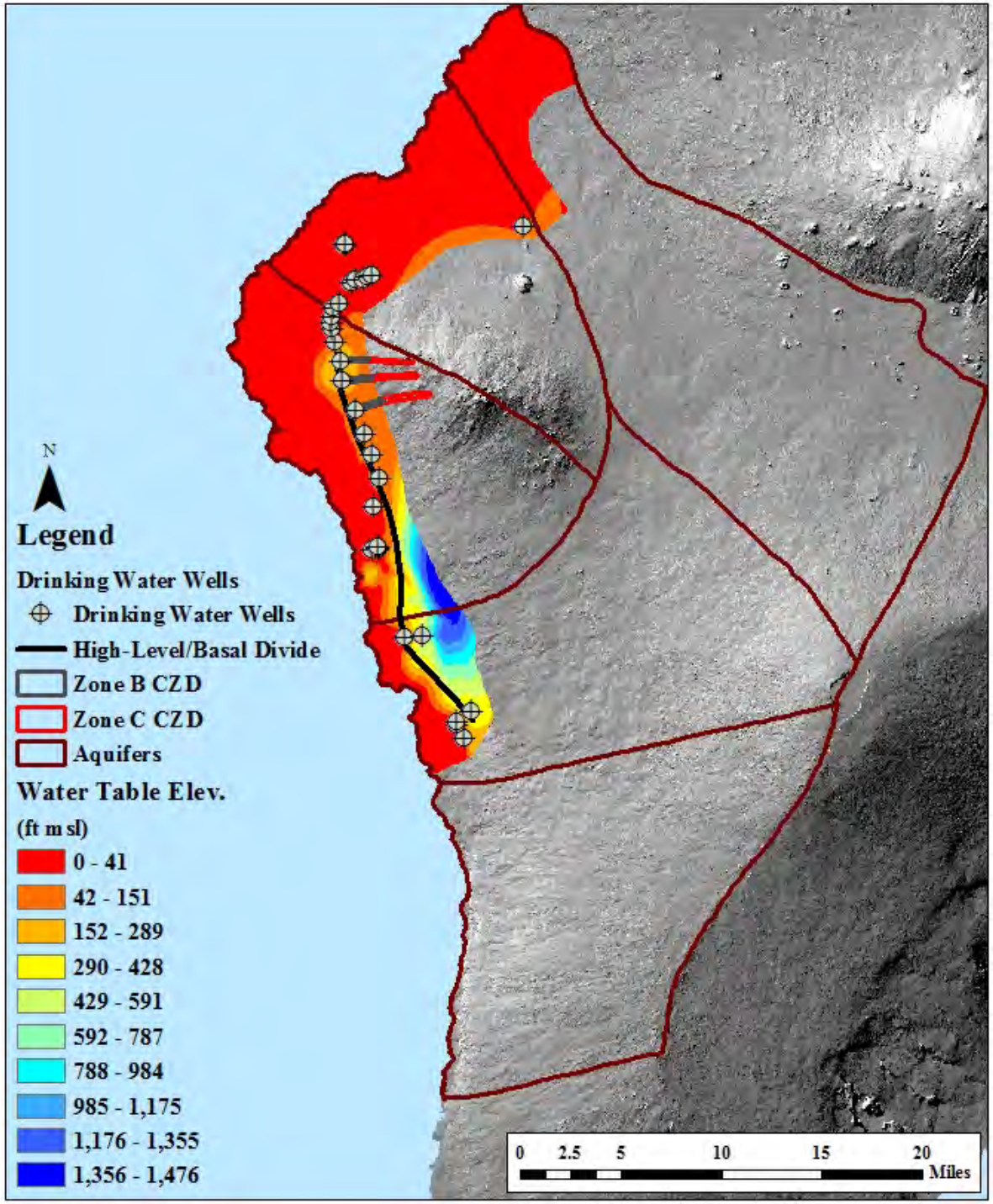






West Hawaii Public Drinking Water Wells

- 30+ Wells



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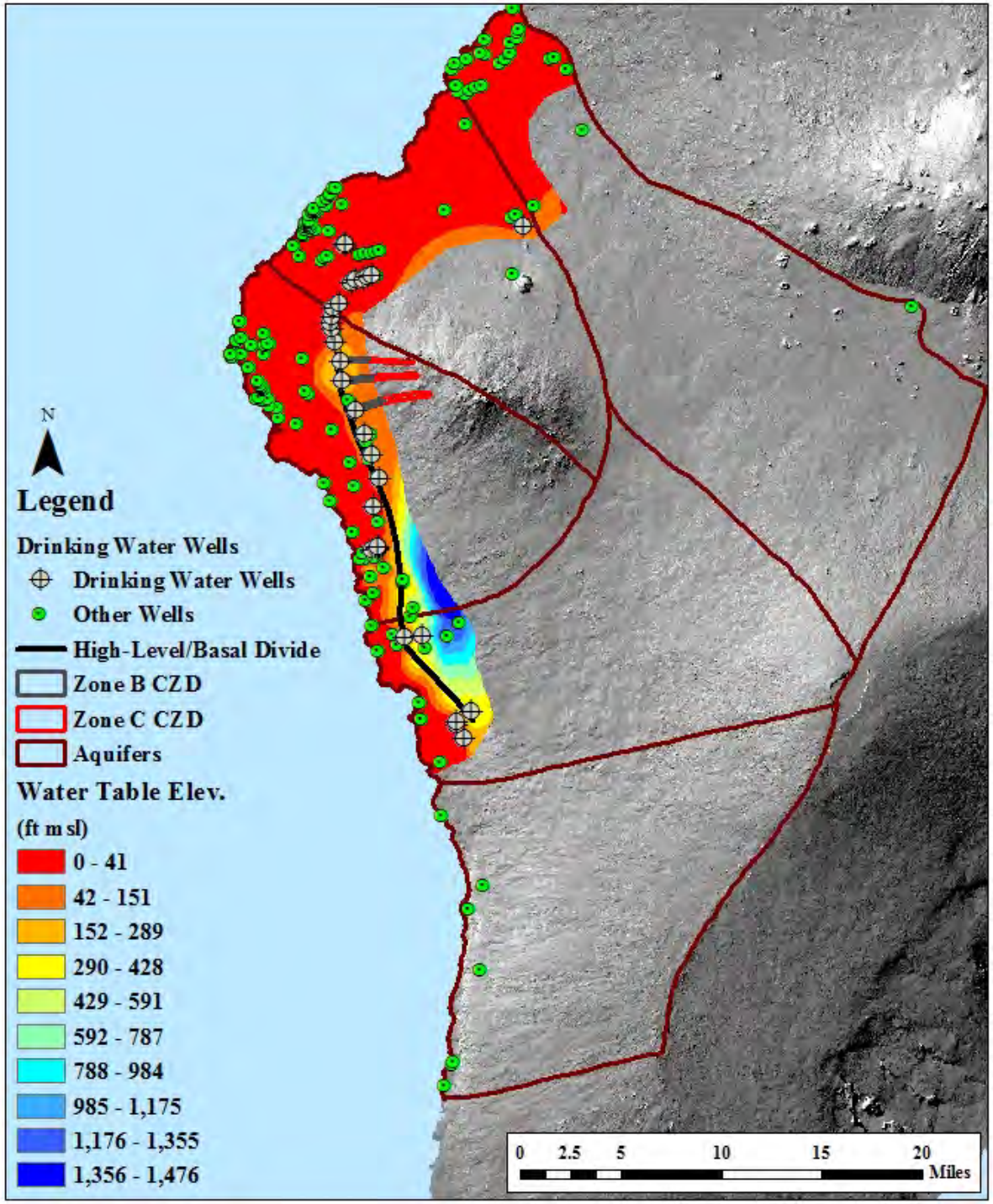
- 30+ Wells
- Need capture zone delineations for each



West Hawaii Public Drinking Water Wells

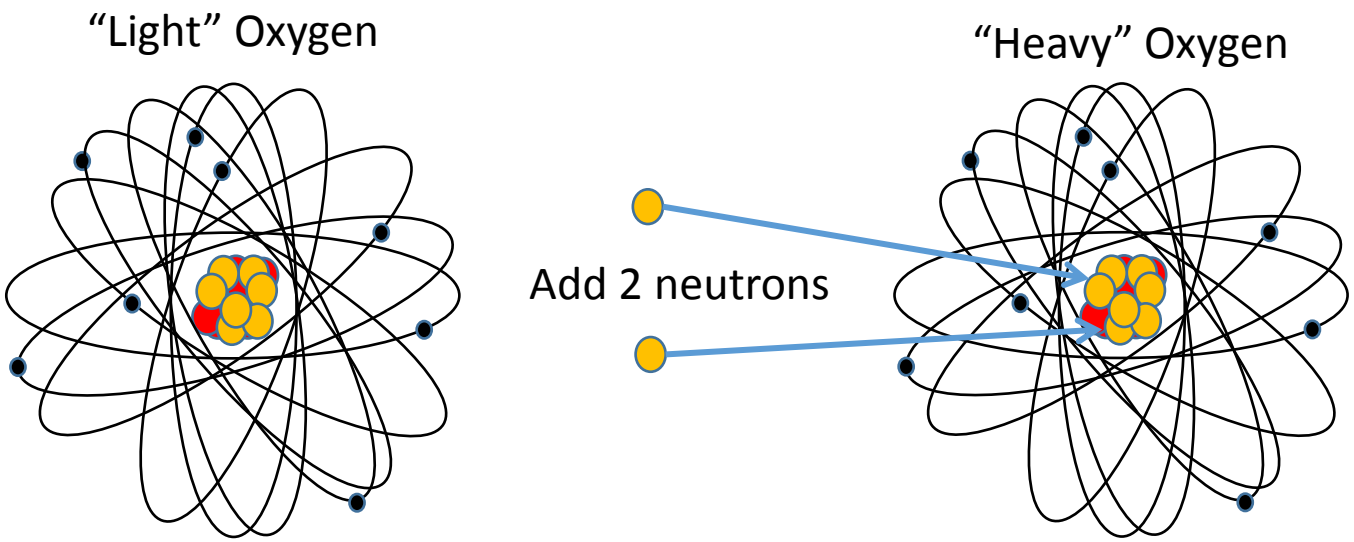
- 30+ Wells
- Need capture zone delineations for each
- No groundwater elevation data upgradient of PWS wells

Groundwater Model Validation Problem

- Insufficient groundwater elevation data
- Still need some metric for model validation
  - Joe's (Fackrell) big idea
    - Use oxygen isotopes as a natural tracer
  - Benefits
    - Know the oxygen isotopic distribution of rain fall
    - Minimal alteration of isotopic composition during recharge
    - Analysis is economical
    - Will be not altered by the unknown nature of the structures that cause the high level water

Oxygen and its Isotopes

- Dominant element (by mass) in water (H_2O)
- Two primary isotopes (^{16}O and ^{18}O)
- Can analyze isotopic ratios with great precision

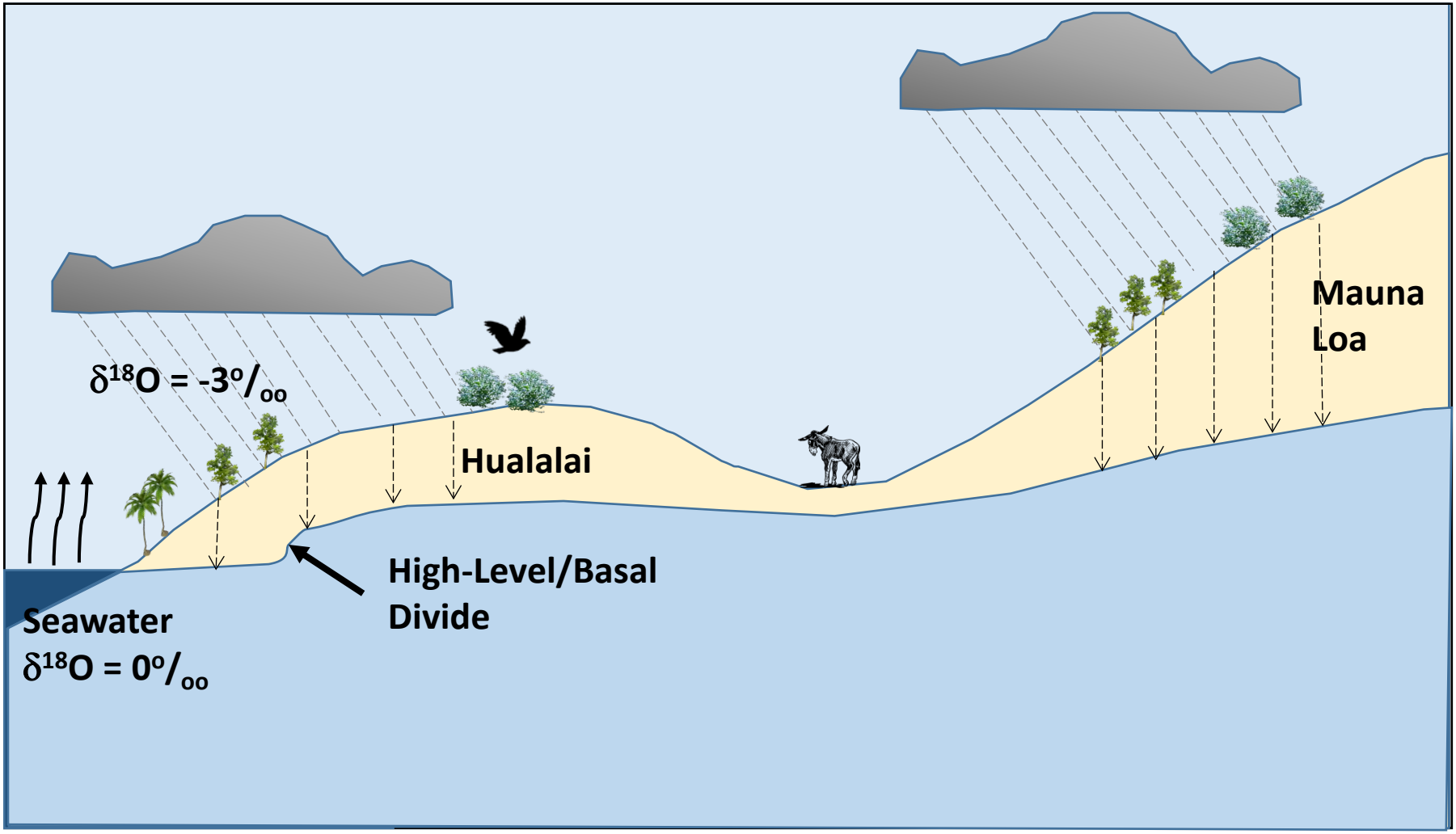


Oxygen 16
8 protons
8 neutrons
99.8%

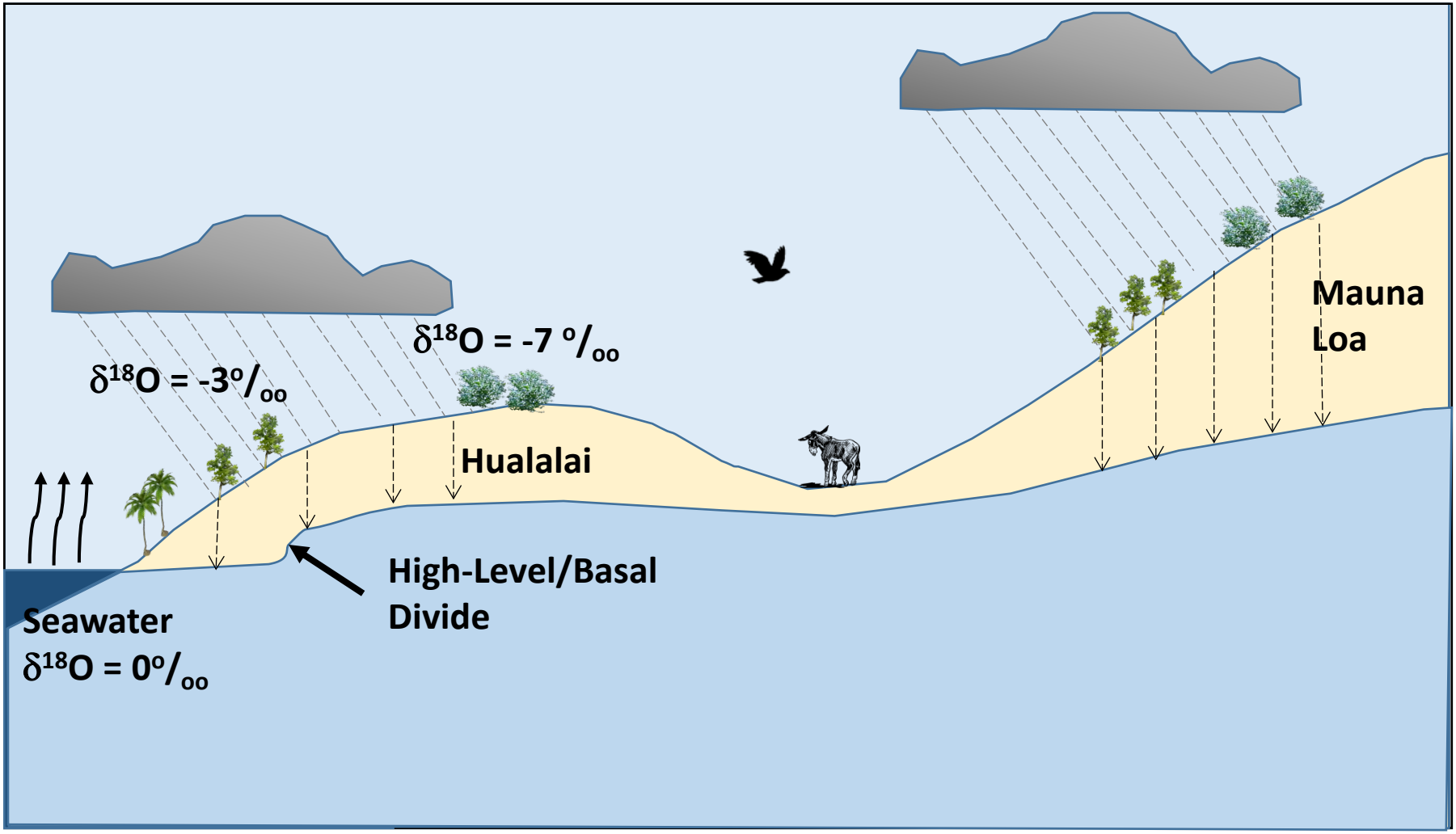
Oxygen 18
8 protons
10 neutrons
0.20%

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

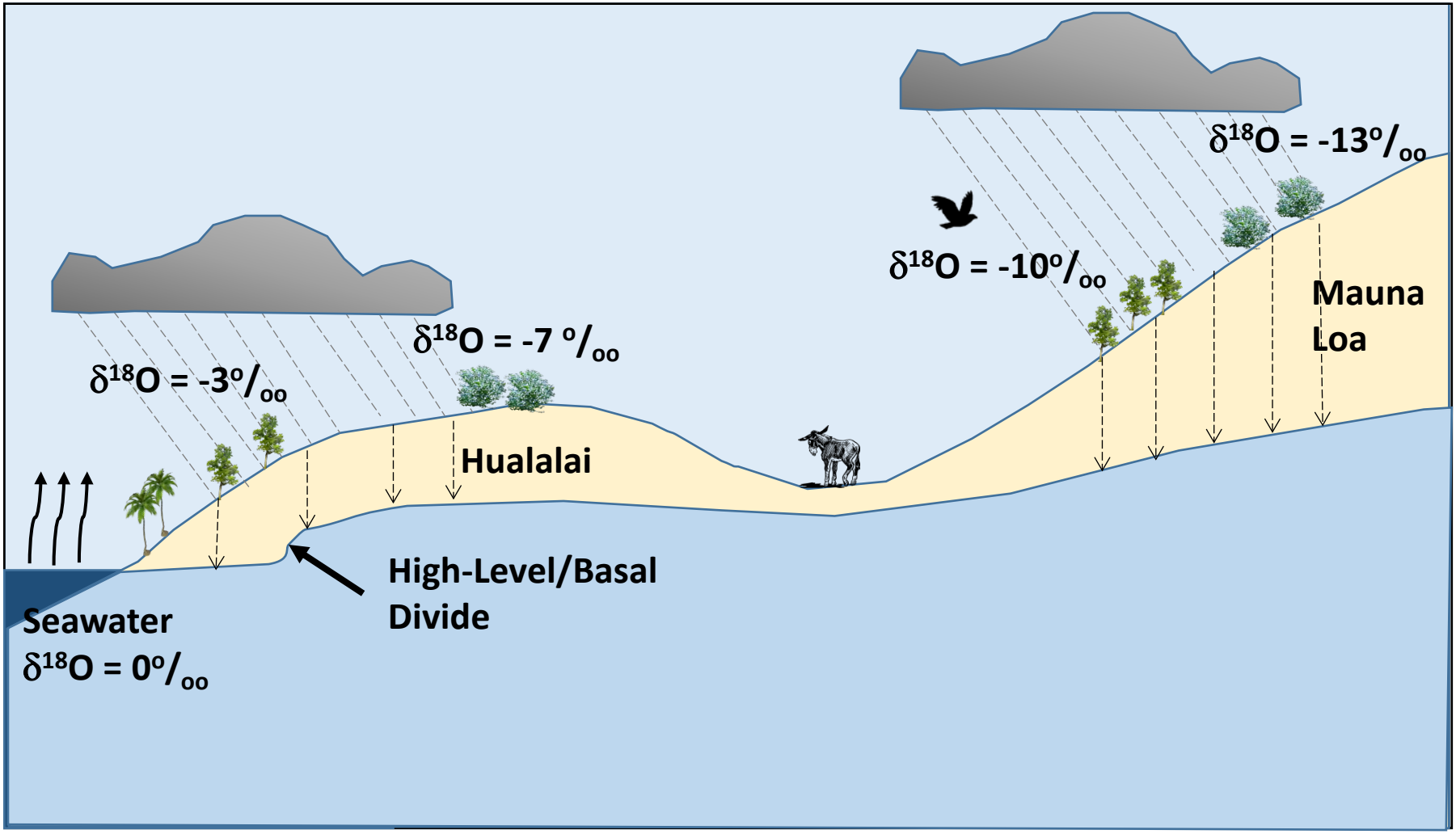
- $\delta^{18}O$ in parts per thousand ($^{o}/_{oo}$)
- $\delta^{18}O$ seawater ~ 0 $^{o}/_{oo}$
- If sample water is isotopically lighter than seawater then $\delta^{18}O$ is negative



- The light isotope ^{16}O preferentially evaporates making atmospheric $\delta^{18}O < 0$ $^{o}/_{oo}$



- The light isotope ^{16}O preferentially evaporates making atmospheric $\delta^{18}O < 0$ $^{o}/_{oo}$
- Heavy isotope "rain out" first, leaving lighter isotope in the clouds



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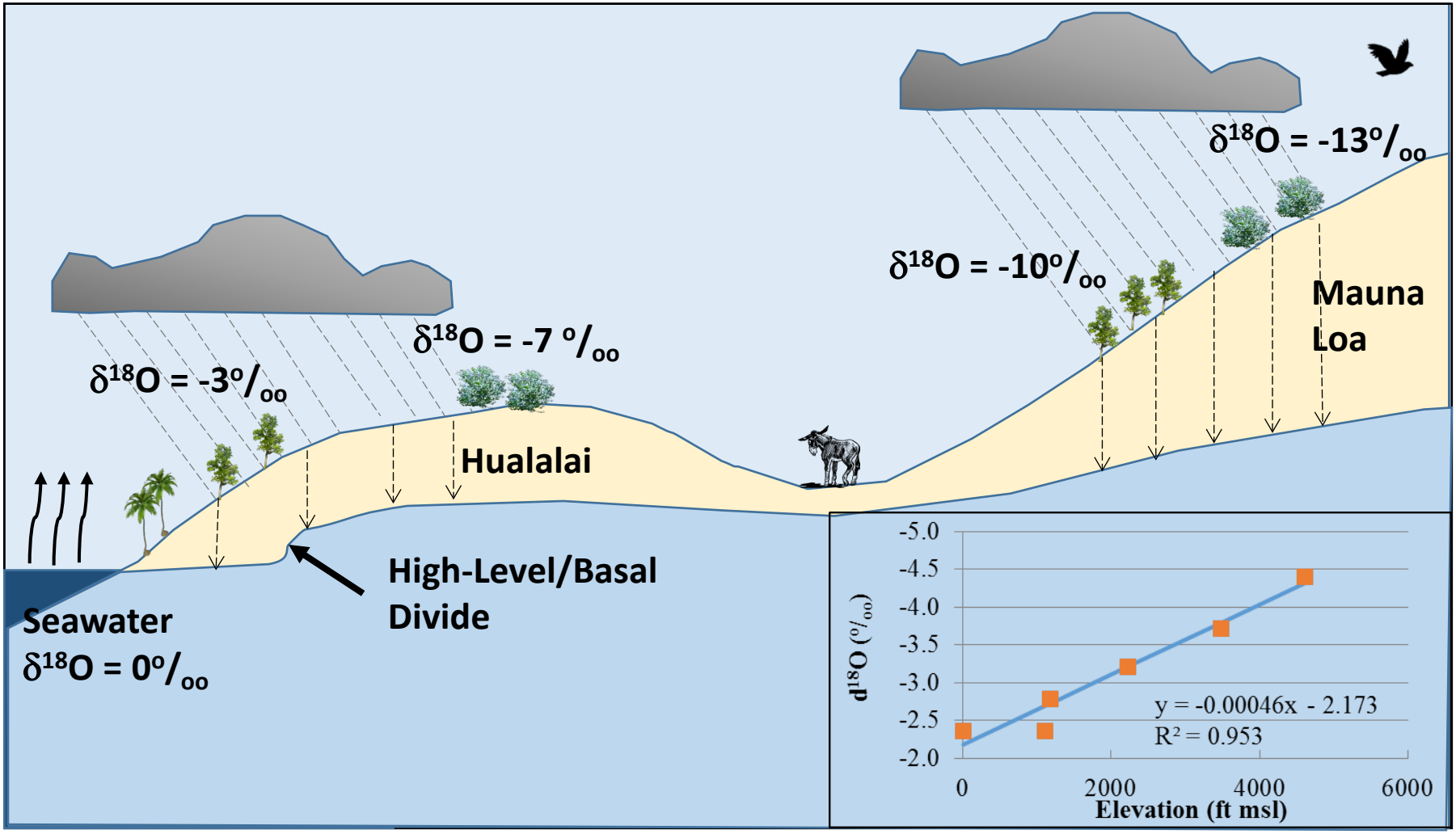
- Predictable relationship between precipitation elevation and isotopic weight



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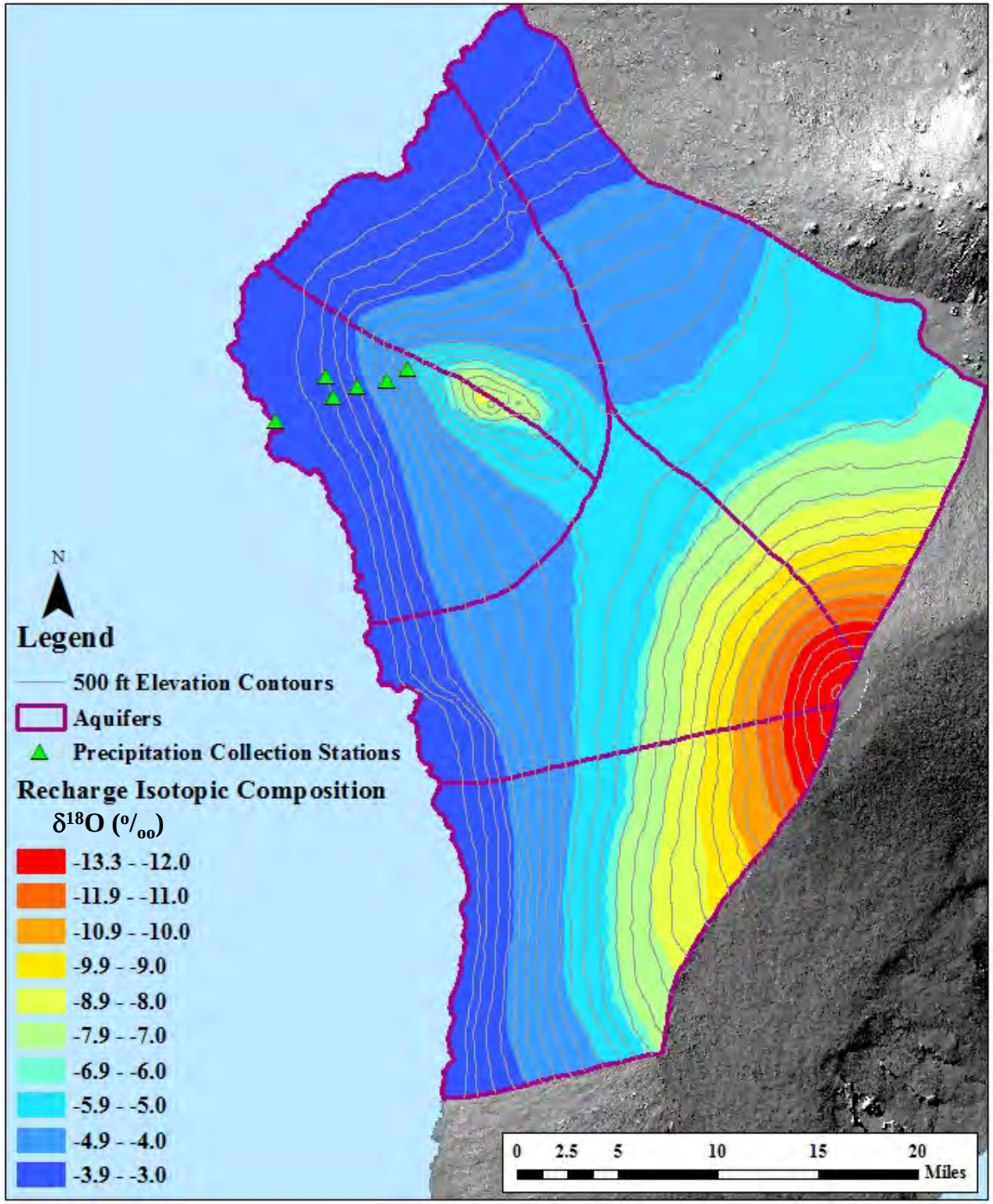
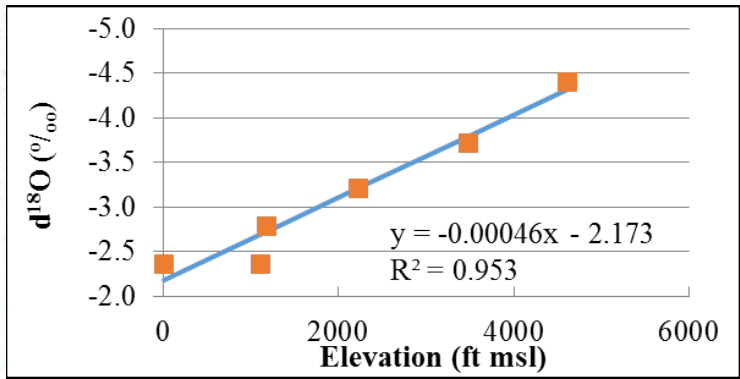
- Data from USGS (Tillman, 2014)



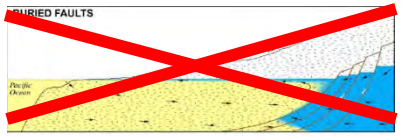
RESULT:

- Predictable distribution of $\delta^{18}O$
- Strong correlation between $\delta^{18}O$ and elevation
- Lightest on Hualalai is -8.1 $^{o}/_{oo}$



Simplify a Complex Geologic Problem

- Since the nature of the structures producing the high level water is unknown
  - They cannot be modeled with any certainty
  - It is not necessary to model them
- The purpose of the SWAP modeling is to define the flow path between the well and the area of recharge



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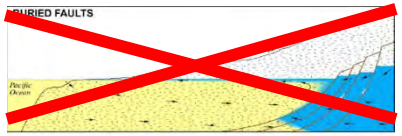
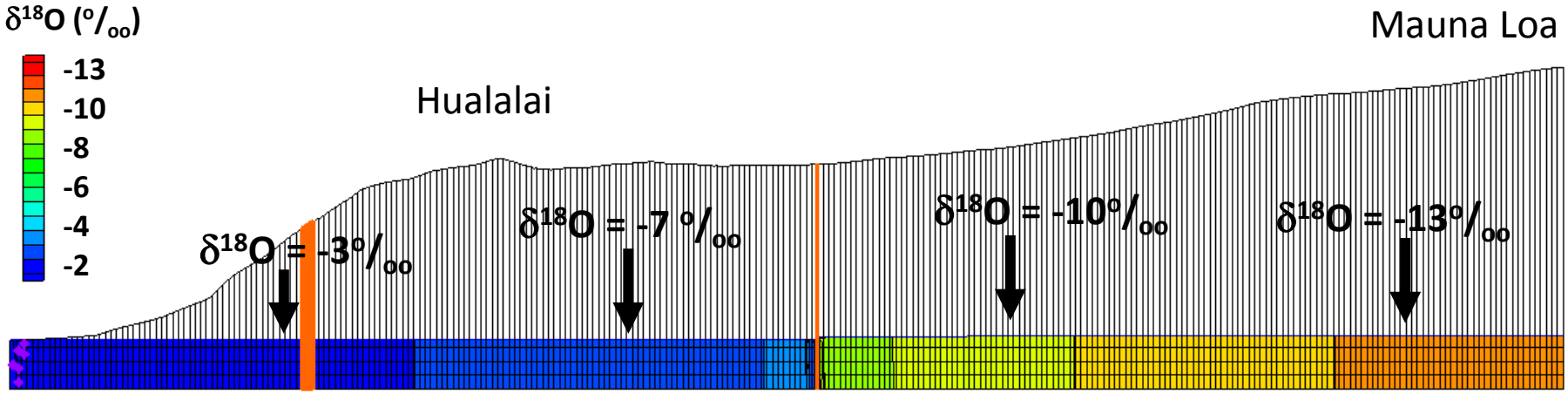
  - They cannot be modeled with any certainty
  - It is not necessary to model them
- The SWAP modeling is defines the flow path between the well and the area of recharge
  - Only necessary to identify flow path from recharge to The well intake
  - A simple homogeneous flow and transport model is sufficient



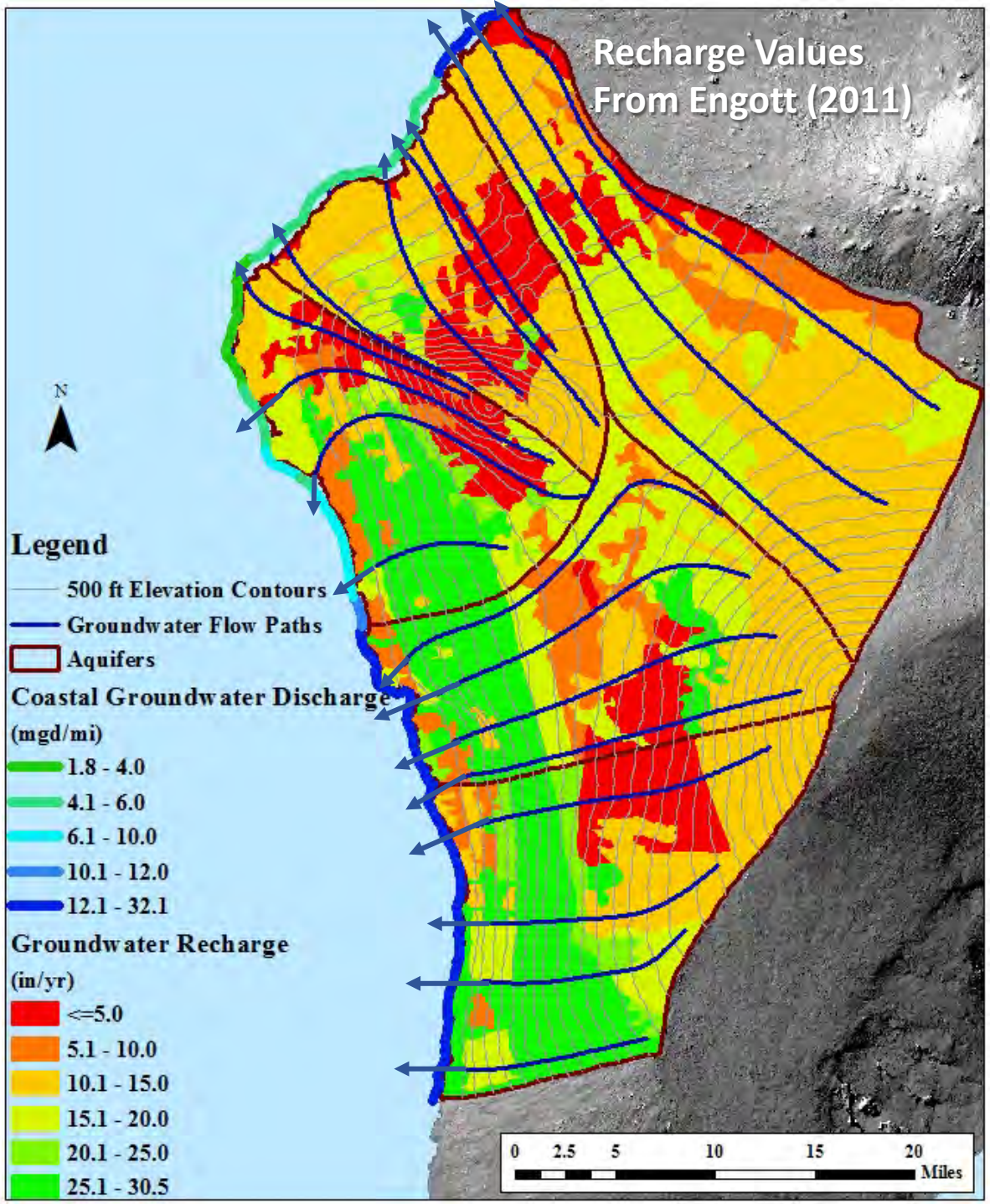


Model mixes water along flow path

Conceptual Models

We tested two conceptual models to evaluate regional groundwater flow in west Hawaii

- **Conceptual Model 1** - Groundwater flow constrained to within the aquifer boundaries
- **Conceptual Model 2** - Groundwater allowed to flow unrestricted from the Mauna Loa to the coast



Groundwater Flow Model

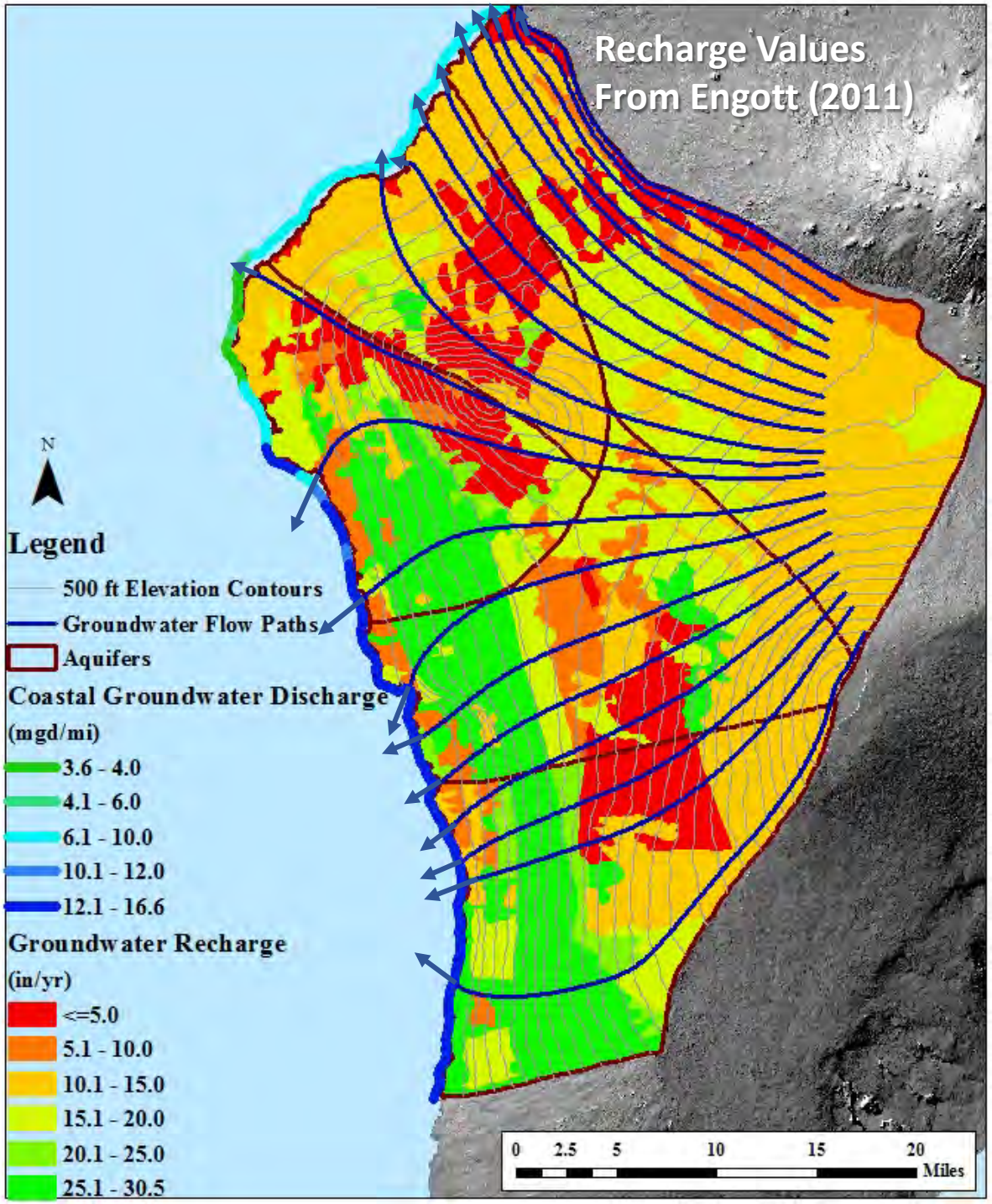
Features common to both conceptual models

- 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

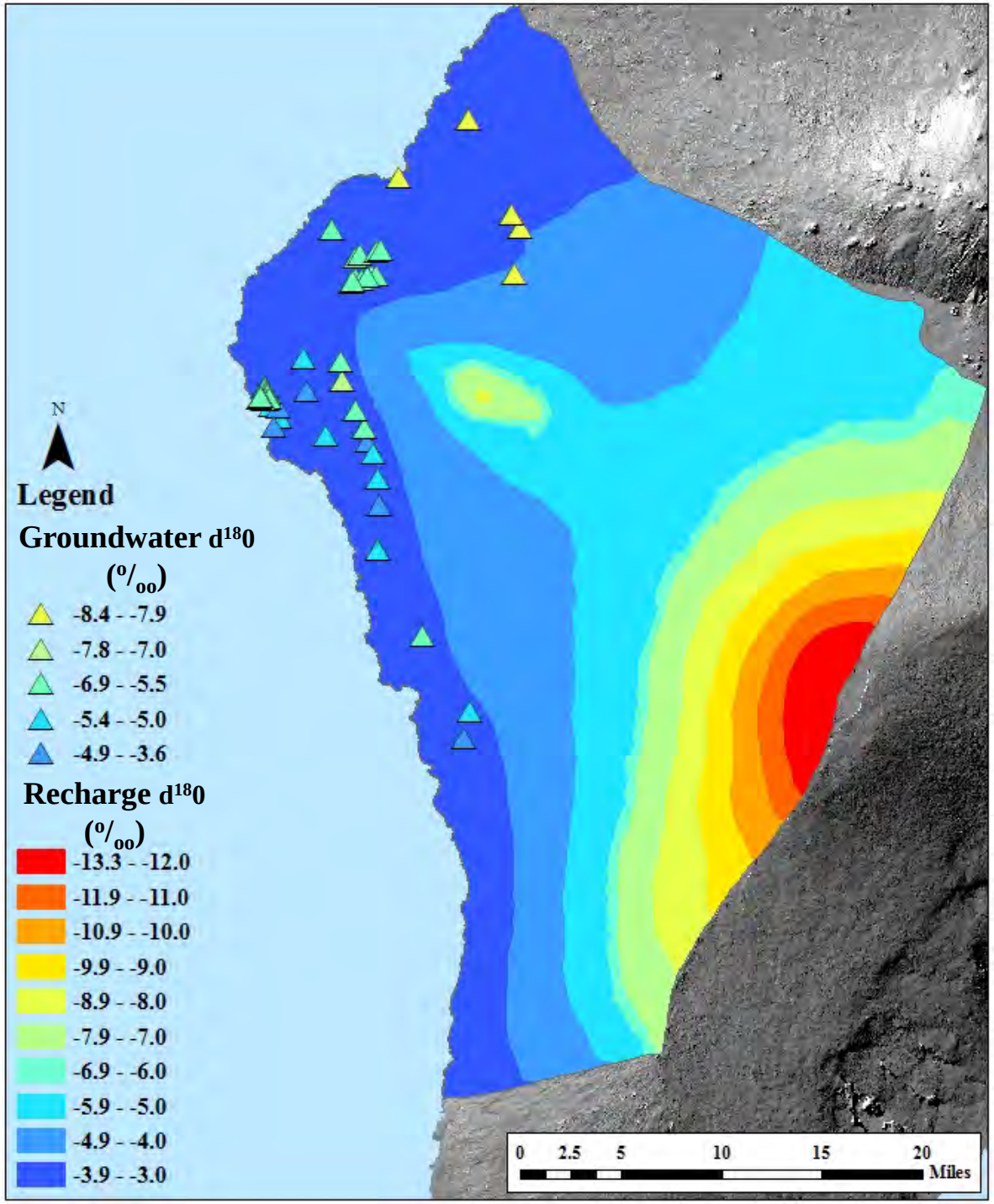
- Groundwater from Mauna Loa flows around Hualalai
- Hualalai and Mauna Loa water don't mix



Conceptual Model 2

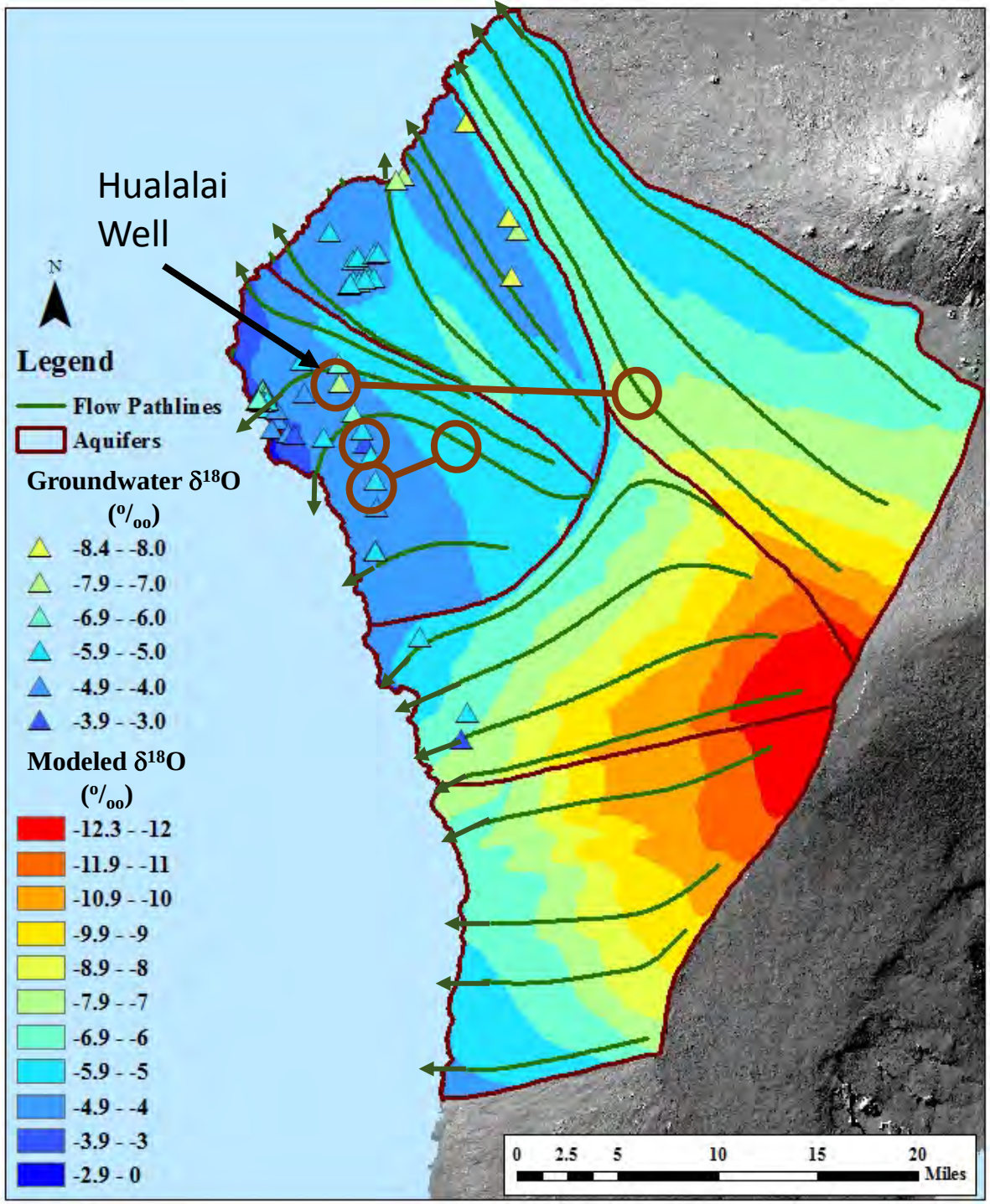
Unobstructed flow from the flanks of Mauna Loa to the coast

- Flow crosses aquifer boundaries
- Hualalai and Mauna Loa water do mix



Transport Model

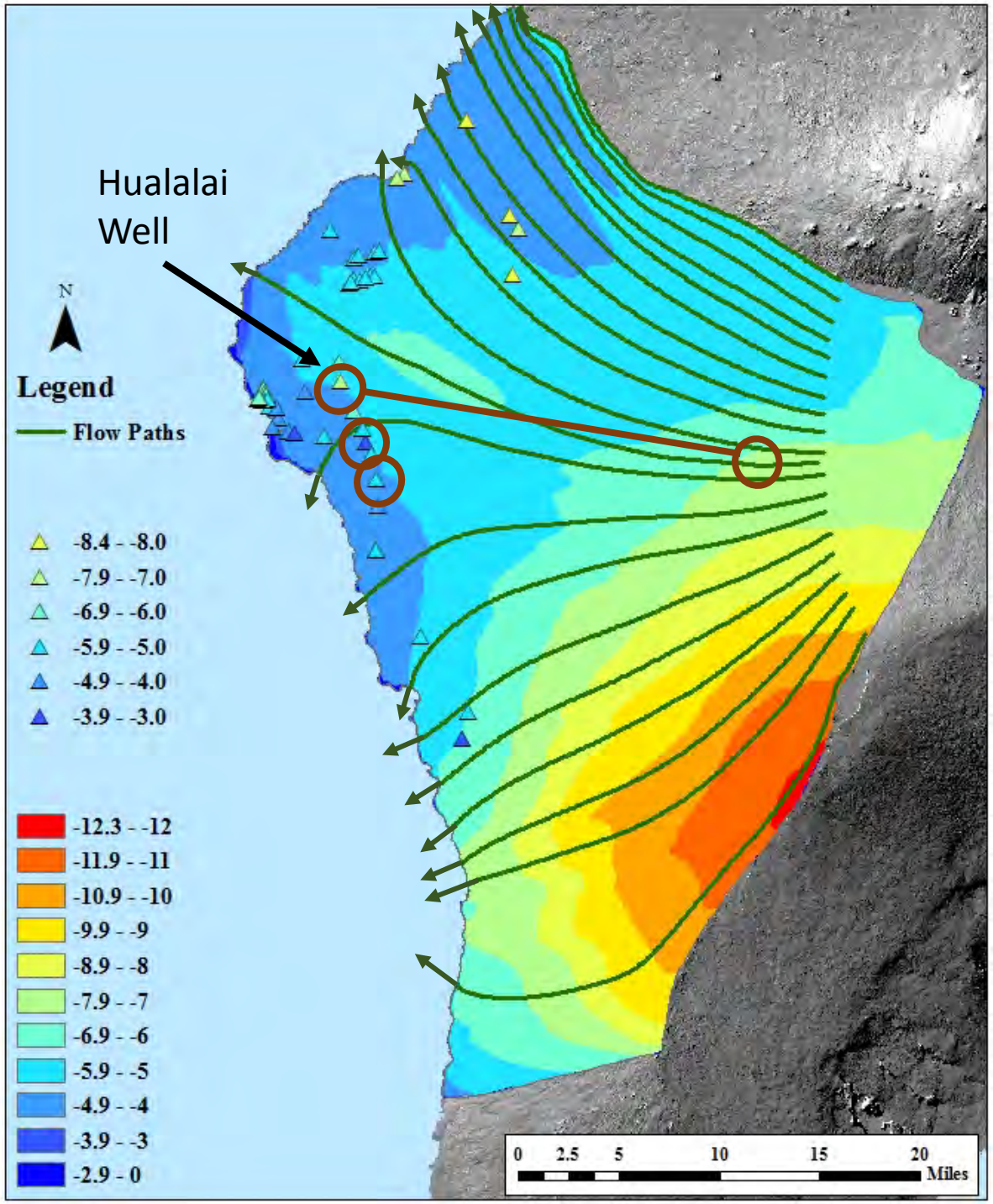
- Input
  - Isotopic composition of the recharge
    - Isotopically heavy near coast
    - Becomes Isotopically lighter as elevation increases
- Validation Points
  - Measured isotopic composition of well water
  - Shown by the Triangles



Conceptual Model 1 Results

Groundwater flow is constrained to within the aquifer boundaries

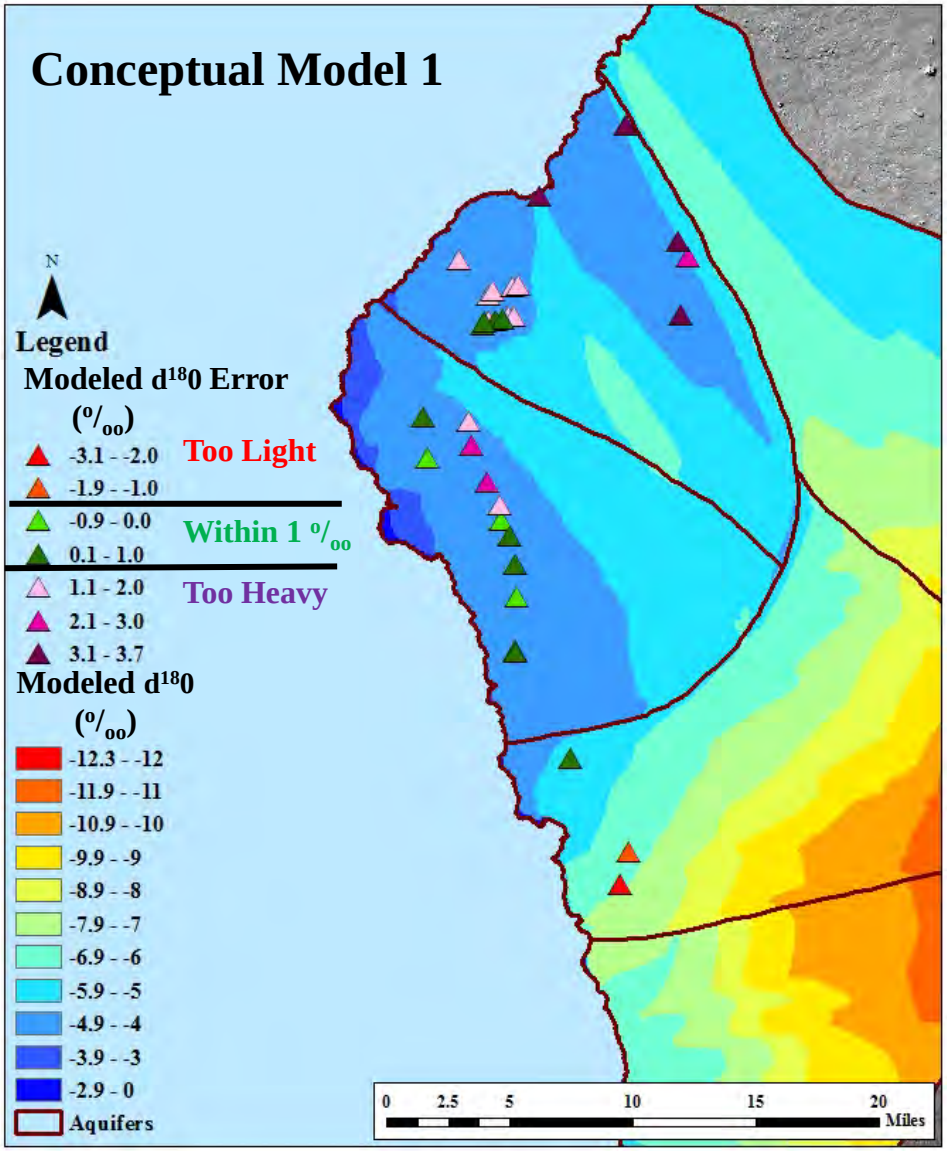
- Map shading show the isotopic composition of groundwater as a result of mixing along the flow paths
- Measured (well water) $\delta^{18}O$ tends to be lighter (lighter blue) than what the model predicts
- The model fails to properly simulate the contribution of high elevation recharge at the well intakes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

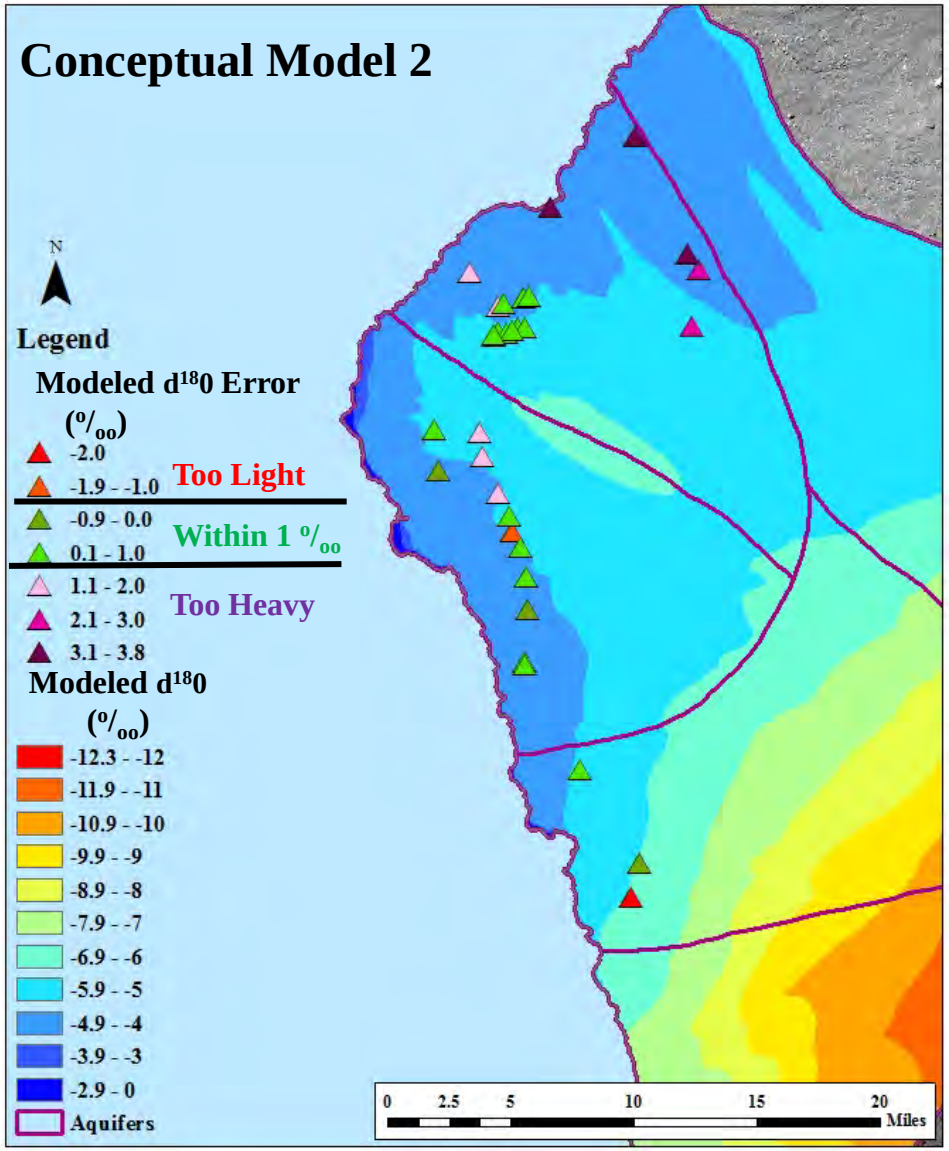


Conceptual Model 2 Results

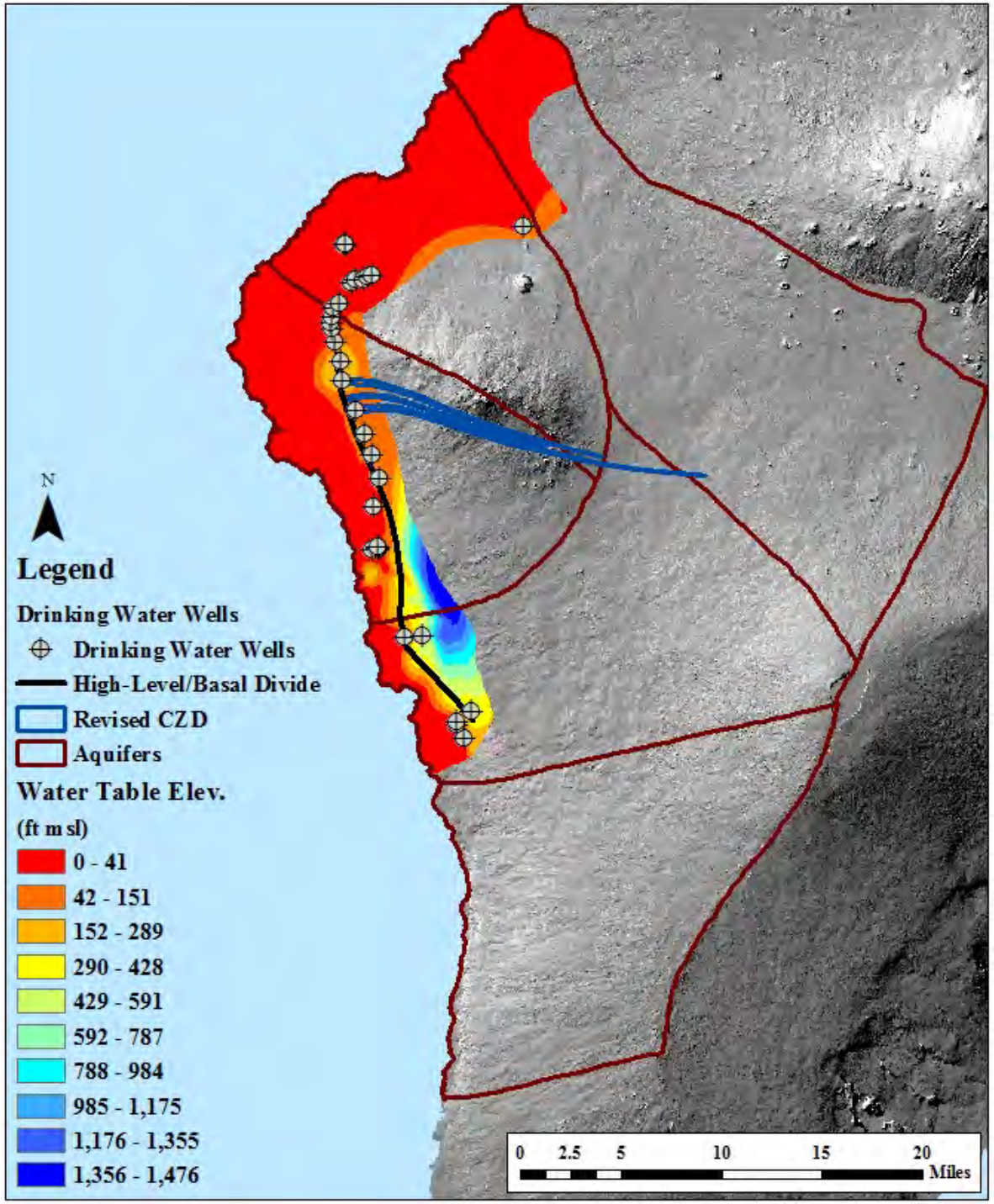
Unobstructed flow allowed from Mauna Loa to the coast

- 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





	CM 1	CM2	
Most Negative Error	-3.08	-2.05	Model simulates too much high elevation water
Average Error	1.3	1.0	<u>Model about right!</u>
Most Positive Error	3.7	3.8	Model simulates too little high elevation water
Points with +/- 1 $^o/_{oo}$	38%	63%	



Summary and Conclusions

Groundwater Flow Paths

- Isotope modeling favors inter-aquifer flow
  - Conceptual Model 2

Capture Zone Delineations

- $\delta^{18}O$ data indicates longer flow path
- Slightly different orientation from original CZDs
- $\delta^{18}O$ does not give time of travel
  - Need to develop method to estimate groundwater velocity

Issues still unresolved

- The nature of the Structures that produce the high level water
- Role of perched water
- Reason for the $\delta^{18}O$ outliers

So Where Does This Leave Us?

- Allowing flow from Mauna Loa to coast produces better match between measured and model $\delta^{18}O$
- The isotopically light water in the Honokohau, Hualalai, and Kalaoa Wells could come from Hualalai
  - However, mixing with heavier water makes this unlikely
- Consider other secondary tracers for model validation (temperature for example)
- Work with UH on refining groundwater flow paths

MAHALO!