EPSCoR

National Science Foundation
Experimental Program to Stimulate Competitive Research

A Proposal for a Collaborative Resource (Re-)Analysis

Geophysics

Don Thomas, Nicole Lautze, Erin Wallin
&
EPSCoR Team

- The quality of Hawai’i’s ground-water resources is among the best in the world
- We all recognize these resources as critical assets for our communities
- For most communities, the available resource is adequate to meet current needs…. BUT

The resource is under varying degrees and urgencies of threat from multiple stressors:

- Over production in some locations
- Contamination
  - Red Hill
  - Pesticide use
  - Wastewater spills
  - On Site Disposal Systems
- Climate Change

- These threats are managed by
  - CWRM – production and protection
  - DOH – water quality and contamination
  - DWS – quality delivered to the user

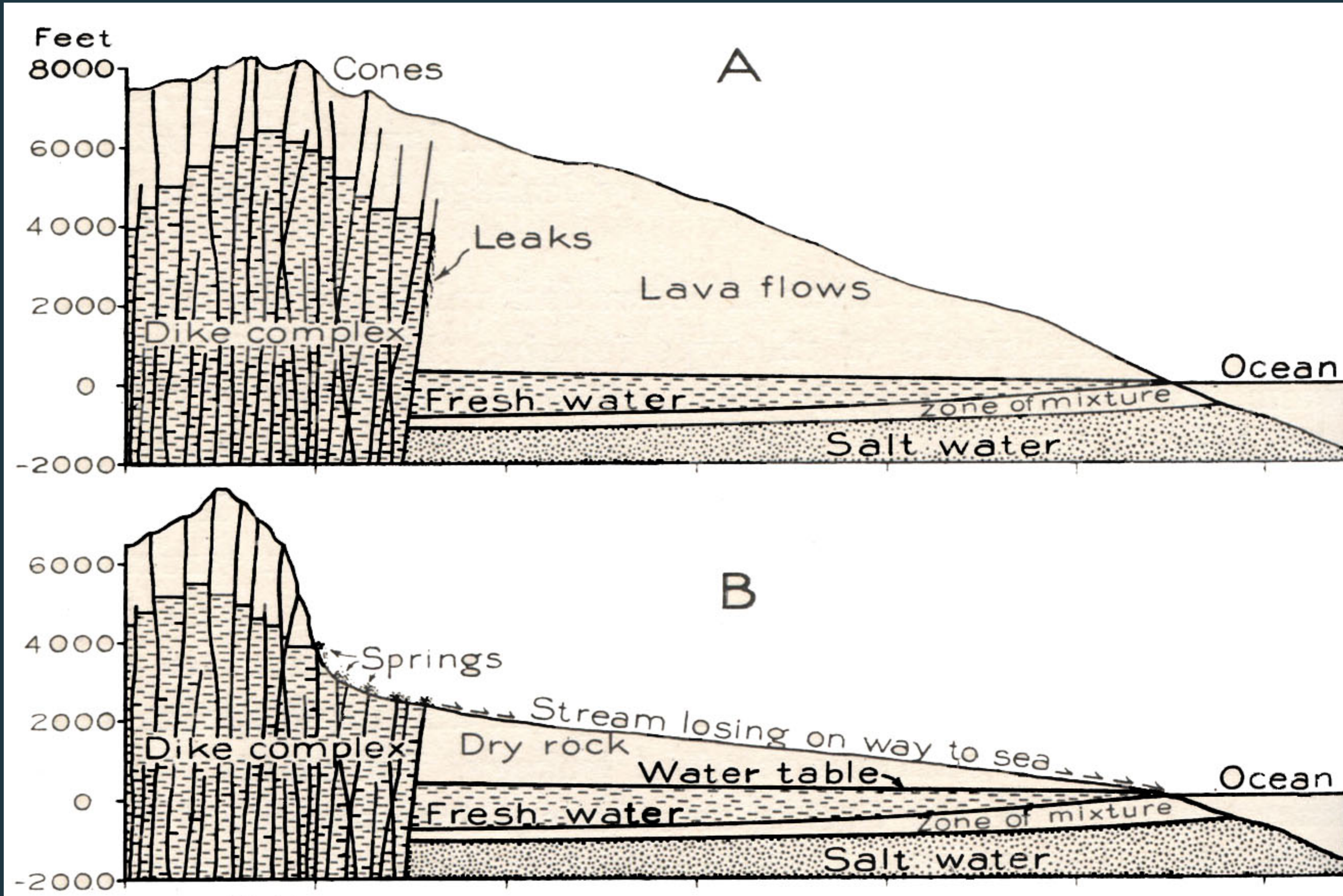
All over committed and under-resourced to fully manage the complete spectrum of threats that the resource is facing…

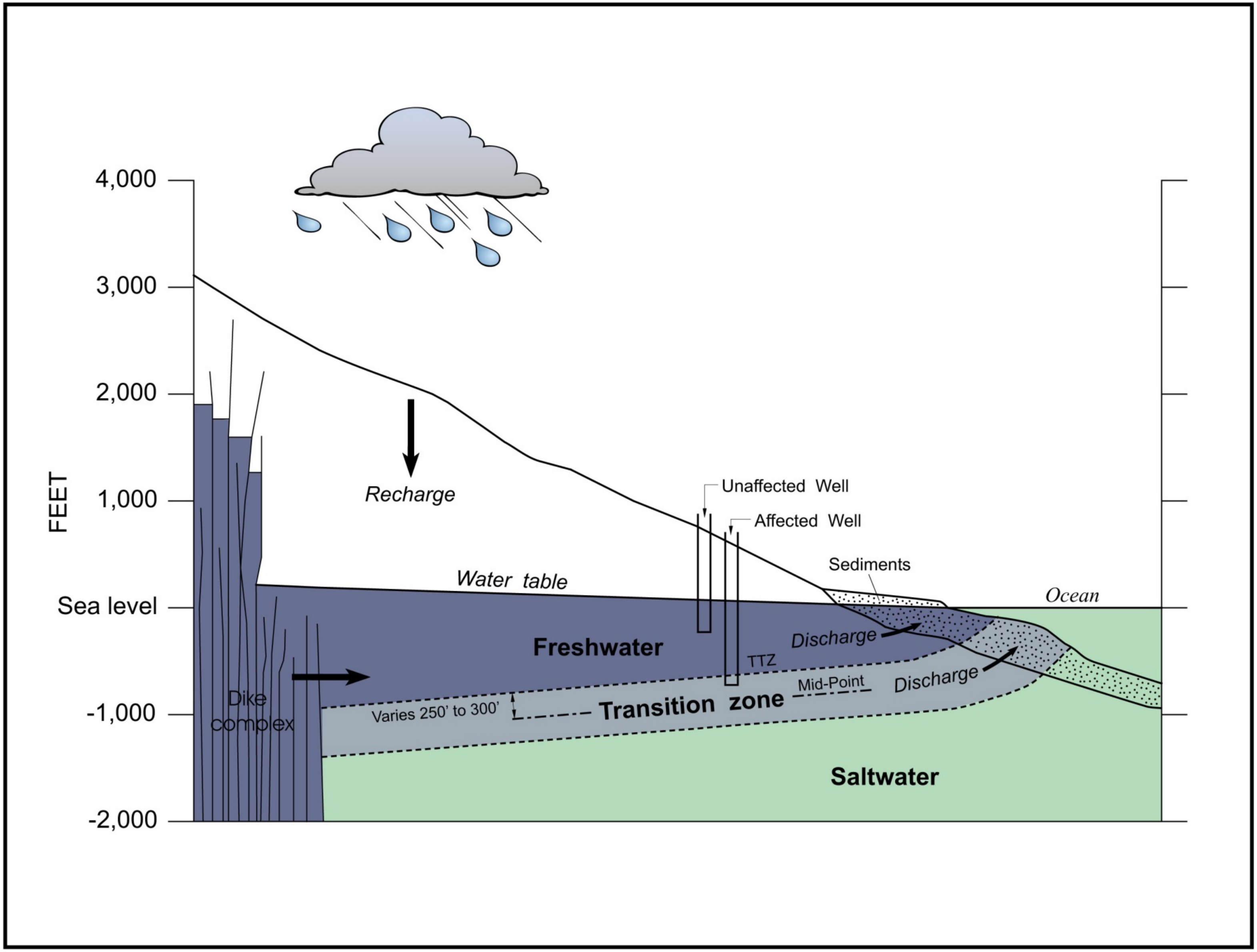
There is a further threat that compounds all the others:

We don’t yet fully understand how water flows, or how it is stored, inside Hawai’i’s volcanoes

Conceptual Model for Hawaii's Groundwater

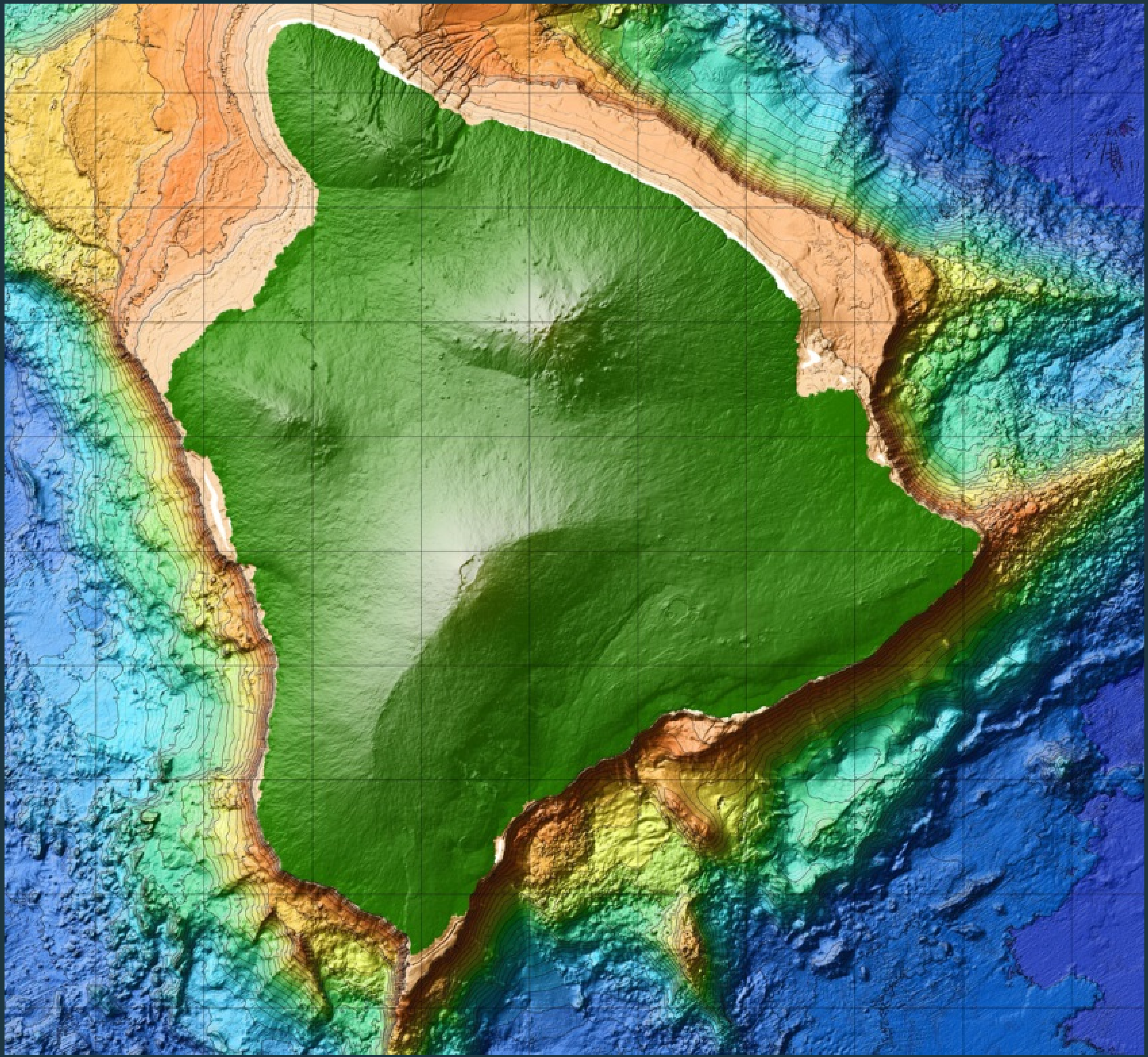
Hasn't changed much in about 70 years

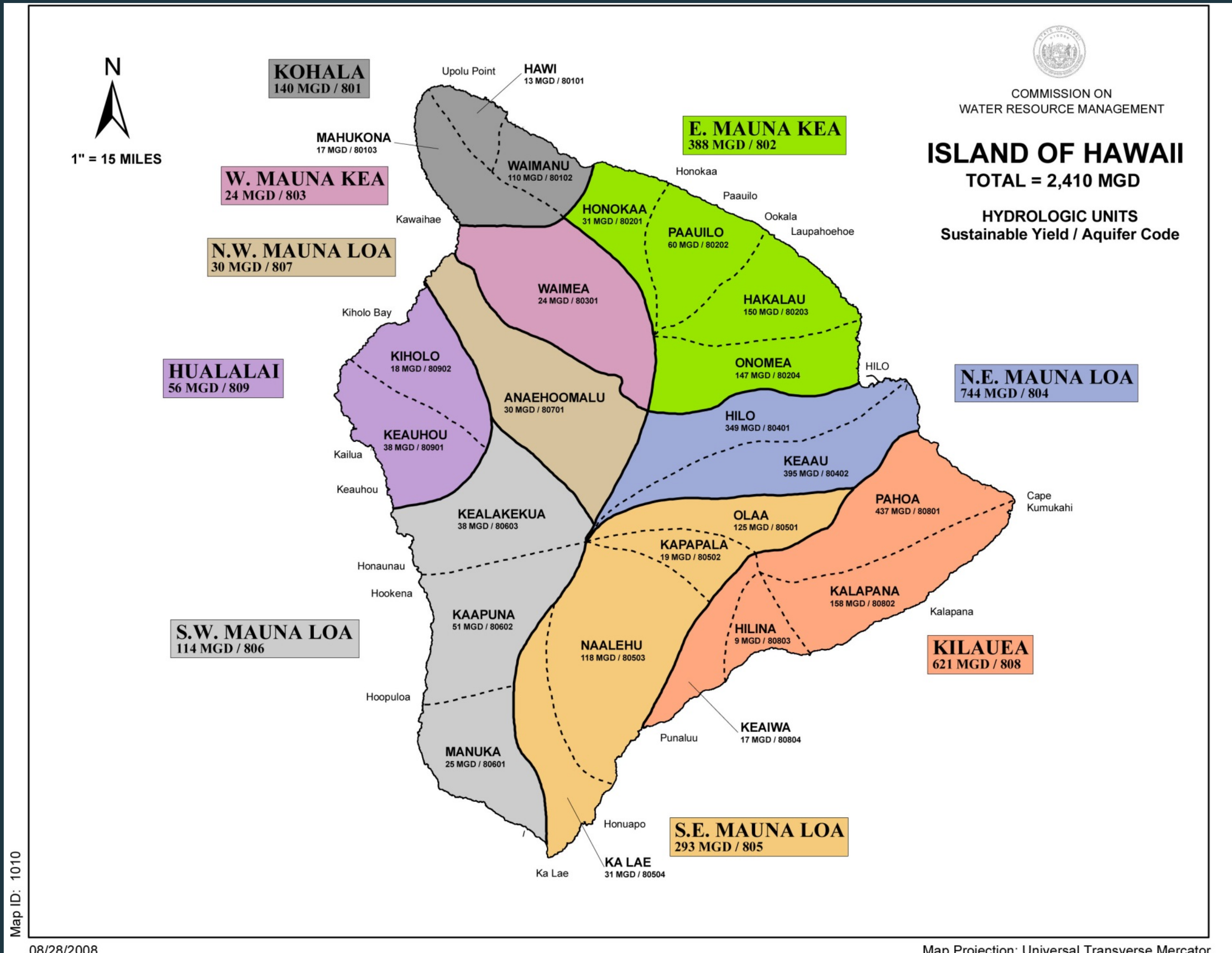

Feet
8000
6000
4000
2000
0
-2000
A
Cones
Leaks
Lava flows
Dike complex
Ocean
Fresh water
Zone of mixture
Salt water
6000
4000
2000
0
-2000
B
Springs
Stream losing on way to sea
Dry rock
Dike complex
Water table
Ocean
Fresh water
Zone of mixture
Salt water



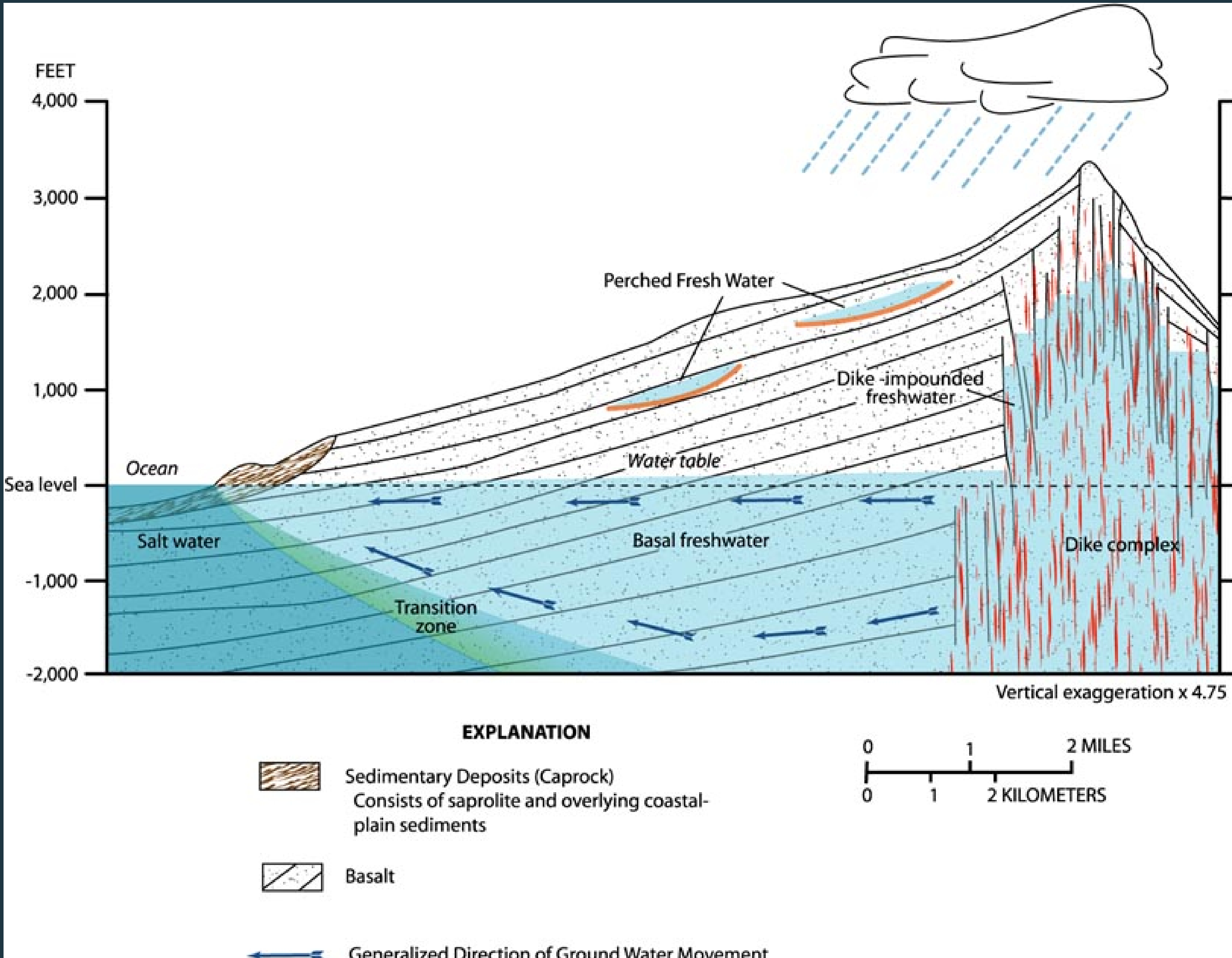
4,000
3,000
2,000
1,000
Sea level
-1,000
-2,000
FEET
Recharge
Unaffected Well
Affected Well
Sediments
Water table
Ocean
Freshwater
Discharge
TTZ
Mid-Point
Discharge
Dike complex
Varies 250' to 300'
Transition zone
Saltwater

Hydrologic Units





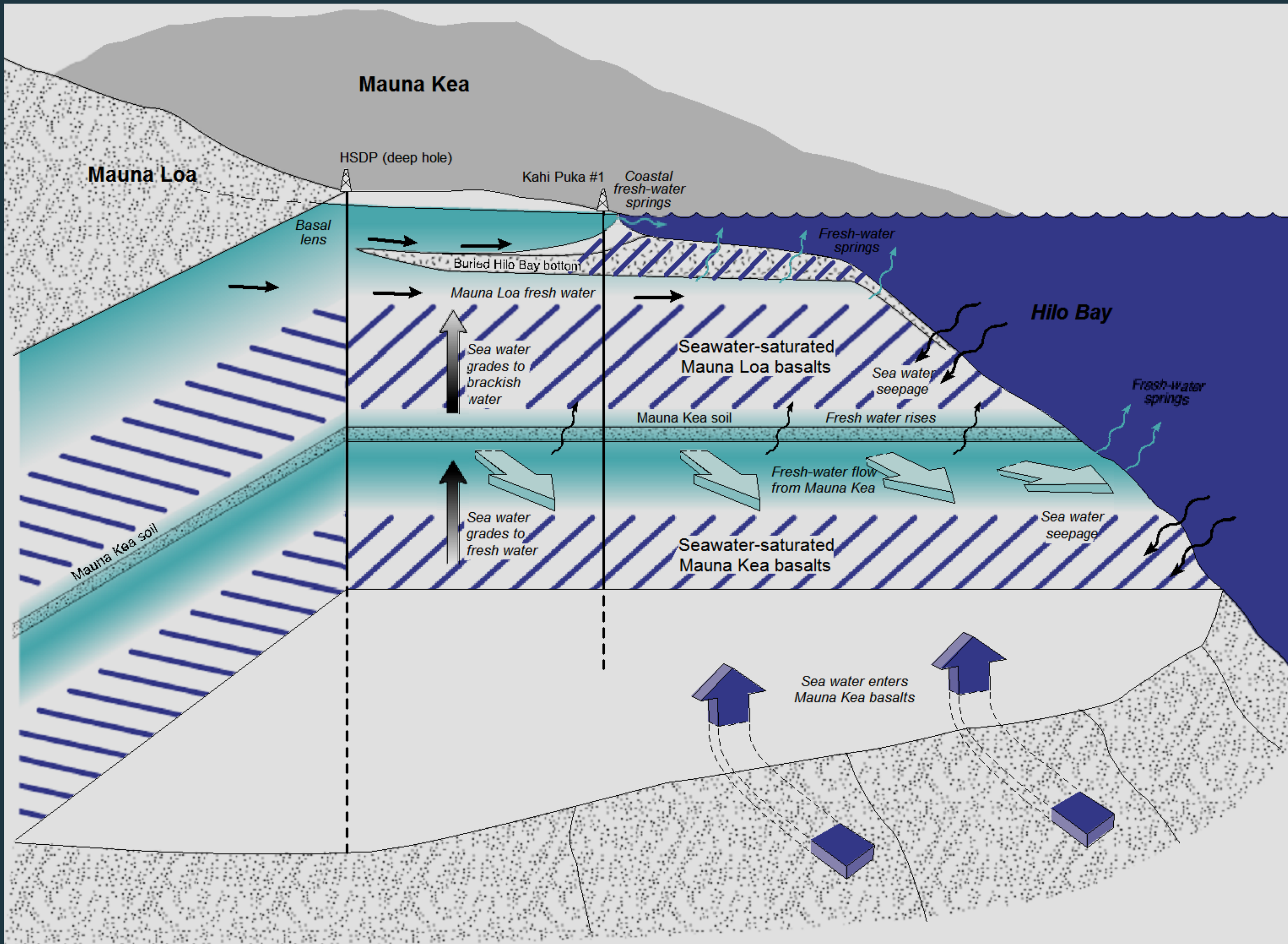
COMMISSION ON WATER RESOURCE MANAGEMENT
ISLAND OF HAWAII
TOTAL = 2,410 MGD
HYDROLOGIC UNITS
Sustainable Yield / Aquifer Code
N
1" = 15 MILES
KOHALA 140 MGD / 801
E. MAUNA KEA 388 MGD / 802
W. MAUNA KEA 24 MGD / 803
N.E. MAUNA LOA 744 MGD / 804
S.E. MAUNA LOA 293 MGD / 805
S.W. MAUNA LOA 114 MGD / 806
N.W. MAUNA LOA 30 MGD / 807
KILAUEA 621 MGD / 808
HUALALAI 56 MGD / 809
HAWI 13 MGD / 80101
WAIMANU 110 MGD / 80102
MAHUKONA 17 MGD / 80103
HONOKAA 31 MGD / 80201
PAAUILO 60 MGD / 80202
HAKALAU 150 MGD / 80203
ONOMEA 147 MGD / 80204
WAIMEA 24 MGD / 80301
HILO 349 MGD / 80401
KEAAU 395 MGD / 80402
OLAA 125 MGD / 80501
KAPAPALA 19 MGD / 80502
NAALEHU 118 MGD / 80503
KA LAE 31 MGD / 80504
MANUKA 25 MGD / 80601
KAAPUNA 51 MGD / 80602
KEALAKEKUA 38 MGD / 80603
ANAEHOOMALU 30 MGD / 80701
PAHOA 437 MGD / 80801
KALAPANA 158 MGD / 80802
HILINA 9 MGD / 80803
KEAIWA 17 MGD / 80804
KEAUHOU 38 MGD / 80901
KIHOLO 18 MGD / 80902
Upolu Point
Kawaihae
Kiholo Bay
Kailua
Keauhou
Honaunau
Hookena
Hoopuloa
Ka Lae
Honuapo
Punaluu
Kalapana
Cape Kumukahi
HILO
Laupahoehoe
Ookala
Paauilo
Honokaa
Map ID: 1010
08/28/2008
Map Projection: Universal Transverse Mercator


FEET
4,000
3,000
2,000
1,000
Sea level
-1,000
-2,000
Perched Fresh Water
Dike -impounded freshwater
Ocean
Water table
Salt water
Basal freshwater
Dike complex
Transition zone
Vertical exaggeration x 4.75
EXPLANATION
Sedimentary Deposits (Caprock)
Consists of saprolite and overlying coastal-plain sediments
Basalt
Generalized Direction of Ground Water Movement
0 1 2 MILES
0 1 2 KILOMETERS

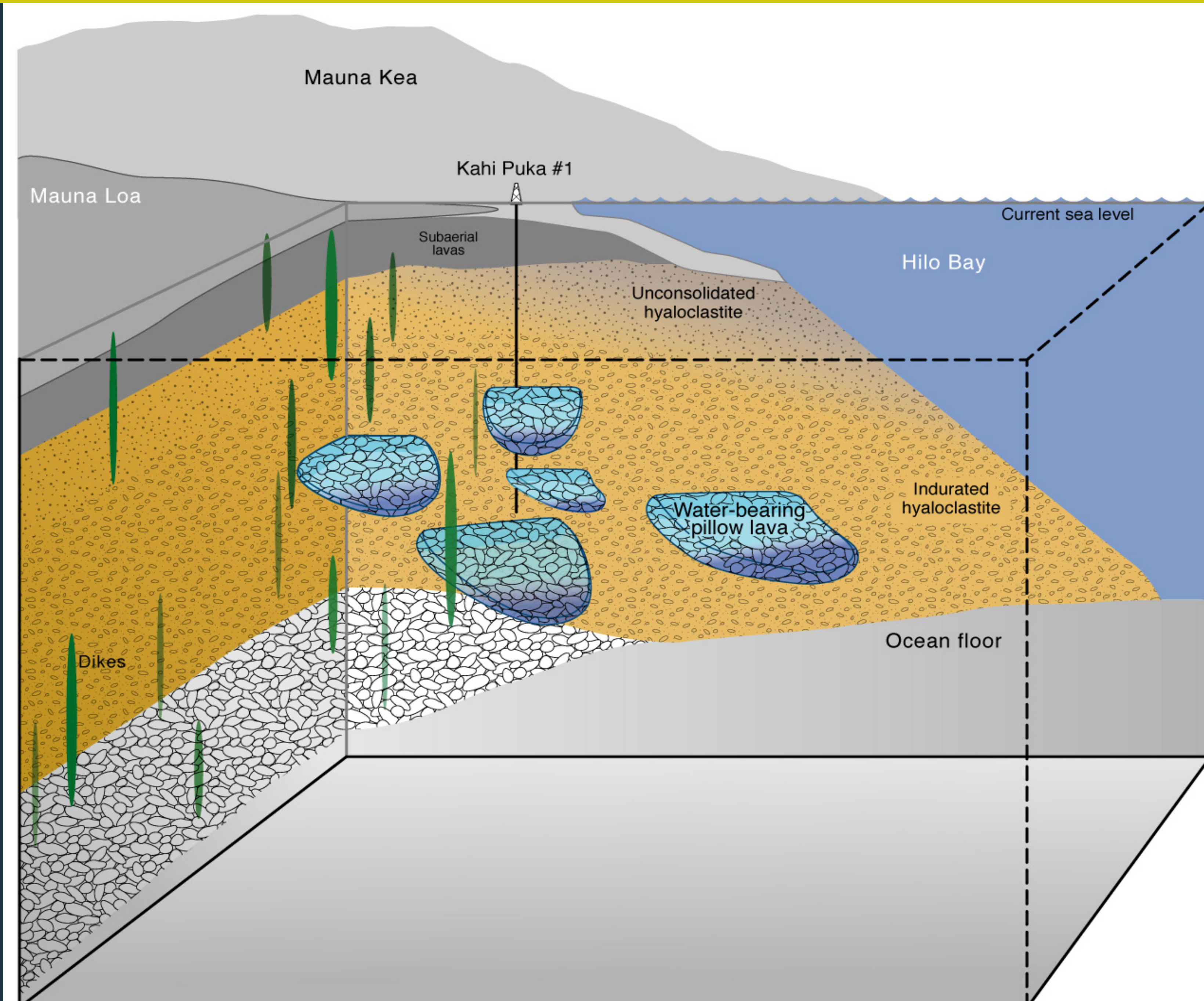
- The hydrology of Mauna Kea is much more complicated than our cartoon:
  - Deep structures
  - Dike complexes
  - Aquitards

Affecting the groundwater storage, accumulation, distribution, and flow

HSDP – Hawaii Scientific Drilling Project



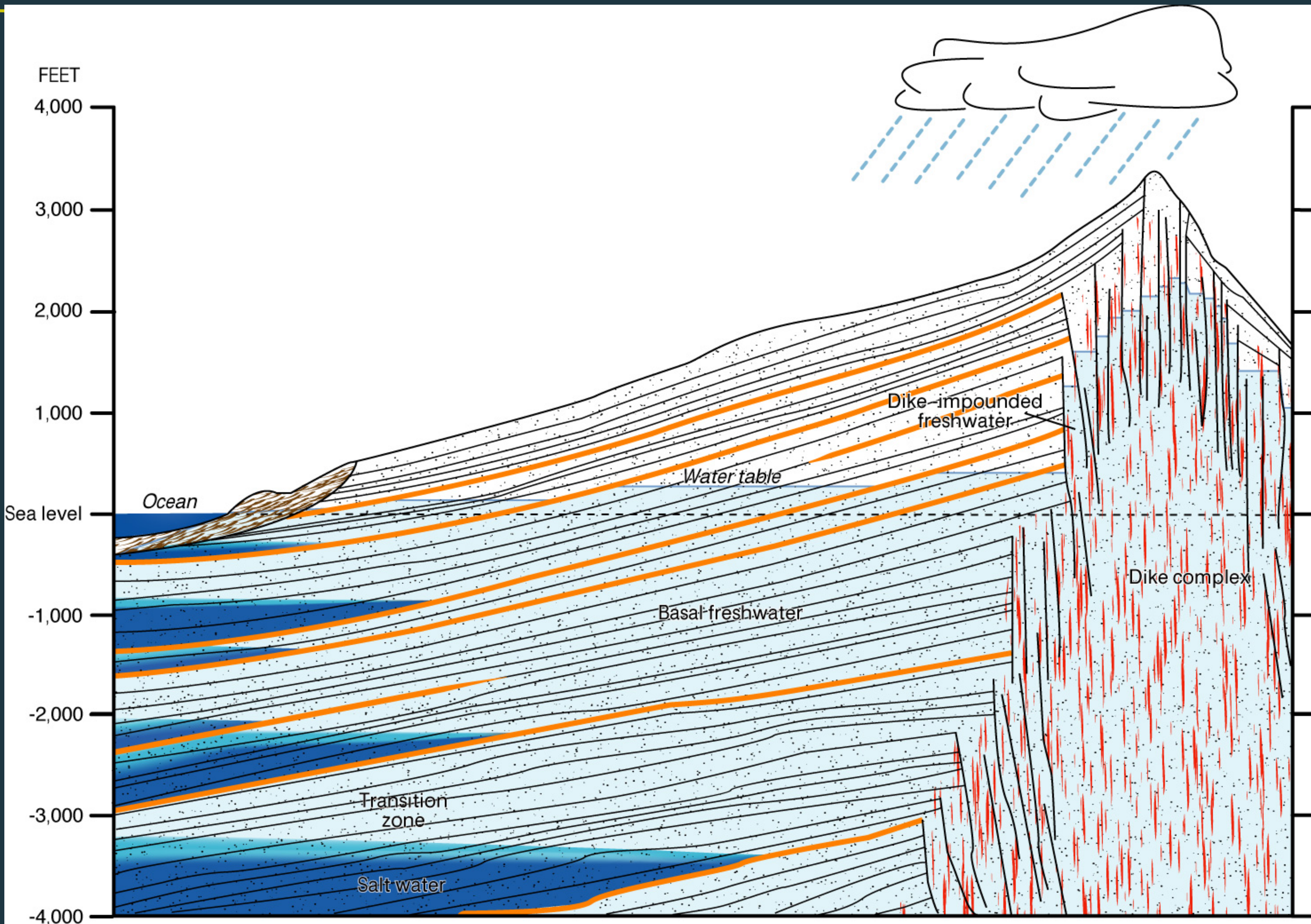
Mauna Kea
Mauna Loa
HSDP (deep hole)
Kahi Puka #1
Coastal fresh-water springs
Basal lens
Buried Hilo Bay bottom
Fresh-water springs
Mauna Loa fresh water
Hilo Bay
Sea water grades to brackish water
Seawater-saturated Mauna Loa basalts
Sea water seepage
Fresh-water springs
Mauna Kea soil
Fresh water rises
Fresh-water flow from Mauna Kea
Sea water grades to fresh water
Seawater-saturated Mauna Kea basalts
Sea water seepage
Mauna Kea soil
Sea water enters Mauna Kea basalts



Mauna Kea
Mauna Loa
Kahi Puka #1
Current sea level
Subaerial lavas
Hilo Bay
Unconsolidated hyaloclastite
Indurated hyaloclastite
Water-bearing pillow lava
Ocean floor
Dikes

The hydrology of Hawaii’s volcanoes is complicated

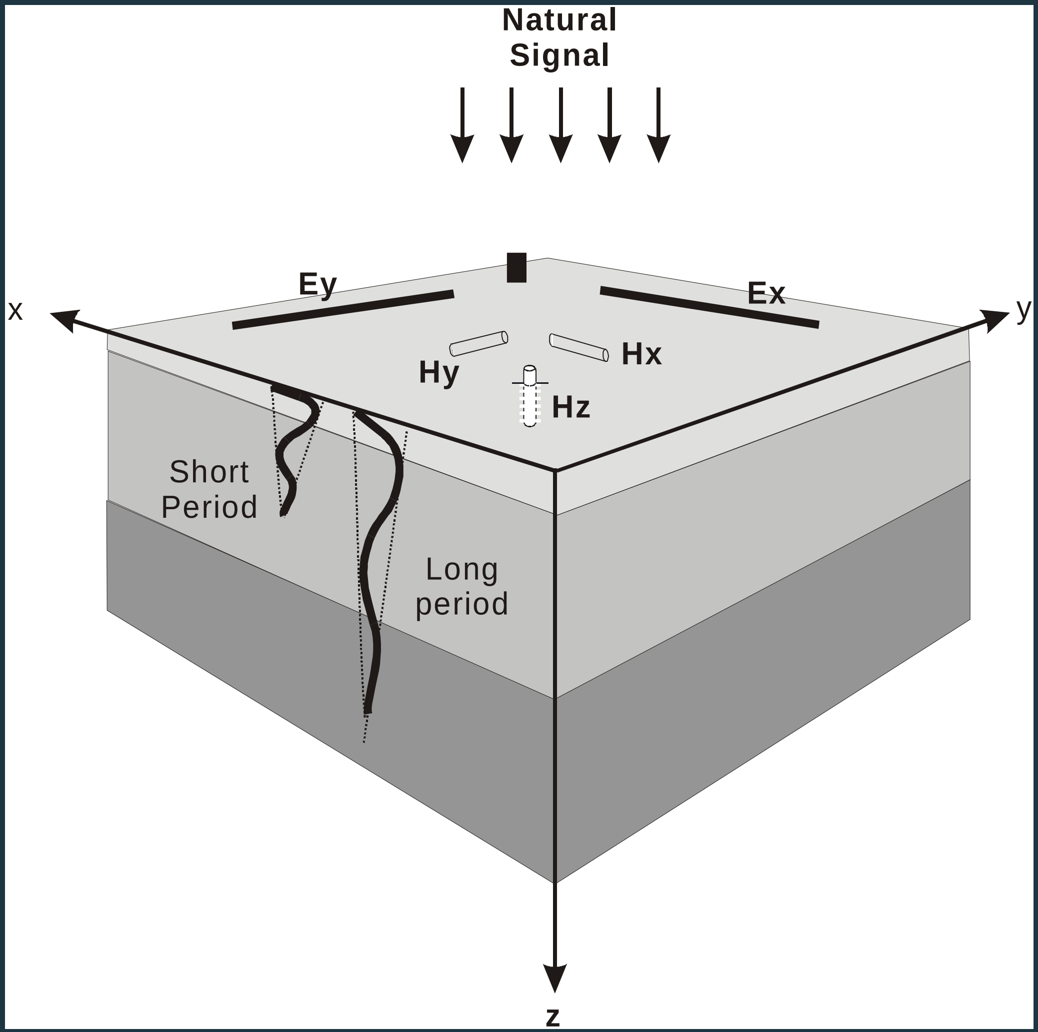
- Hawaii’s volcanoes are not large homogeneous “sponges” with uniform flow
- Deep structures, including dike complexes and aquitards are controlling groundwater accumulation, distribution, storage, and flow
- More water is being stored inside Mauna Kea than was thought
- To optimally manage and protect the aquifers we need to understand how these internal structures affect water (and contaminant) flow


FEET
4,000
3,000
2,000
1,000
Sea level
-1,000
-2,000
-3,000
-4,000
Ocean
Water table
Dike-impounded freshwater
Basal freshwater
Dike complex
Transition zone
Salt water

Geophysical Investigations

- Magnetotelluric and audiomagnetotelluric surveys and modeling
- Gravity surveys and modeling
- Develop better models for groundwater flow that can more reliably project the rates and direction of flow of the groundwater (and potential contaminants)

Magnetotellurics (MT and AMT)

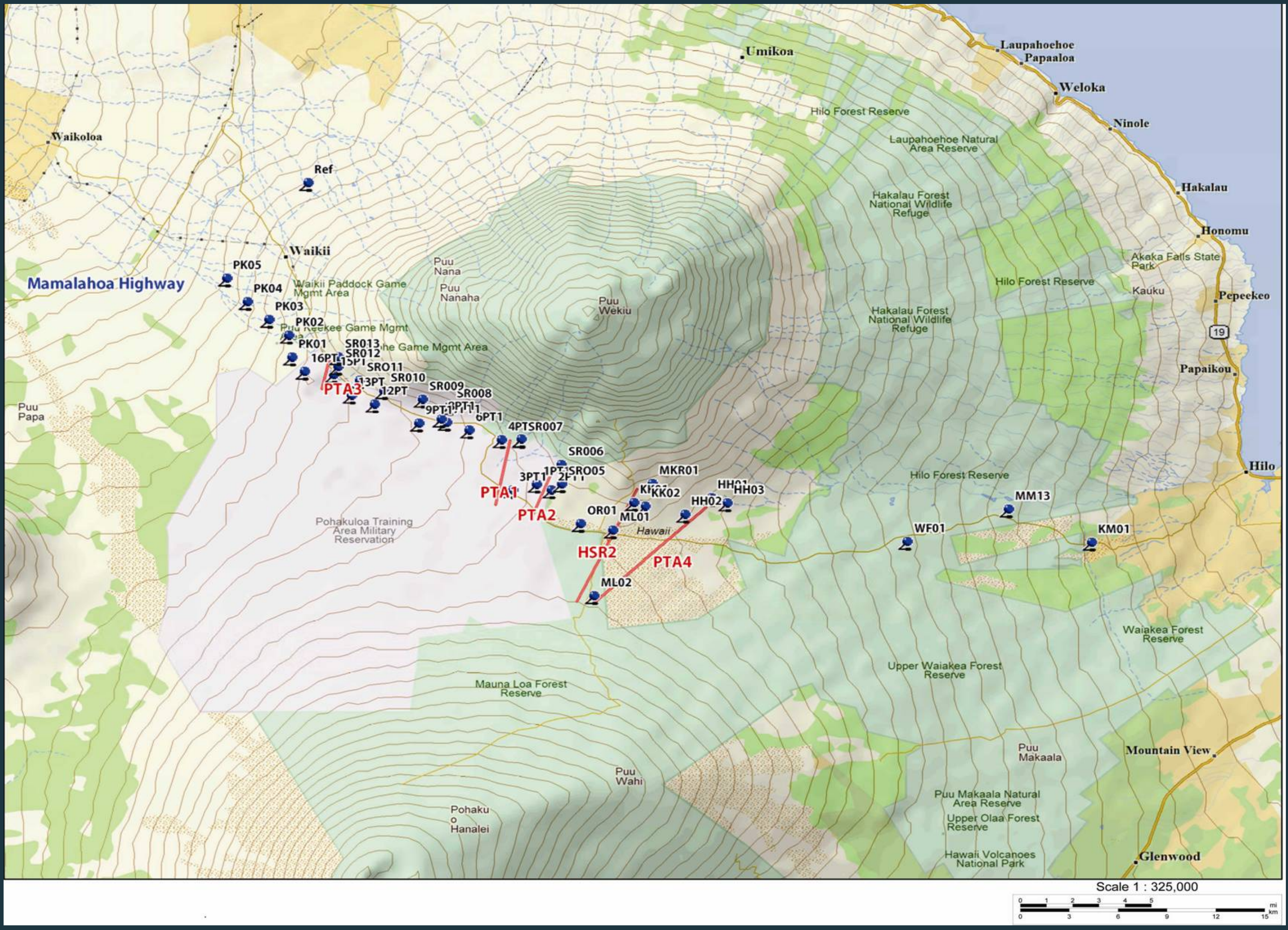


Natural fluctuations in the earth's magnetic field are used as a source of low frequency electromagnetic waves.

Detection depth depends on the frequency (or period) of the wave and electrical conductivity.

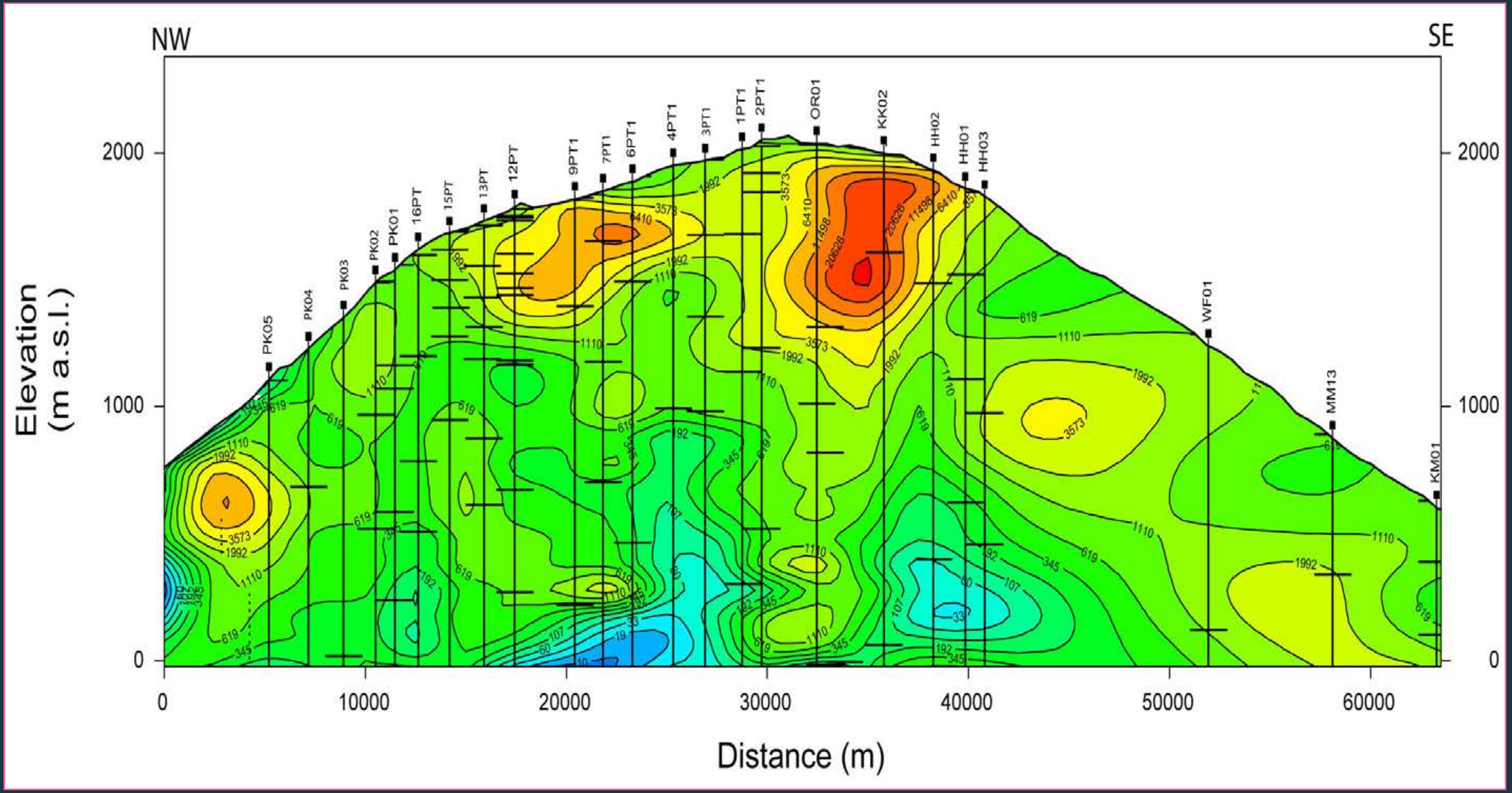
Long periods (low frequencies) penetrate more deeply into the earth than short periods; get a picture from depths of a few 10 s of metres to depths of 10 s of kilometres.

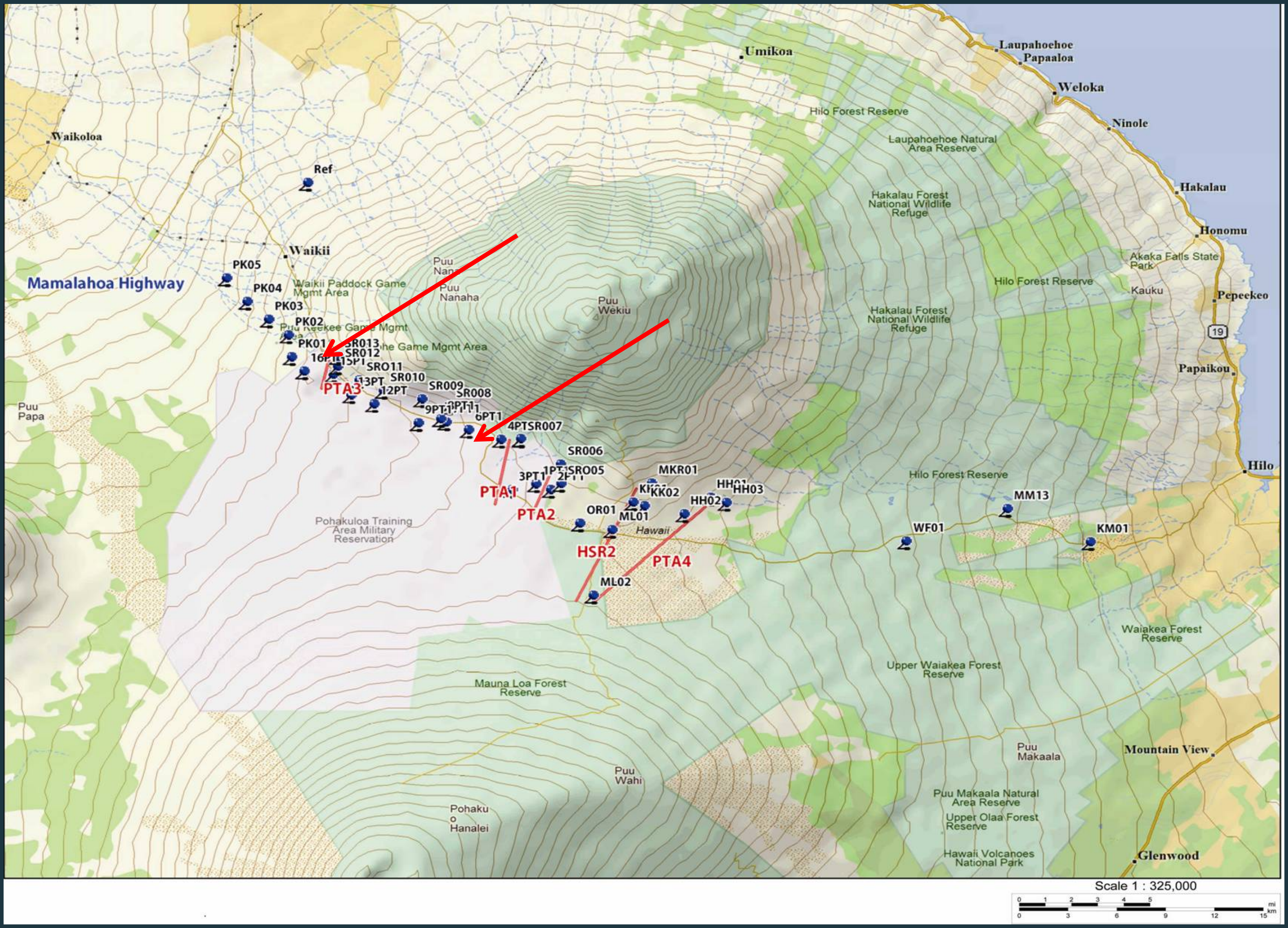
Magnetotelluric (MT) equipment in the field



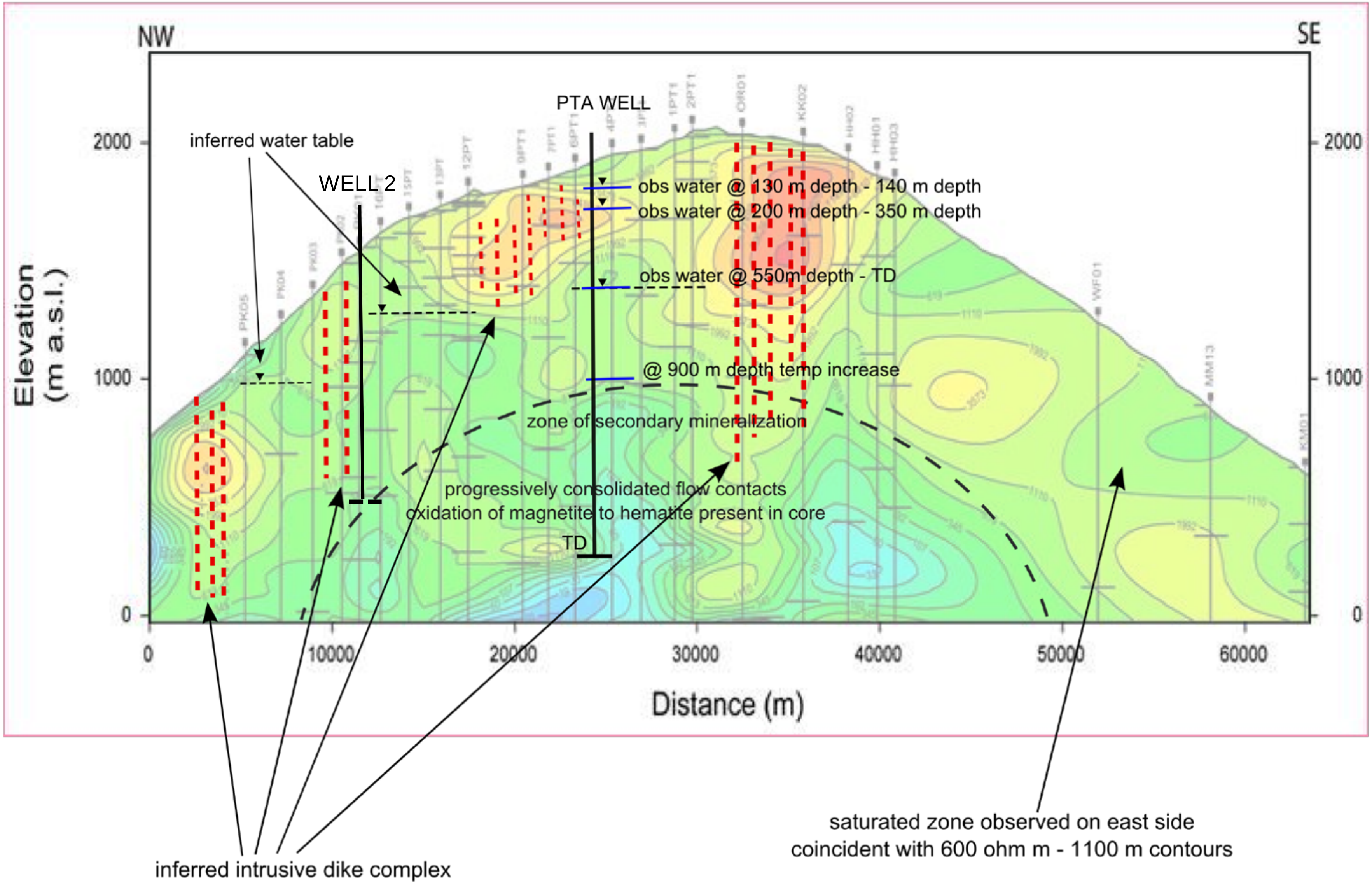
Umikoa
Laupahoehoe
Papaaloa
Weloka
Ninole
Hilo Forest Reserve
Laupahoehoe Natural Area Reserve
Waikoloa
Ref
Hakalau
Hakalau Forest National Wildlife Refuge
Honomu
Waikii
Akaka Falls State Park
PK05
Mamalahoa Highway
PK04
Waikii Paddock Game Mgmt Area
Puu Nana
Puu Nanaha
Puu Wekiu
Hilo Forest Reserve
Kauku
Pepeekeo
PK03
PK02
PK01
SR013
SR012
16PT
SRO11
SR010
SR009
SR008
13PT
12PT
PTA3
Papaikou
Puu Papa
9PT1
6PT1
4PTSR007
SR006
SRO05
3PT1
MKR01
KK02
HH03
HH02
Hilo
Hilo Forest Reserve
MM13
PTA1
PTA2
OR01
ML01
Hawaii
WF01
KM01
Pohakuloa Training Area Military Reservation
HSR2
PTA4
ML02
Waiakea Forest Reserve
Upper Waiakea Forest Reserve
Mauna Loa Forest Reserve
Puu Makaala
Mountain View
Puu Wahi
Pohaku o Hanalei
Puu Makaala Natural Area Reserve
Upper Olaa Forest Reserve
Hawaii Volcanoes National Park
Glenwood
Scale 1 : 325,000

Electrical Resistivity Across the Saddle



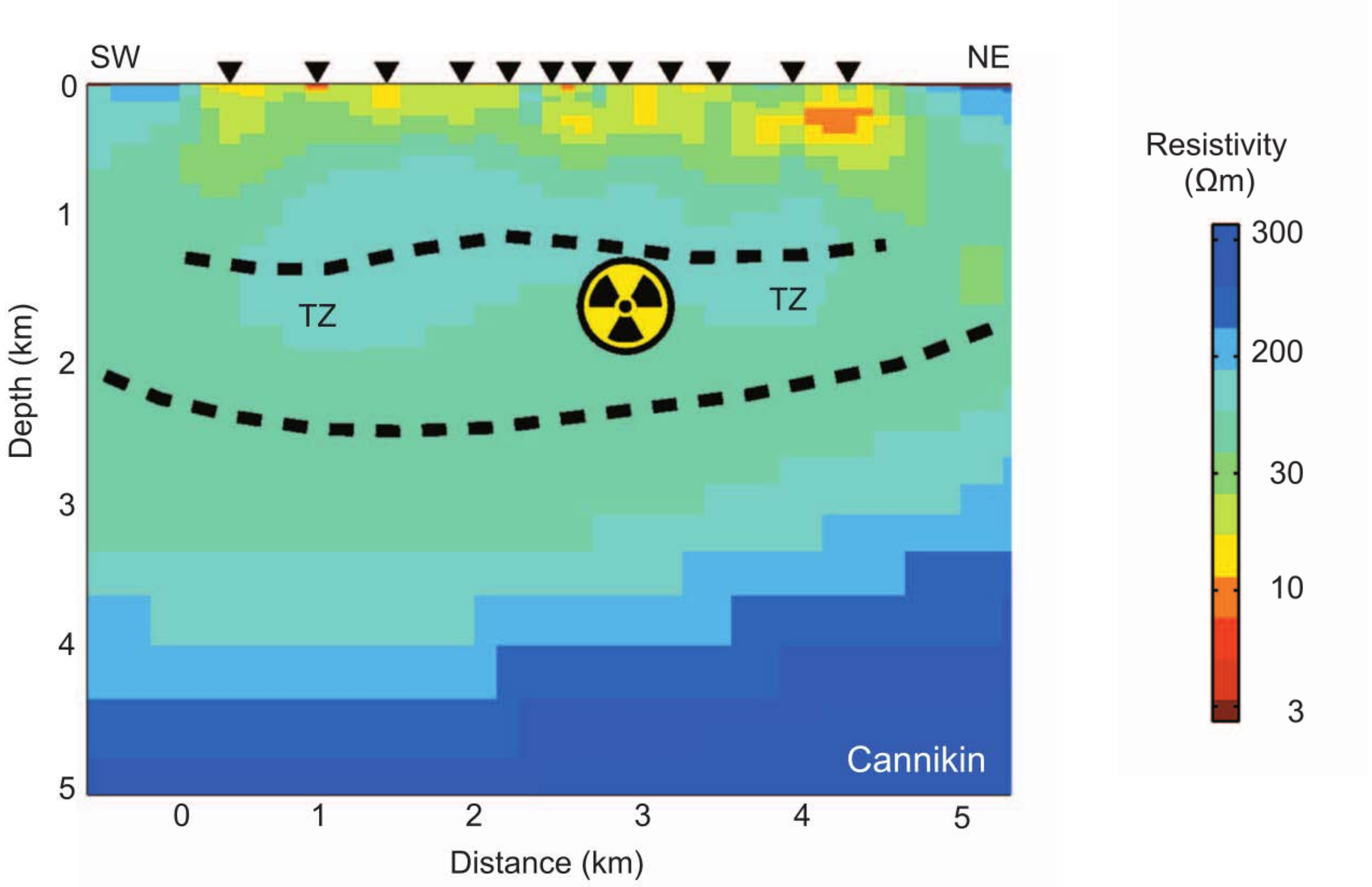


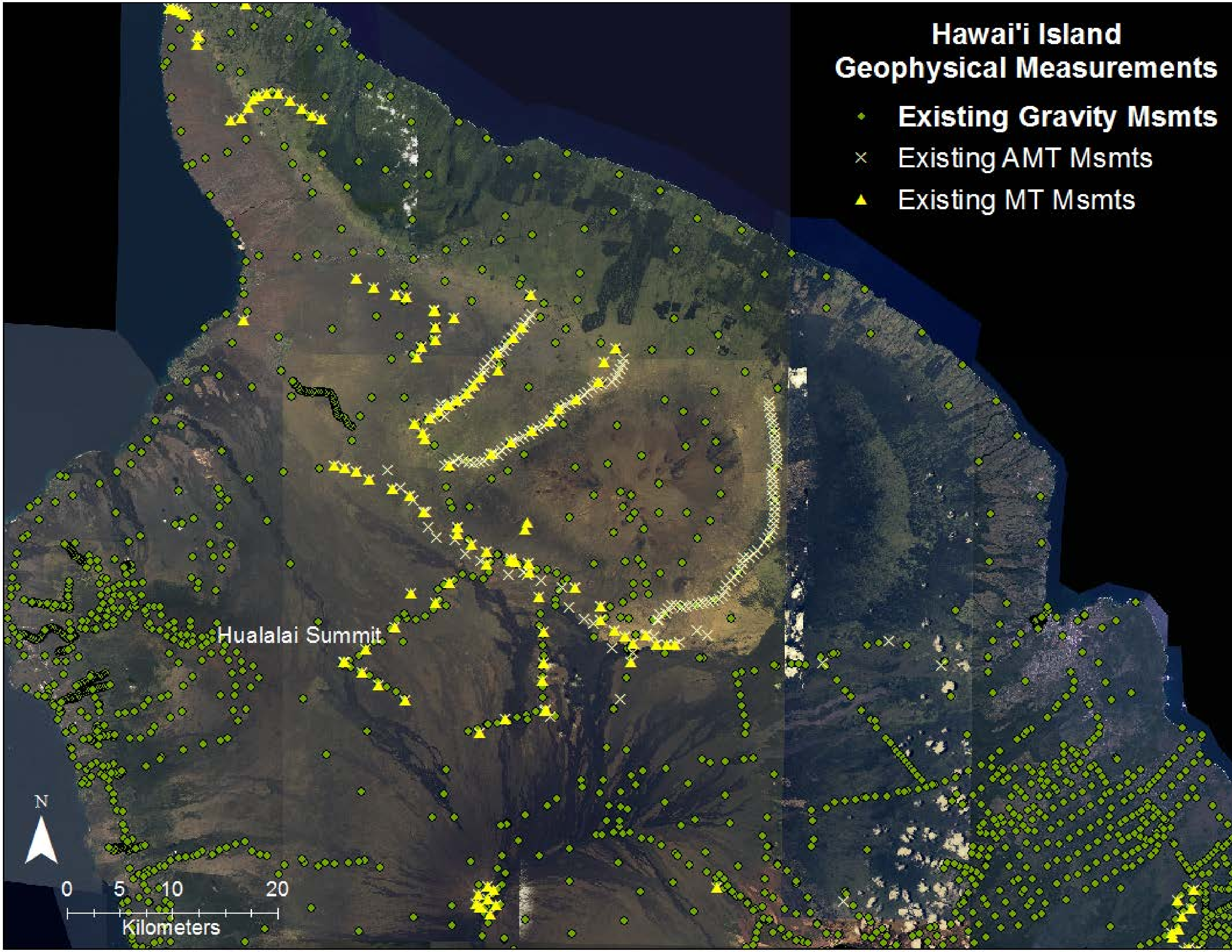
Umikoa
Laupahoehoe
Papaaloa
Weloka
Ninole
Hilo Forest Reserve
Laupahoehoe Natural Area Reserve
Hakalau
Hakalau Forest National Wildlife Refuge
Honomu
Akaka Falls State Park
Kauku
Pepeekeo
Hilo Forest Reserve
Hakalau Forest National Wildlife Refuge
19
Papaikou
Hilo
Waikoloa
Ref
Waikii
PK05
Mamalahoa Highway
PK04
PK03
PK02
PK01
Waikii Paddock Game Mgmt Area
Puu Nanaha
Puu Wekiu
SR013
SR012
SRO11
SR010
SR009
SR008
PTA3
13PT
12PT
6PT1
4PT
SR007
SR006
SRO05
3PT1
PTA1
PTA2
MKR01
KK02
HH03
HH02
OR01
ML01
Hawaii
HSR2
PTA4
ML02
Hilo Forest Reserve
MM13
WF01
KM01
Puu Papa
Pohakuloa Training Area Military Reservation
Mauna Loa Forest Reserve
Waiakea Forest Reserve
Upper Waiakea Forest Reserve
Puu Makaala
Mountain View
Puu Wahi
Pohaku o Hanalei
Puu Makaala Natural Area Reserve
Upper Olaa Forest Reserve
Hawaii Volcanoes National Park
Glenwood
Scale 1 : 325,000



NW
SE
PTA WELL
inferred water table
WELL 2
obs water @ 130 m depth - 140 m depth
obs water @ 200 m depth - 350 m depth
obs water @ 550m depth - TD
@ 900 m depth temp increase
zone of secondary mineralization
progressively consolidated flow contacts
oxidation of magnetite to hematite present in core
TD
Elevation (m a.s.l.)
2000
1000
0
Distance (m)
0
10000
20000
30000
40000
50000
60000
inferred intrusive dike complex
saturated zone observed on east side
coincident with 600 ohm m - 1100 m contours

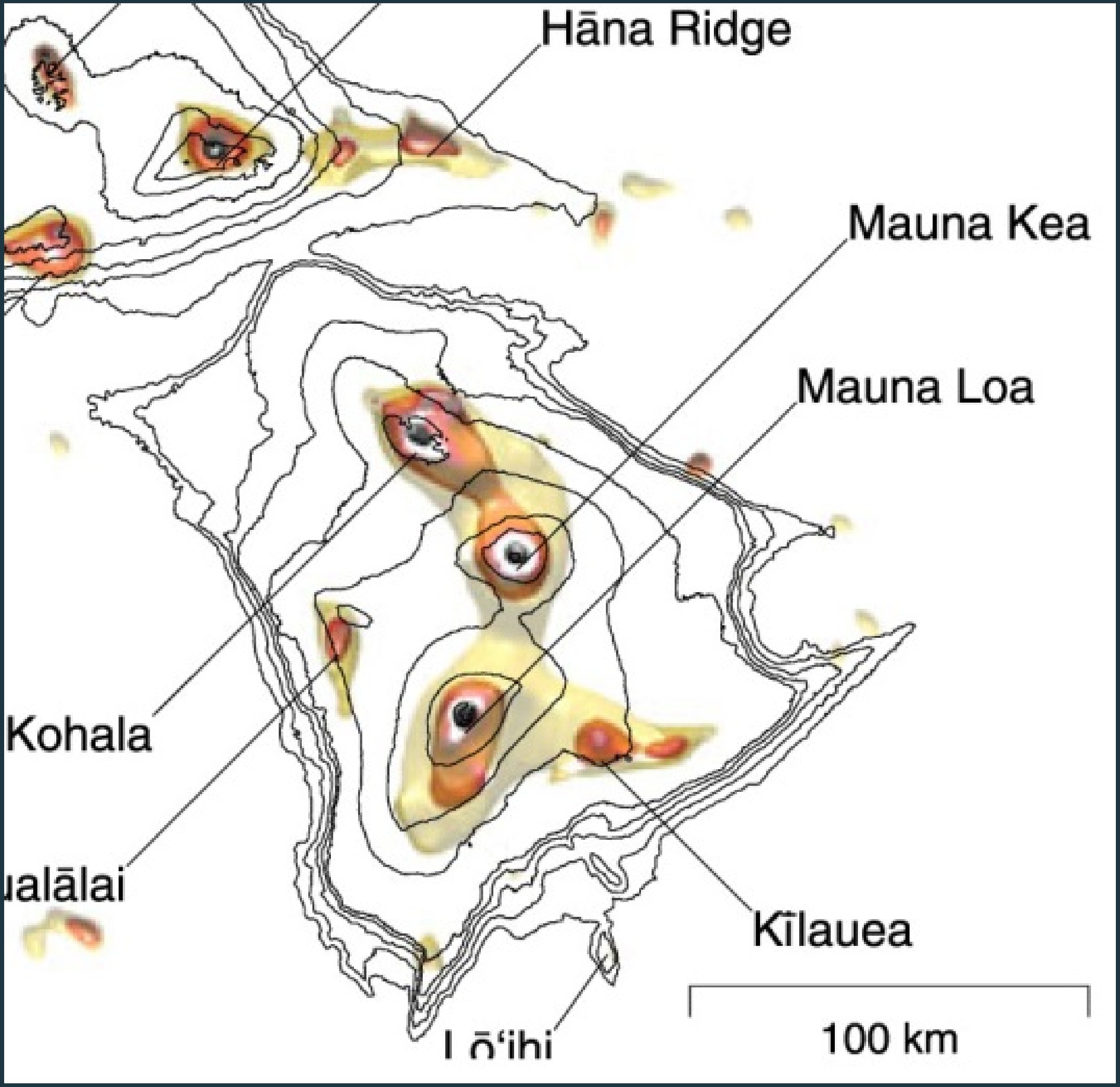
Transition Zone Amchitka (MT)





Hawai'i Island
Geophysical Measurements
Existing Gravity Msmts
Existing AMT Msmts
Existing MT Msmts
Hualalai Summit
N
0 5 10 20
Kilometers

Gravity Survey and Modeling



High Density

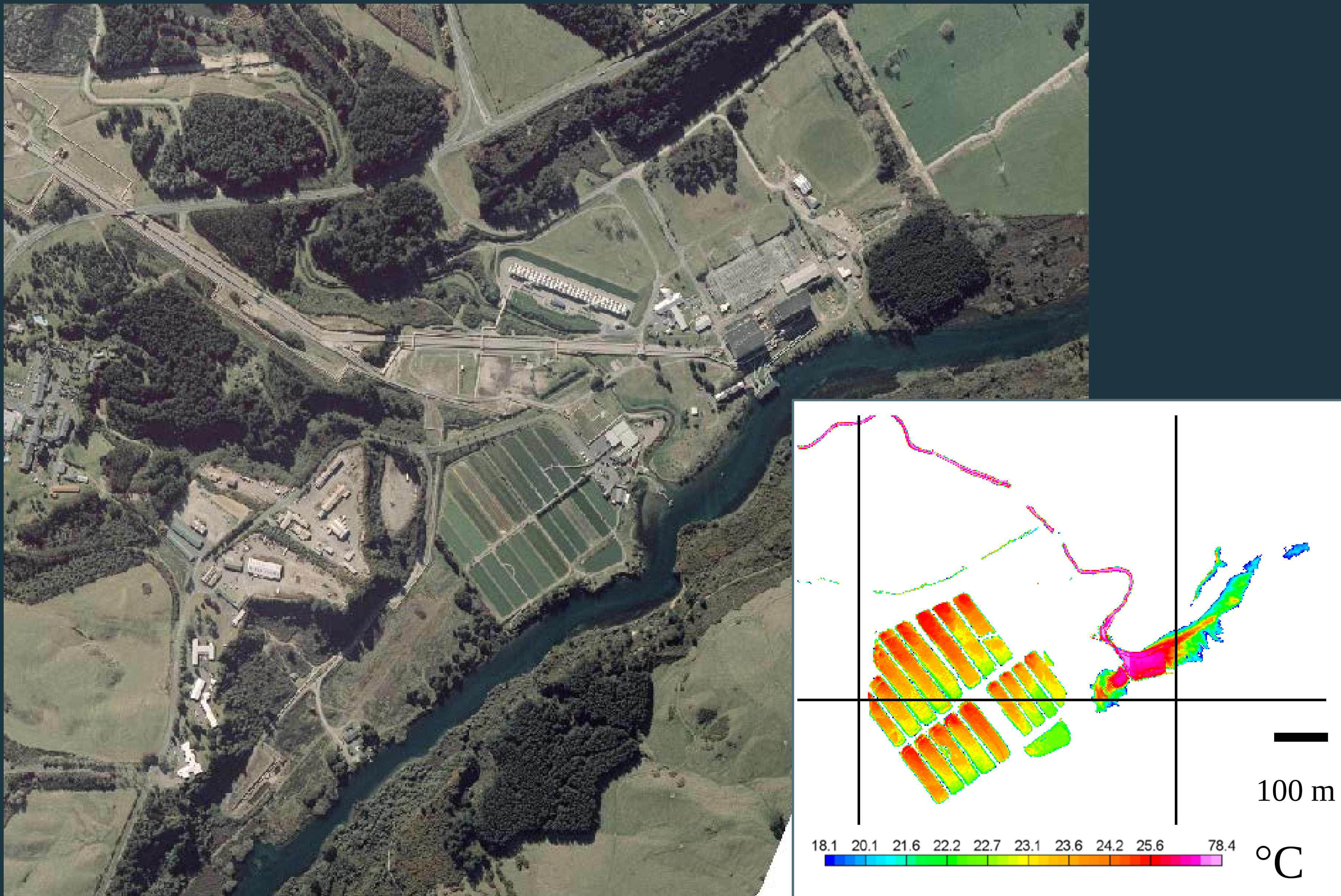
Volcanic necks

Dike complexes

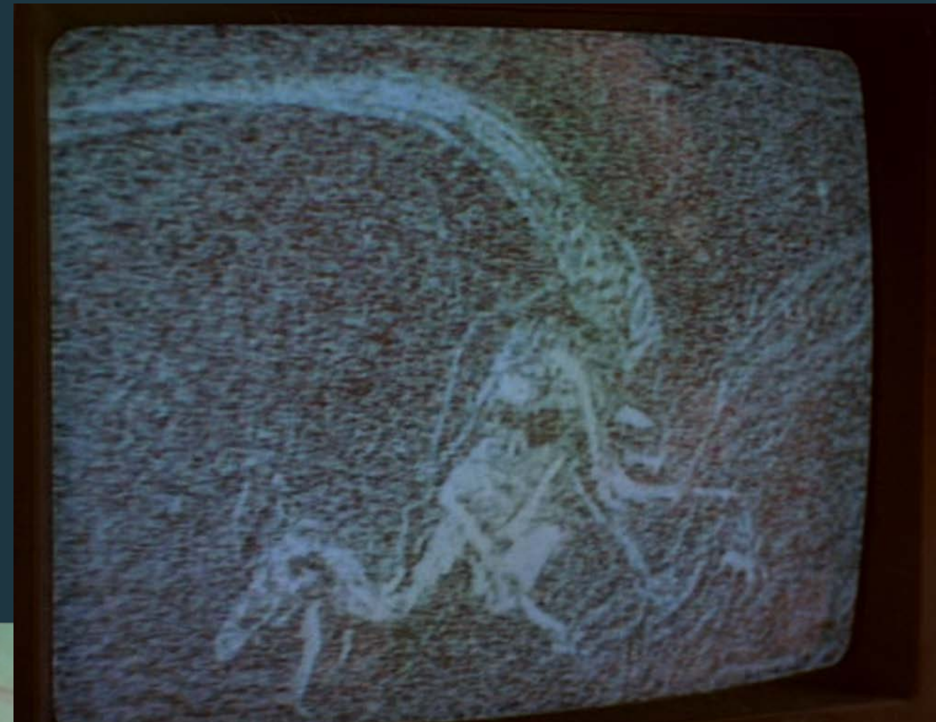
Geophysical Method Depends on the Properties and Depth of the target

- **SURFACE:** Thermal Infrared (**TIR**)
- **0 - 20 METERS:** Ground Penetrating Radar (**GPR**)
- **0 - 60 METERS:** Electrical Resistivity Tomography (**ERT**) and seismic refraction
- **20 METERS TO 2 KM:** Controlled source audiomagnetotellurics (**CSAMT**), Time Domain Electromagnetics (**TEM**)
- **1 KM – 10's KM:** Magnetotellurics (**MT**)

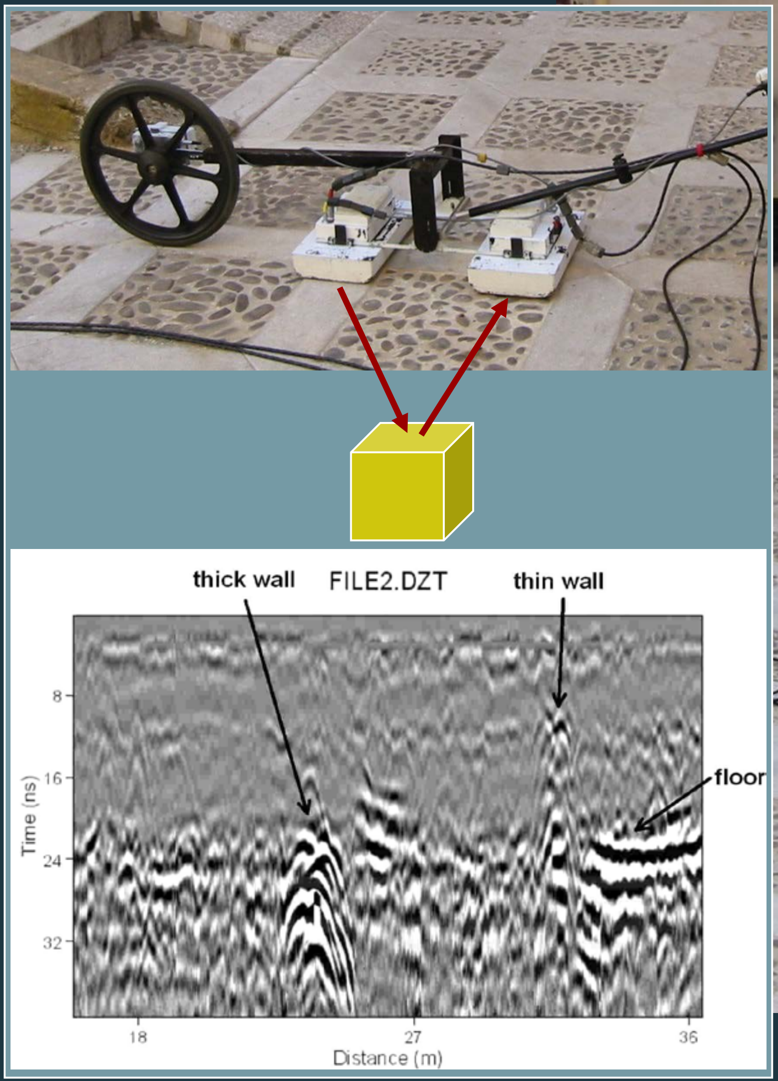
Aerial Thermal Infrared (TIR) Mapping and Monitoring

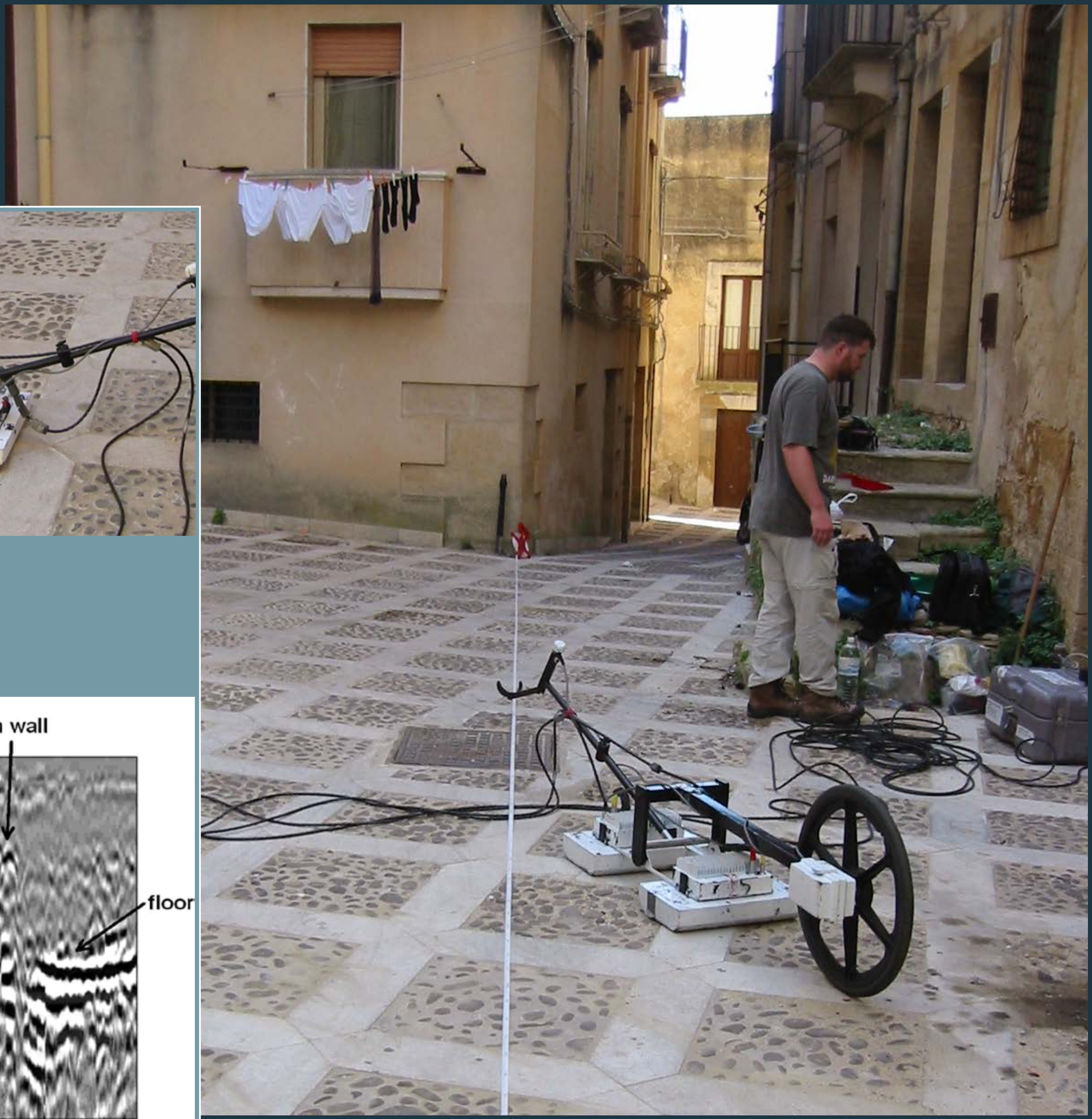


Is this how GPR works?



GPR for Archaeology





Via Cappa Santa,
Salemi Sicily
house floor remnants
4th - 6th c. BC

PCE Spill Experiment

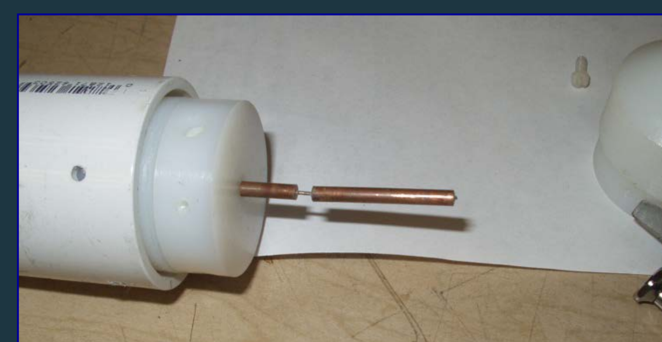
Experimental monitoring:

- ***Crosswell GPR***

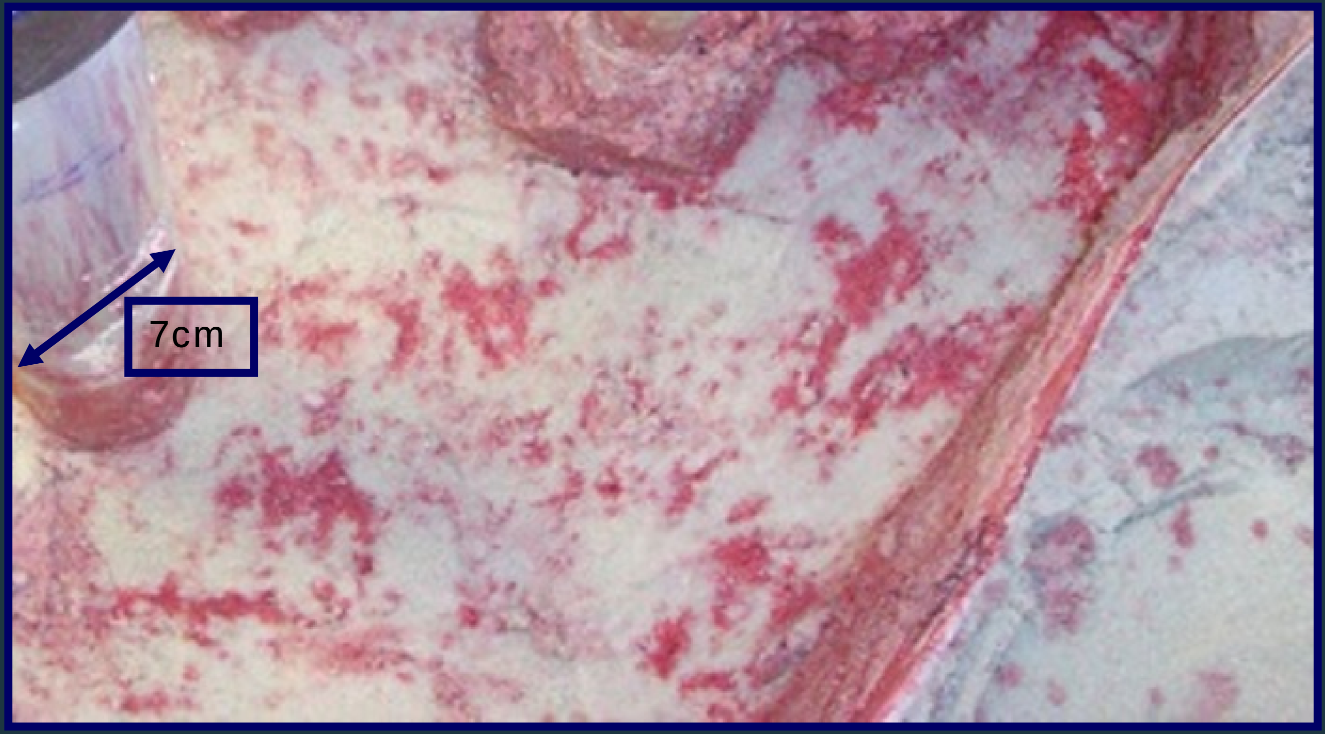
- **Surface GPR**
- **Complex resistivity**
- **Directional borehole radar**
- **Acoustic logging**
- **Dielectric logging**
- **High frequency sounding**
- **Very early time EM**

Parameters of Crosswell Radar

- Zero Offset Gathers
- Common Source Gathers
- 23.8 L PCE in 72 hours
- 1.4 GHz antenna (air)
- Recorded 100 ns data trace
- 20 ps sample interval
- 2.5 cm depth interval

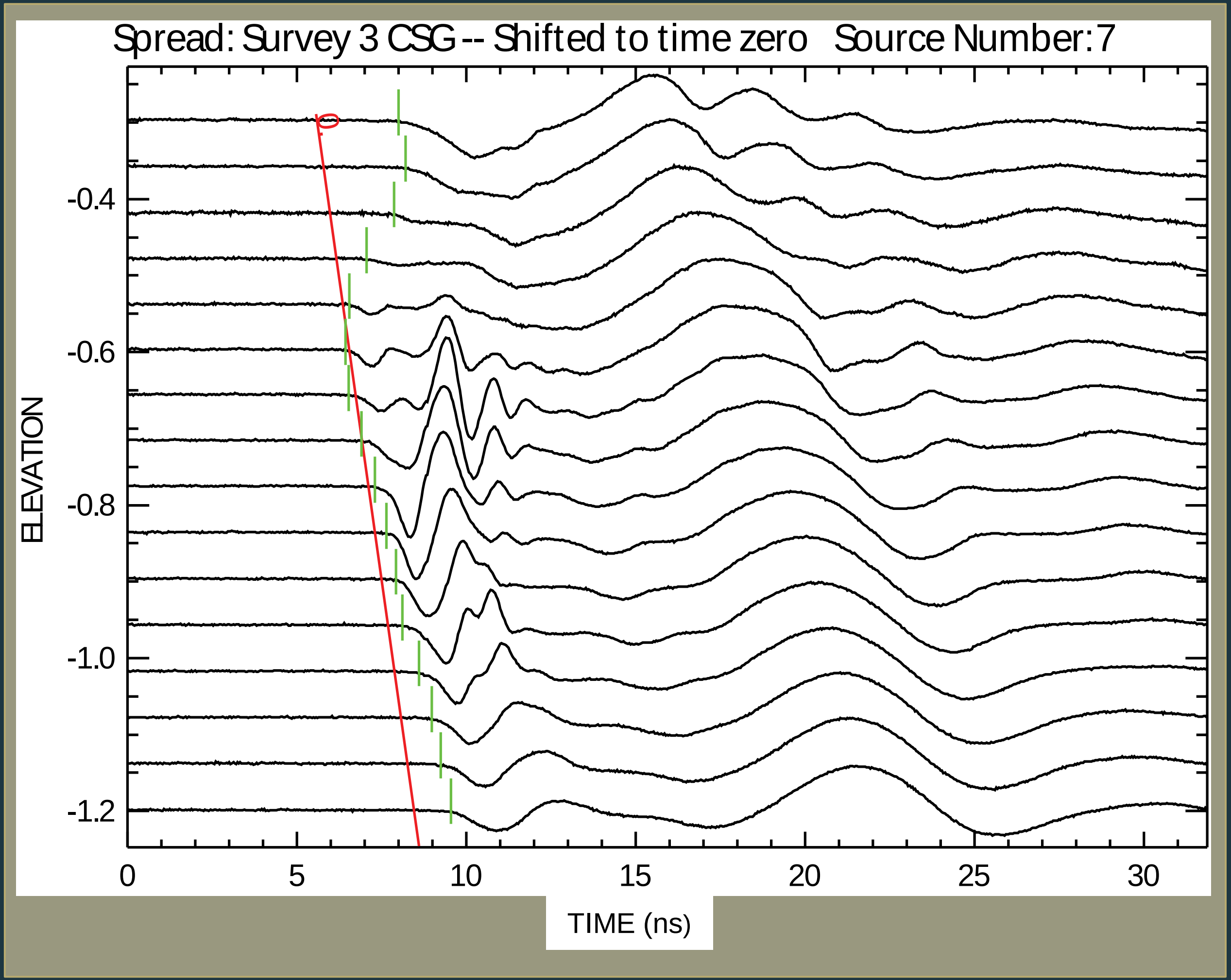


PCE Distribution



Variation in PCE size and shape at depth of 77cm (4 cm below boundary between 3% clay-sand and 5% clay-sand interface)

Velocity of Direct Arrivals $\Rightarrow \varepsilon$

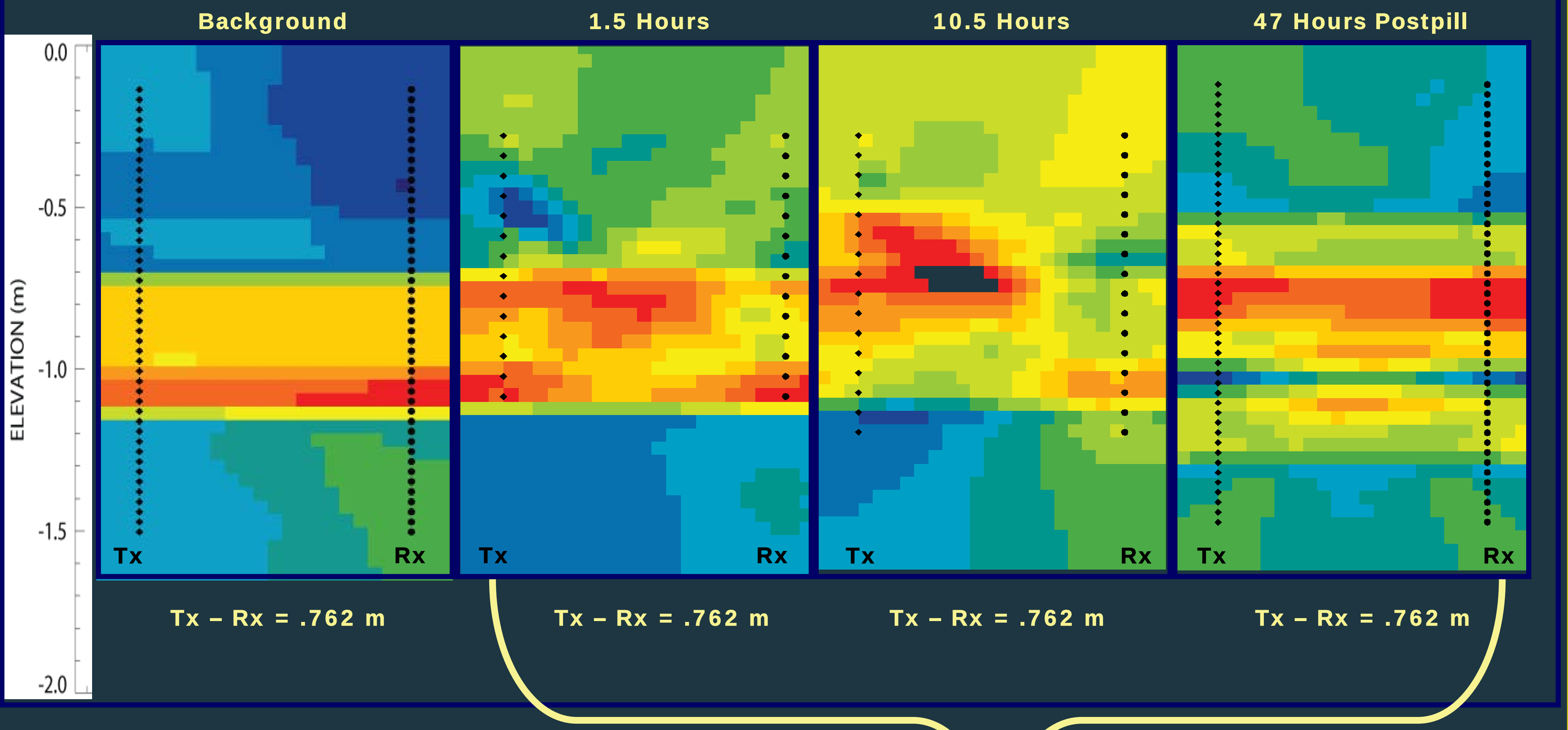


$$RDP = \left(\frac{v_0}{v_m}\right)^2$$

$$v_m = \frac{\text{distance between wells}\,(m)}{\text{direct arrival time}\,(s)}$$

$$v_0 = 3\times 10^8\, m/s$$

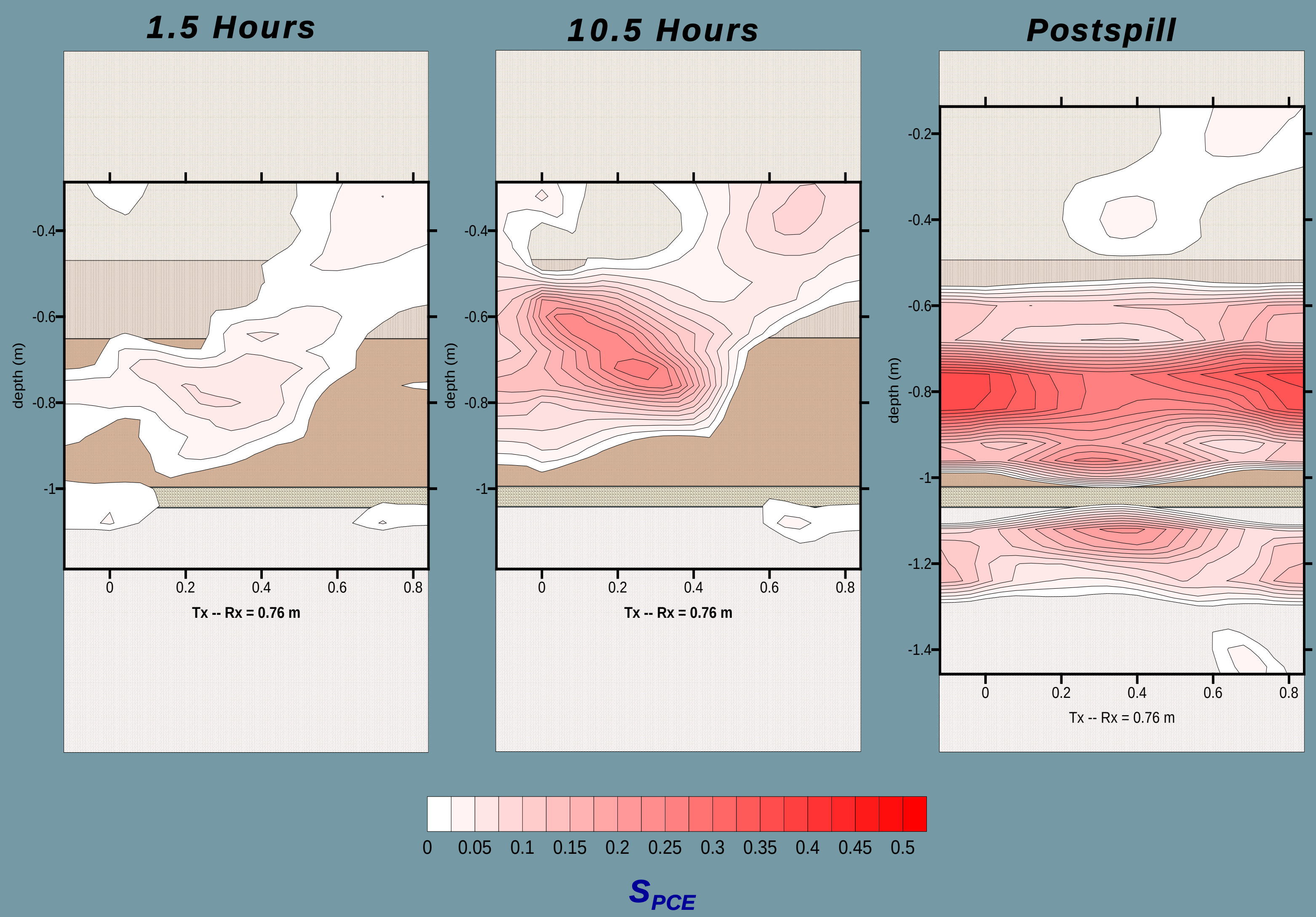
Velocity Tomograms



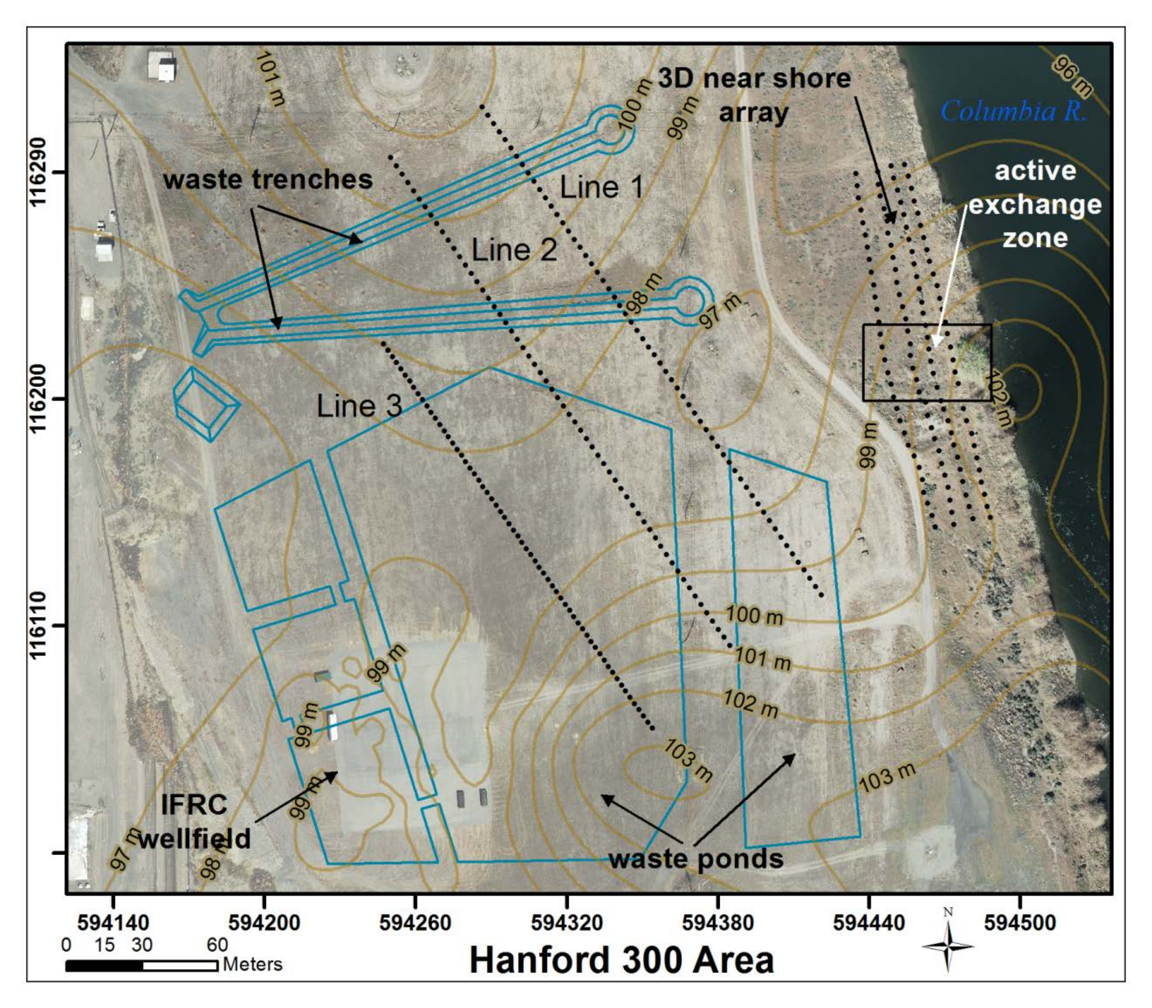
$$\varepsilon_{comp} = (c^2)(slowness^2)$$

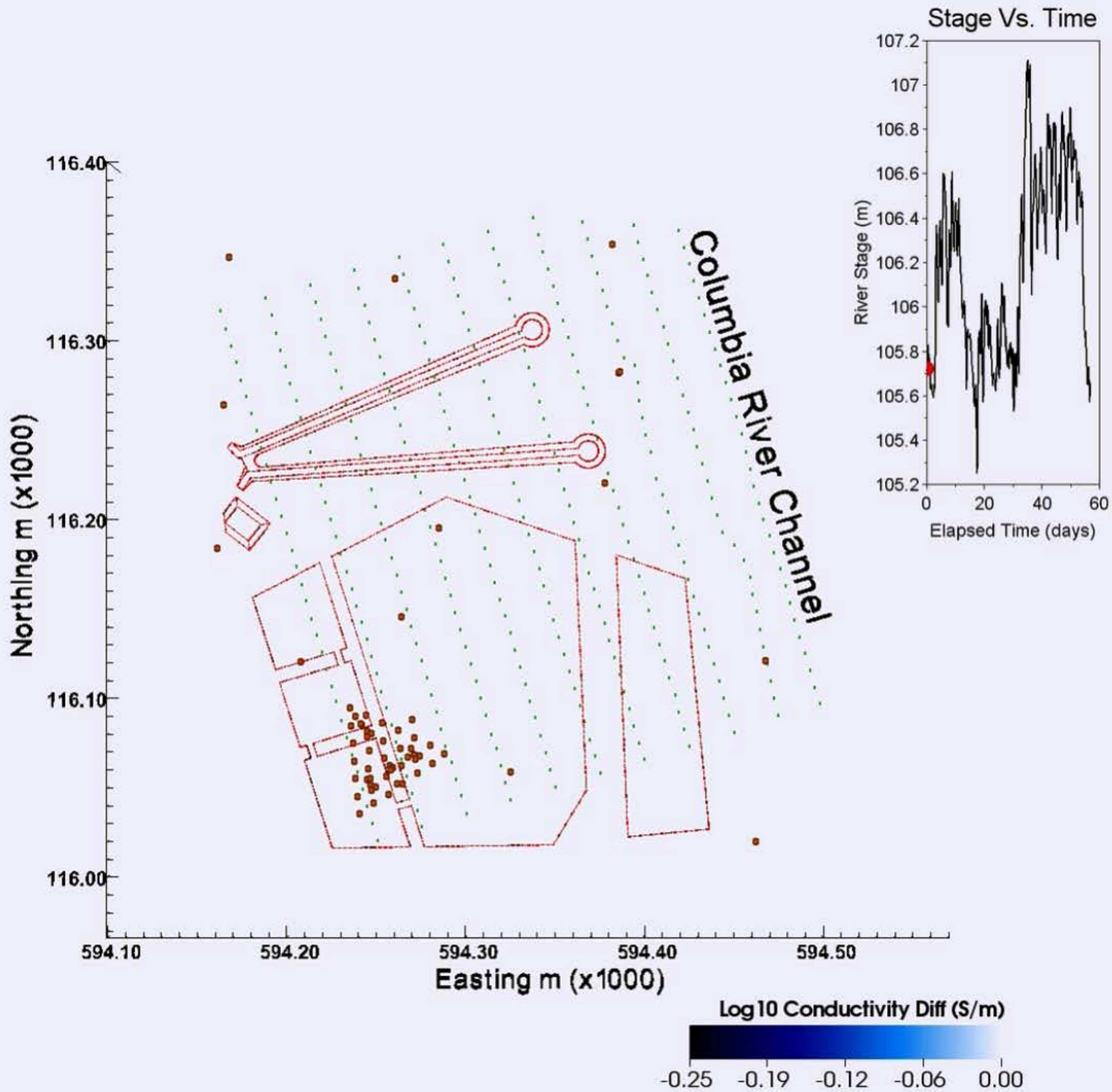
Bruggeman-Hanai Sen mixing formula ⇒ Porosity ⇒ S_{PCE}
(Sander 1994 and Sneddon 2000)

Contoured PCE Saturations (from BHS formula)



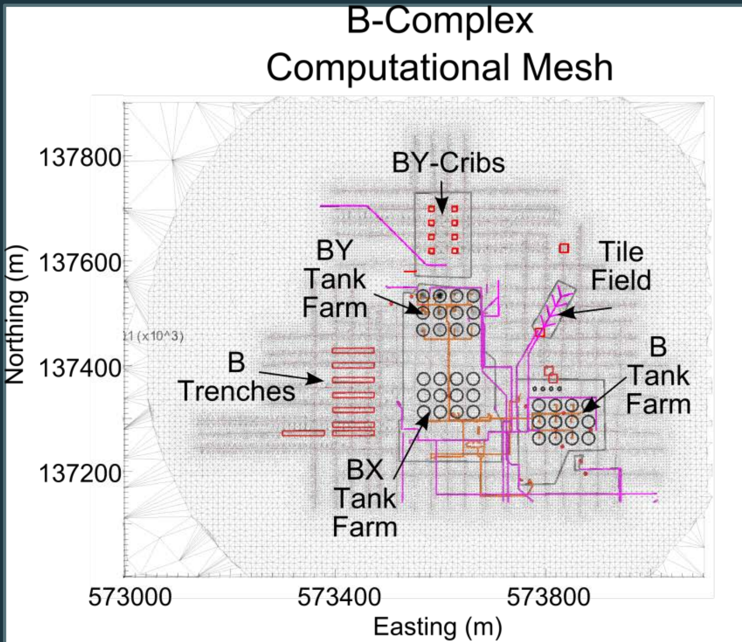
Electrical Resistivity Tomography

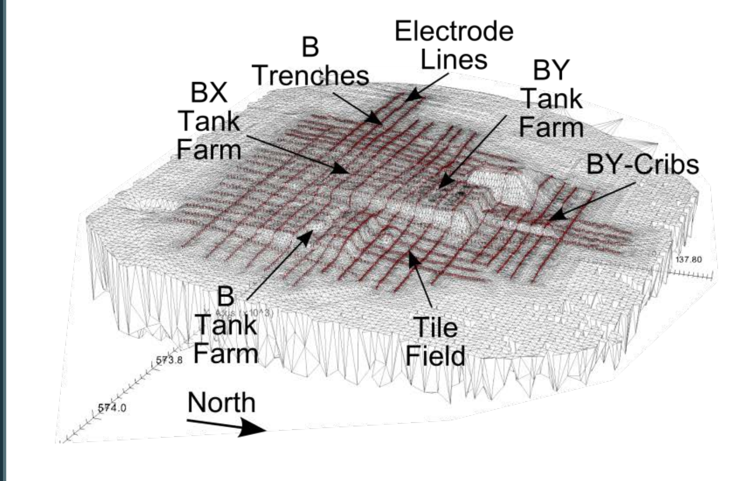




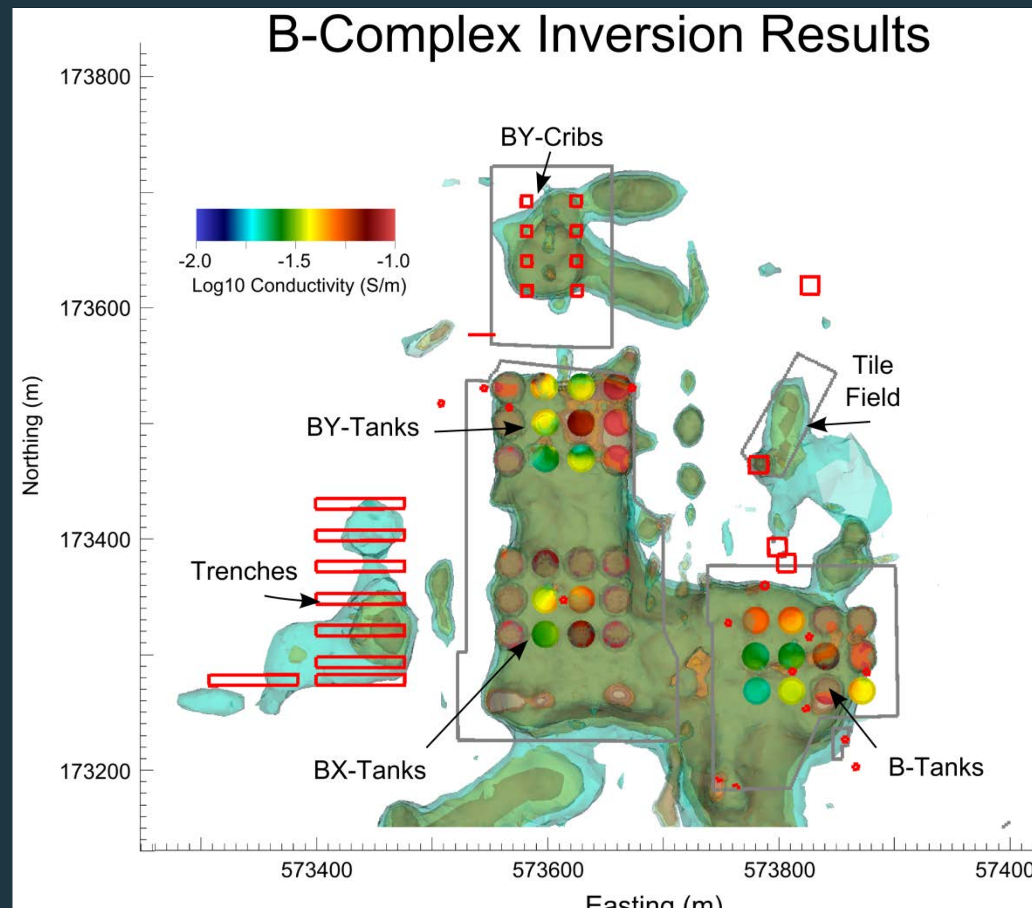
Stage Vs. Time
River Stage (m)
Elapsed Time (days)
107.2
107
106.8
106.6
106.4
106.2
106
105.8
105.6
105.4
105.2
0
20
40
60
Columbia River Channel
Northing m (x1000)
116.40
116.30
116.20
116.10
116.00
594.10
594.20
594.30
594.40
594.50
Easting m (x1000)
Log10 Conductivity Diff (S/m)
-0.25
-0.19
-0.12
-0.06
0.00

Electrical Resistivity Tomography



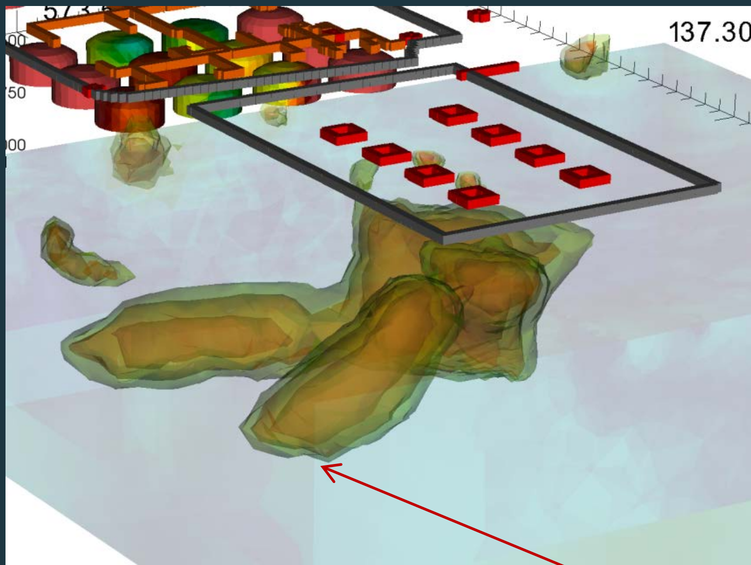


Leaking tanks

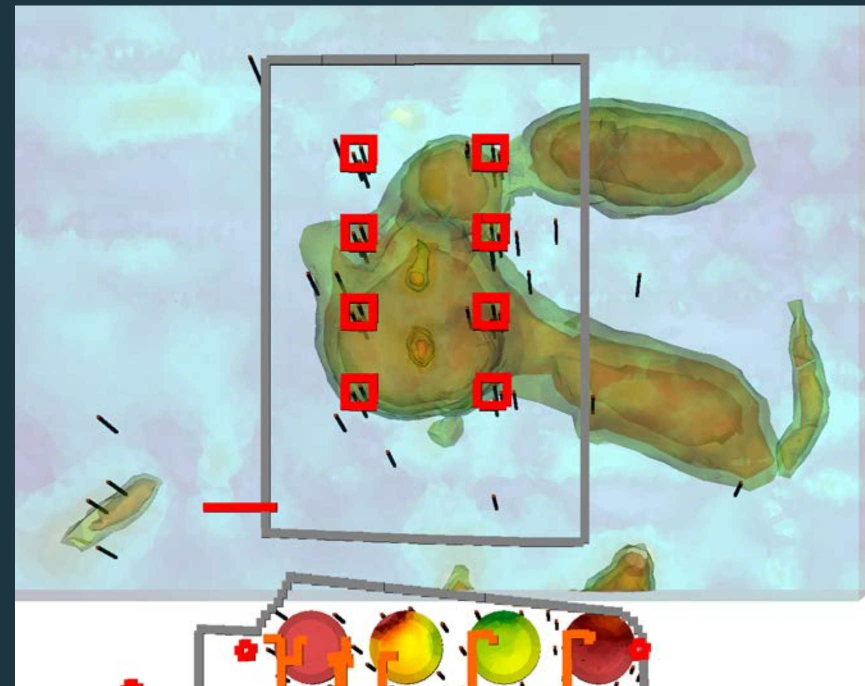


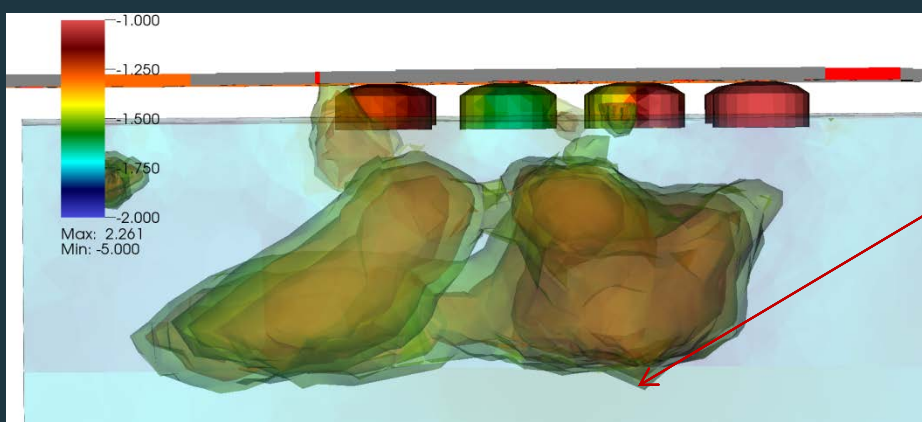
BY-Cribs

Oblique View



Plan View



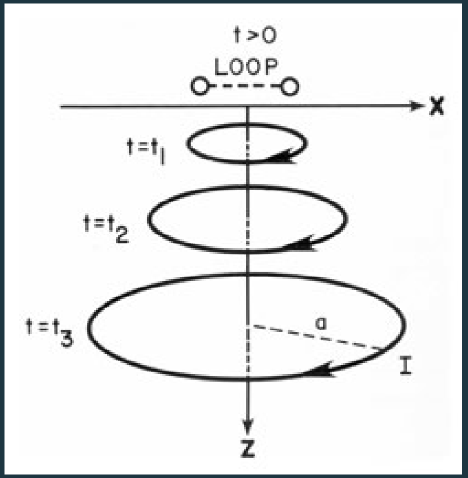


water table

One primary contaminant plume with two lobes that appear to settle at the water table and extend eastward.

Time Domain Electromagnetics

TEM Soundings provide information about the electrical conductivity of the upper few hundred metres of the earth's crust



Proposal

– Develop a collaborative effort among the UH, CWRM, DOH, and county DWS to:

  – Better define the distribution and extent of groundwater aquifers statewide

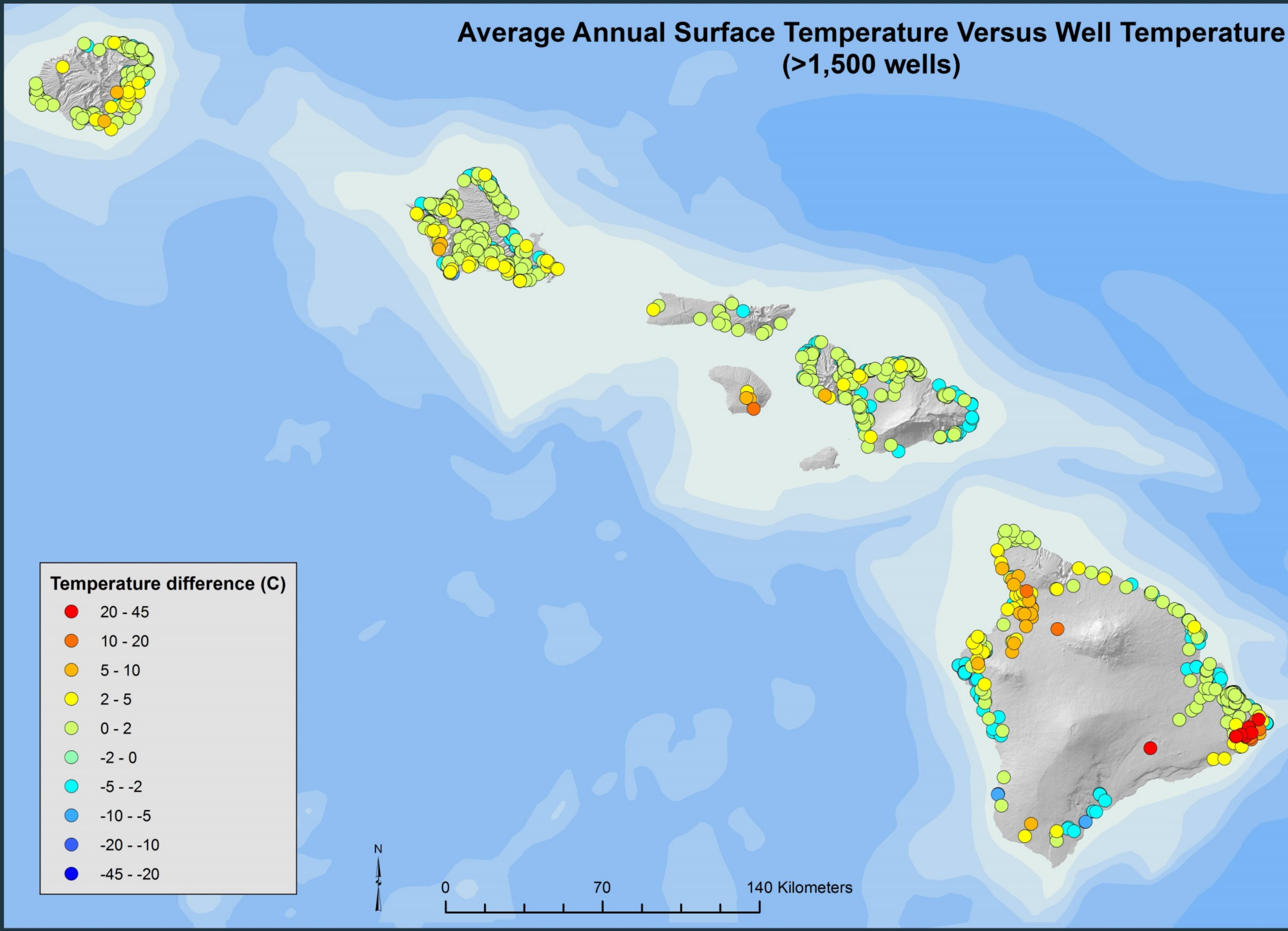
  – Develop better models for groundwater flow that can more reliably project the rates and direction of flow of the groundwater (and potential contaminants)

"…we still don't have an understanding of the groundwater system. There's nowhere near enough outflow in the surface waters to balance the recharge…" MacDonald, 1974

How Do We Propose To Do This

- Compile “legacy” data into geospatial database
- Develop suite of visualization tools
- Conduct geophysical surveys to characterize subsurface distribution of GW
- Geophysical experiments at monitoring wells
- Apply geophysical methods to contaminant problems
- Sampling and analysis of GW for non-compliance parameters as novel tracers
- Downhole monitoring instruments for real-time water level and chemistry data in select wells
- Improved estimates of coastal discharge
- Use new and legacy data to test and refine models

Simple database example



How Do We Propose To Do Thi$

- NSF proposal that would allow us to accomplish these goals in the Keauhou/Kiholo and Pearl Harbor/Honolulu aquifers

- Provide funding for interns, field work, development of the visualization software, monitoring tools, models, etc.

- Now working on a proposal to DOD for site specific work in the Pearl Harbor area

Cooperation from our Collaborators

- Access to legacy data and clear guidance on (C.I.) access restrictions
- Guidance on the types of monitoring that would be most beneficial
- Access to a subset of wells that can be monitored
- Guidance on what mapping or sorting capabilities would be most useful to potential users
- Feedback on areas of interest for conducting active or passive geophysical surveys and tests

Outcomes

- Better understanding of GW flow and storage
- Suite of useful, user-friendly tools for agency staff
- Tools to allow agencies to convey information to the public and decision makers
- Robust modeling capabilities
- Knowledge on how to best access water resources – sustainably – while minimizing costs and adverse impacts


Pau
Mahalo