

Understanding the Fate of Spilled Fuel at Red Hill Bulk Fuel Storage Facility, O‘ahu, Hawai‘i

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Distribution of Ancient Carbon in Groundwater and Soil Gas from Degradation of Petroleum near the Red Hill Bulk Fuel Storage Facility, O‘ahu, Hawai‘i



Scientific Investigations Report 2024–5034

U.S. Department of the Interior
U.S. Geological Survey

Report published June 13, 2024

A November 2021 jet fuel spill at the Navy's Red Hill facility threatened drinking water supplies

Pearl Harbor families are alarmed about petroleum found in their tap water

DECEMBER 3, 2021 · 10:17 AM ET



<https://www.npr.org/2021/12/03/1061194511/pearl-harbor-tap-water-petroleum-fuel>

Thousands displaced from Oahu military base due to contamination in Navy water system

DECEMBER 15, 2021 · 1:12 PM ET



<https://www.npr.org/2021/12/15/1064514935/water-contamination-hawaii>

In Hawaii, Fears Grow Over Unsafe Levels of Petroleum in Drinking Water

State health officials warned residents at a military base near Pearl Harbor to avoid using the water after the Navy found petroleum in samples taken from one of its wells.



Joint Base Pearl Harbor-Hickam in 2012. Kent Nishimura/AFP — Getty Images

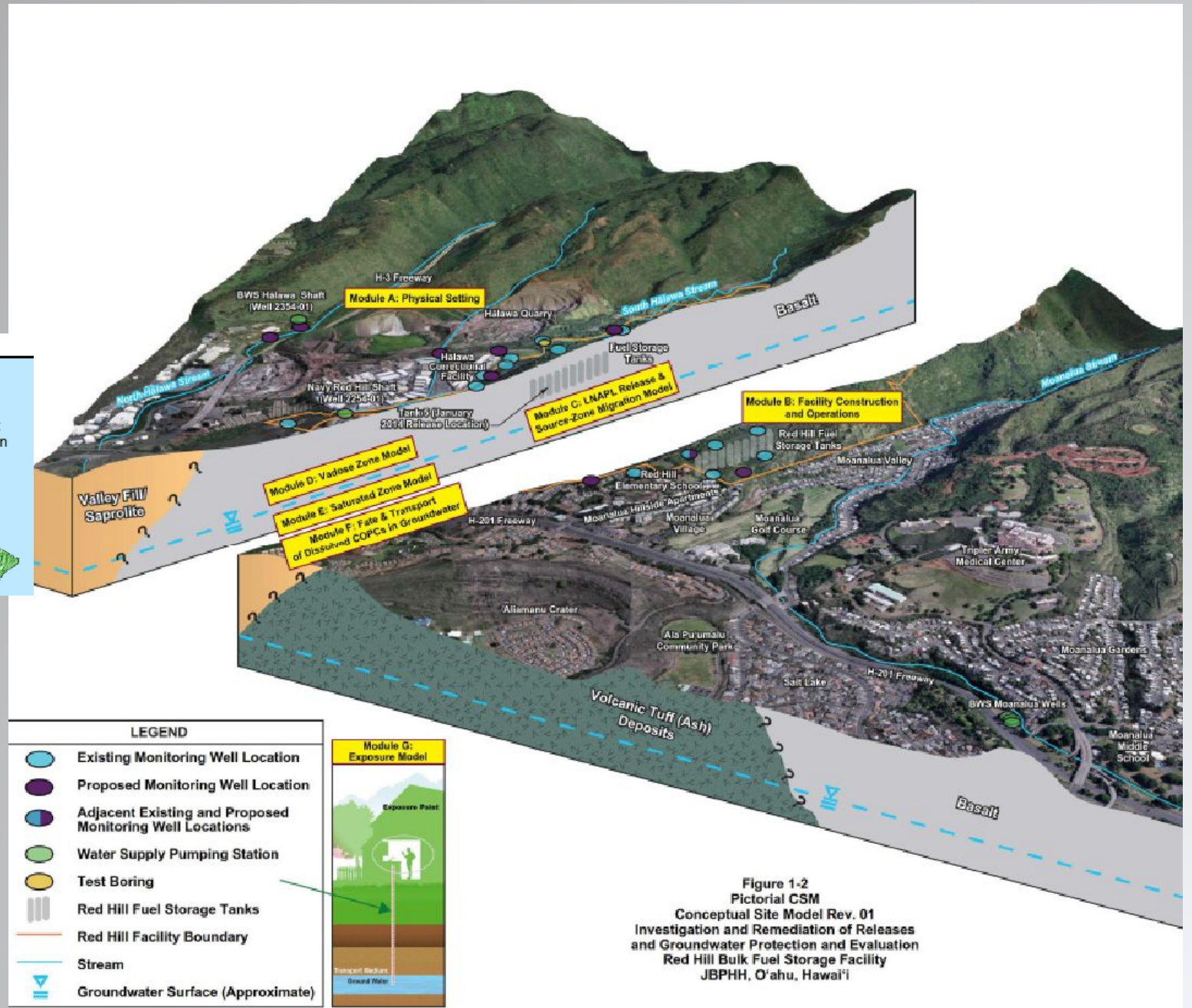
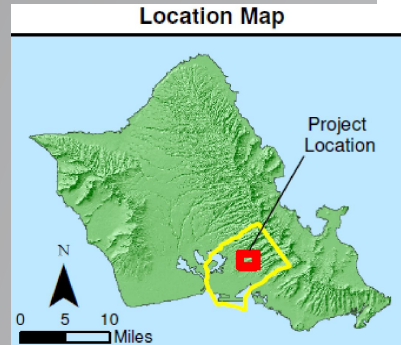
By **Maria Cramer**

Dec. 11, 2021

New York Times, Dec. 11, 2021

<https://www.nytimes.com/2021/12/11/us/hawaii-petroleum-navy.html>

Red Hill Bulk Fuel Storage Facility O'ahu, Hawai'i



The tanks are constructed within basalt overlying a major water supply aquifer

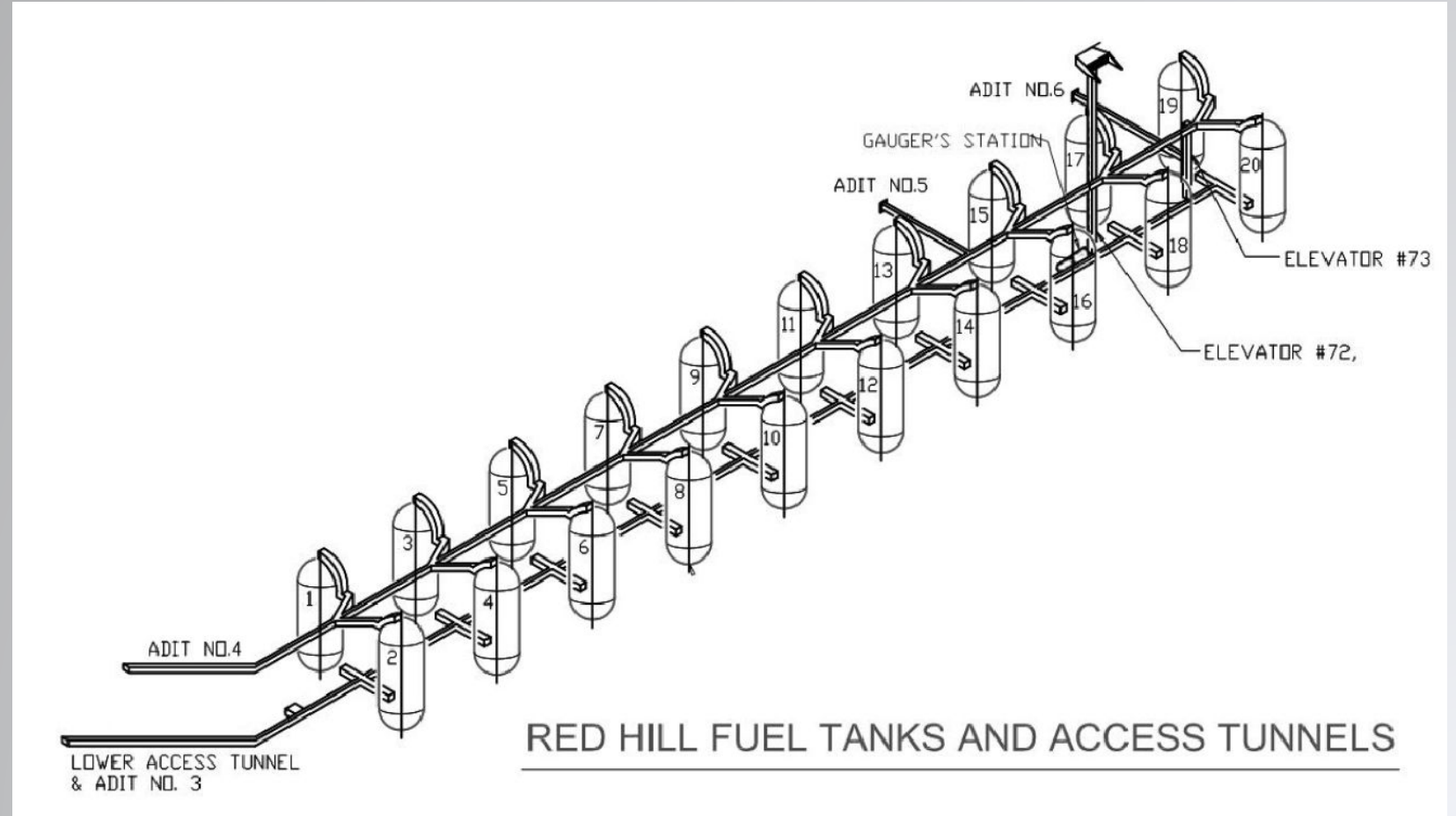
LEGEND	
	Existing Monitoring Well Location
	Proposed Monitoring Well Location
	Adjacent Existing and Proposed Monitoring Well Locations
	Water Supply Pumping Station
	Test Boring
	Red Hill Fuel Storage Tanks
	Red Hill Facility Boundary
	Stream
	Groundwater Surface (Approximate)



The facility built during 1941-1943 consists of 20 tanks connected by tunnels to Joint Base Hickam Pearl Harbor

Tanks:

- 250 ft high
- 100 ft diameter
- Encased in concrete
- Lined with steel
- 12.5 million gallons per tank



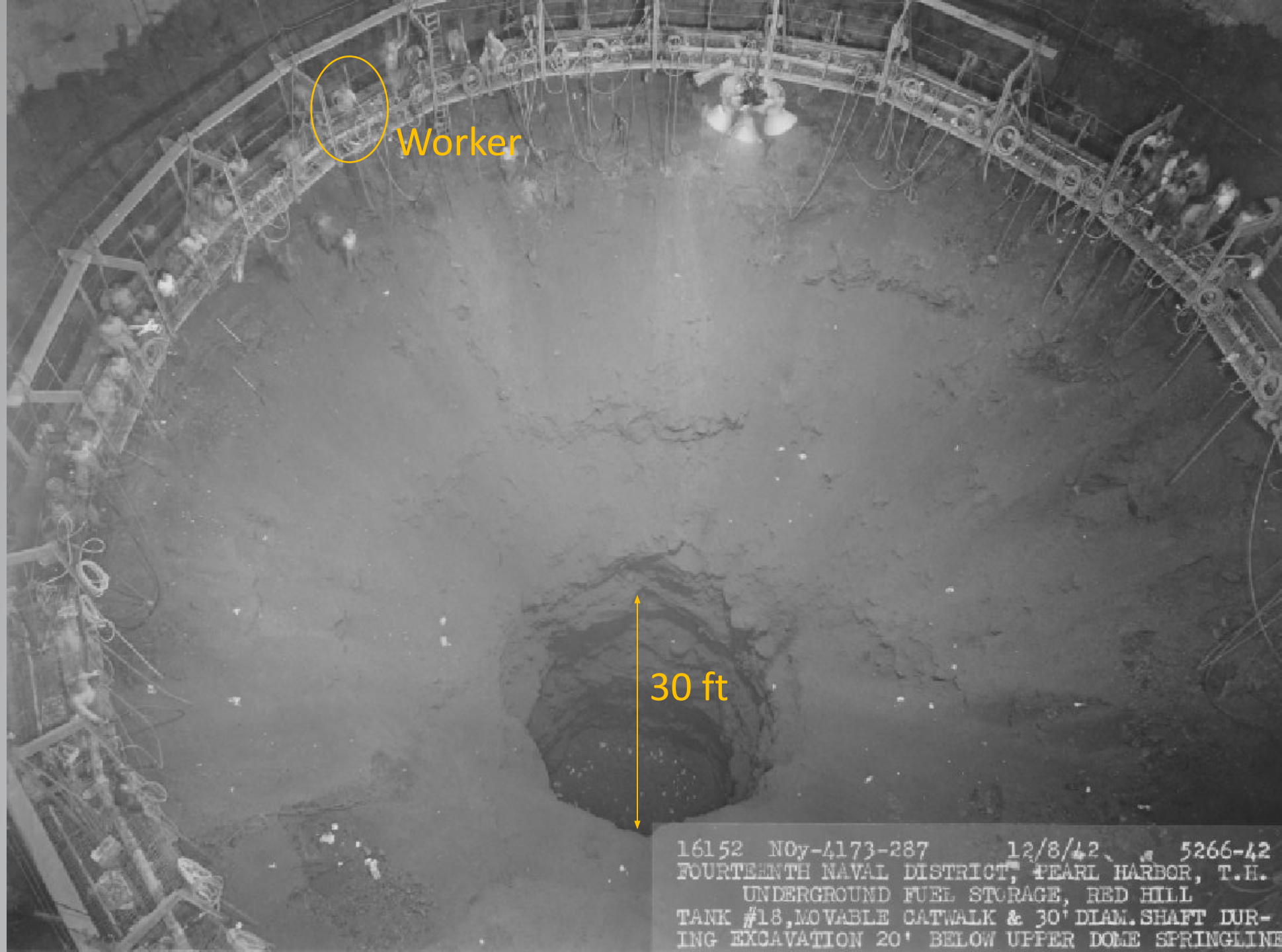
Tanks were excavated from the top down

December 8, 1942, photo of Fuel Tank 18 with movable catwalk and shaft for disposal of excavated rock below.

3600 workers
16 fatalities

HISTORIC AMERICAN ENGINEERING RECORD, No. HI-123, National Park Service, 2015

Builders for Battle, 1946



2021 Spill scenario

May 6, 2021 : ~19,000 gallons of fuel released from Tank 20 located at the top of the tank farm.

Responders cleaned up ~1600 gallons but did not realize that most of the spill ended up in a drain line of the facility's fire suppression system where it sat for months

Nov. 20, 2021: Fuel from the fire drain line was released when a cart operator ran into a valve and broke it.

The released fuel pooled in the walkway of the tunnel and entered a drain line designed to collect natural groundwater and route it to a sump and leach tank.

The sump overflowed backing up into the drain line where it flowed out the inlet slots into the surrounding basalt

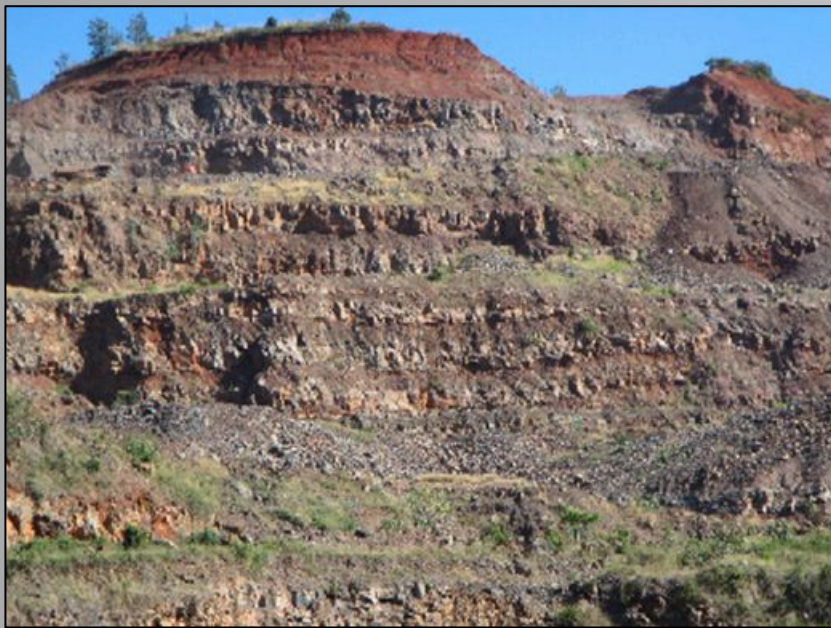


Photo credit: Honolulu Civil Beat,
<https://www.civilbeat.org/2022/07/watch-fuel-spewed-full-blast-into-red-hill-tunnel-in-november/>

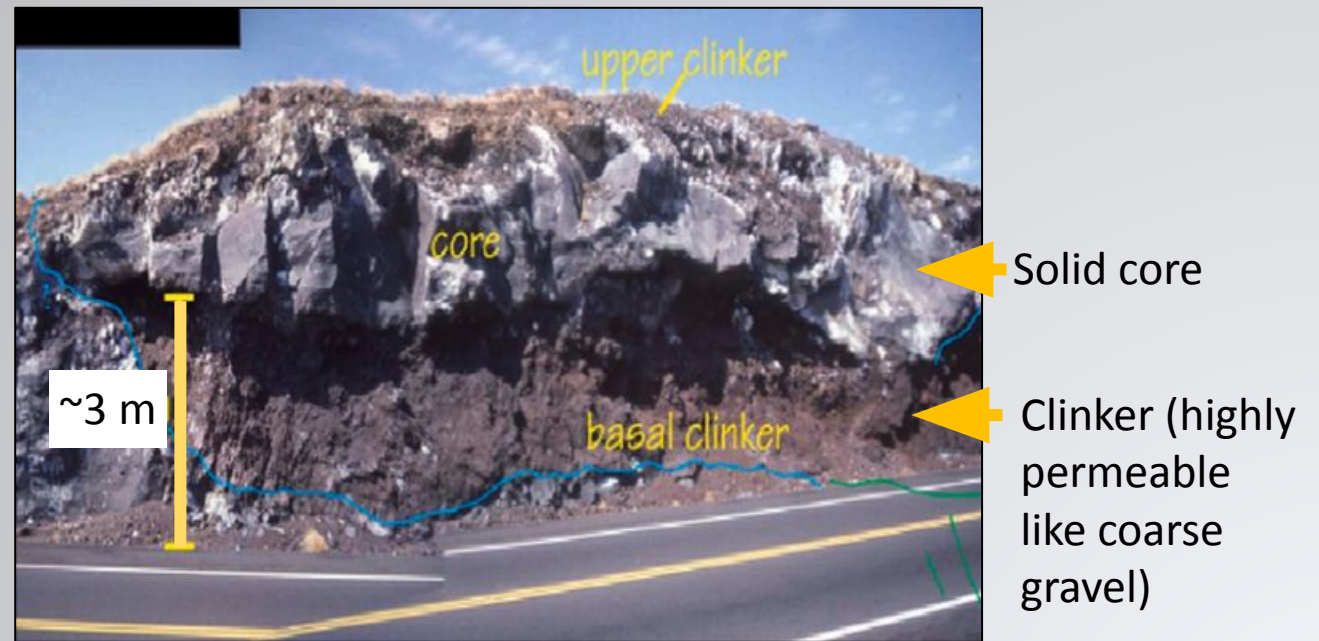
During a tour, a Navy official showed lawmakers the fire suppression drain line that released water and fuel on Nov. 20, 2021.

The site is challenging for monitoring spills in groundwater and migration away from the source

- Thick unsaturated zone of volcanic basalt (up to 400 ft)
- Complex sequence of fractured lava flows
- Hydraulically conductive formation with very small groundwater gradients



Quarry-cut showing the sequencing of lava units. The zones between hard layers are typically a'a clinker.



Road-cut showing the detail, geometric variability and scale of an a'a core overlying a basal clinker zone.

Source: Beckett et al., 2022

Methods are needed that are sensitive to detect evidence of petroleum-derived compounds in a sparse well network

- Diverse spill history
- Routine monitoring for total petroleum hydrocarbons (DRO, ORO) and a suite of specific hydrocarbons, but routine methods miss many partial transformation products
- Partial transformation products in NVDOC were the largest mass of petroleum-derived carbon at a crude oil spill site, being 3-20 times higher than DRO (Bekins and others, 2016, 2020)
- Petroleum is carbon-14 dead in contrast to “modern” atmospheric carbon-14

Therefore, we focused on groundwater NVDOC, ^{14}C -NVDOC, and a suite of biodegradation indicators

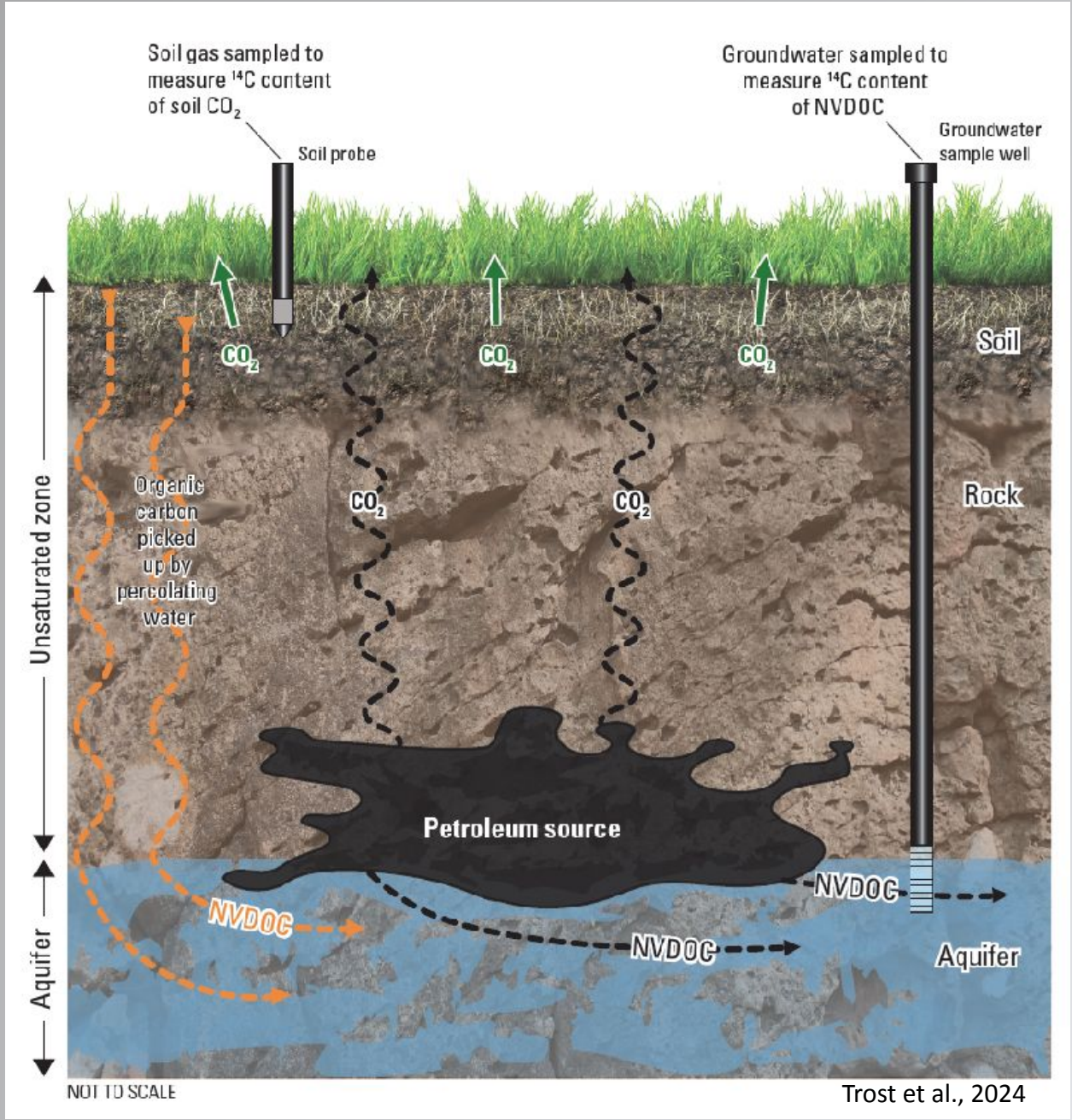
- *TPH = total petroleum hydrocarbons*
- *DRO = Diesel range organics*
- *ORO = oil range organics*
- *NVDOC = non-volatile dissolved organic carbon*



Photo credit: U.S. Geological Survey

Two Carbon Sources

Percent modern (or ancient) carbon quantifies CO₂ and non-volatile dissolved organic carbon (NVDOC) derived from modern and contaminant sources



- ↑ Natural background CO₂ from plants and soil (*0 % ancient carbon*)
- ↑ Natural background NVDOC (*~38 % ancient carbon*)
- ↑ CO₂, NVDOC from petroleum (*100 % ancient carbon, ¹⁴C-dead*)



Percent Ancient C = 100 - Percent Modern C

Red Hill Project goals

The presence of fuel from past spills in the unsaturated zone above the aquifer creates a need to understand the fate of any fuel from past spills still present in the subsurface.

Surface soil

- Does ancient CO₂ from biodegradation in the petroleum source zone migrate out of the surface?
- Can ancient CO₂ efflux be used to locate source zones?

Groundwater

- Can ancient NVDOC be used to detect dissolved partial hydrocarbon oxidation products migrating in groundwater from source zones?
- What direction does groundwater containing elevated NVDOC migrate away from the facility?

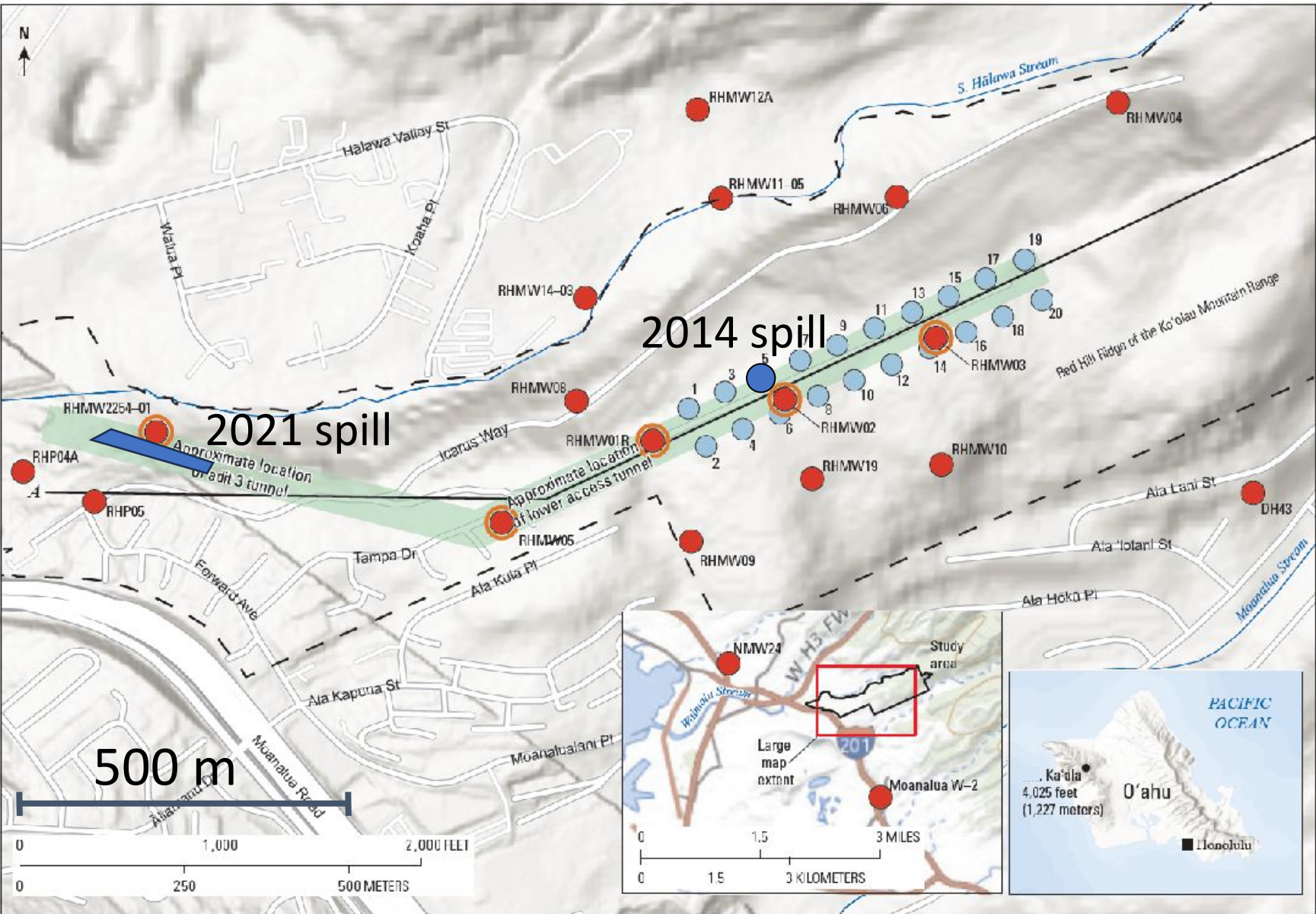


Photo credit: U.S. Geological Survey

The team sampled 19 wells

The samples were analyzed for:

- Non-volatile dissolved organic carbon (NVDOC)
- Carbon-14 content of NVDOC (¹⁴C-NVDOC)
- Diesel-range organics (DRO)
- Major ions
- Trace metals
- Alkalinity



Data from U.S. Geological Survey digital data, various scales and dates
 Universal Transverse Mercator, zone 1 north
 North American Datum of 1983

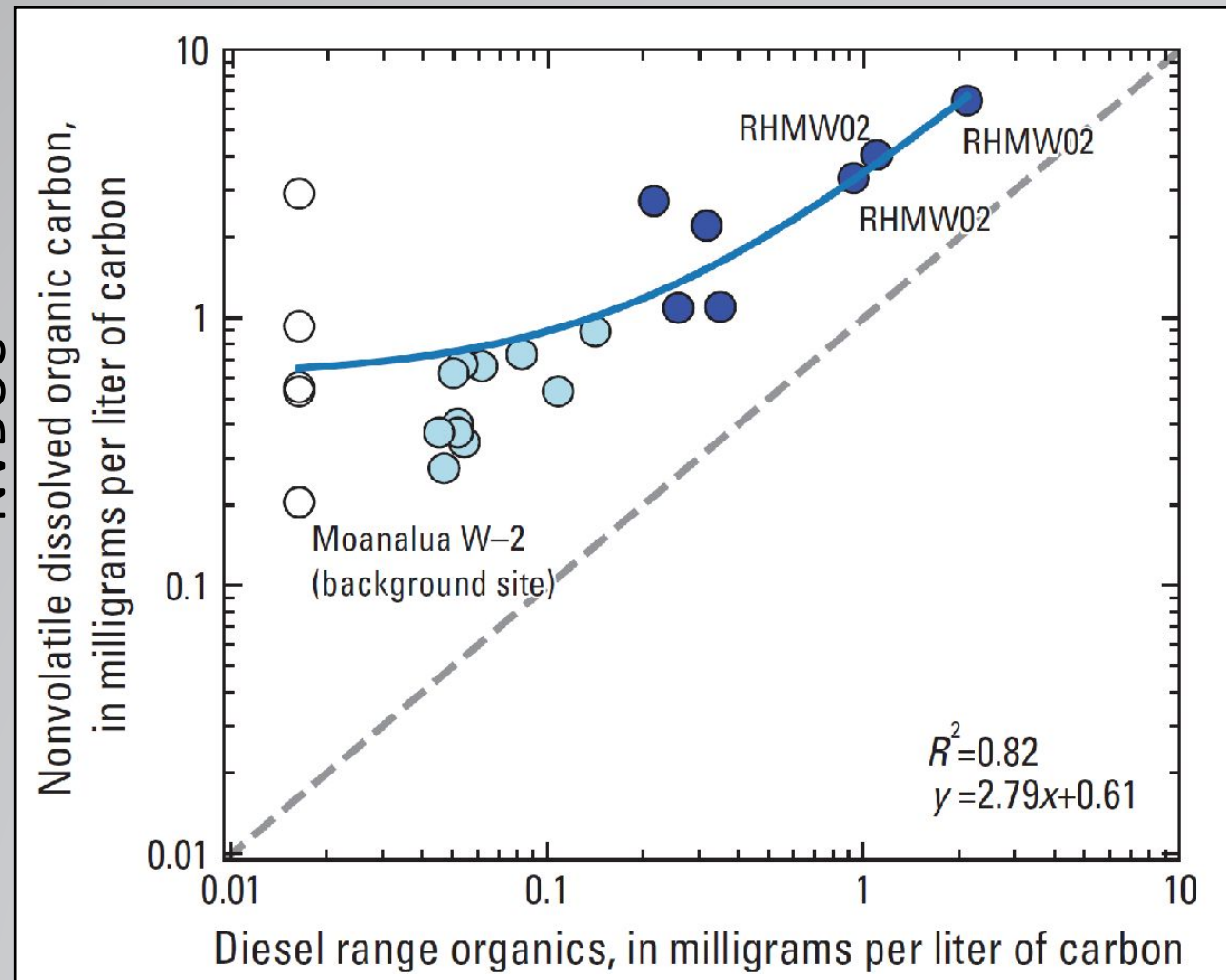
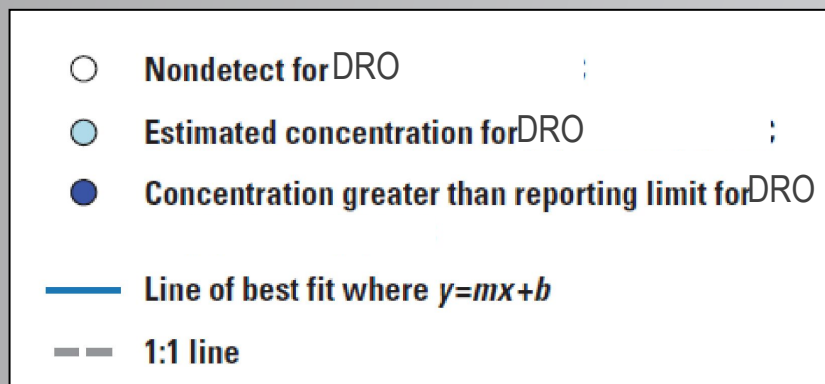
EXPLANATION

- — — Red Hill Bulk Fuel Storage Facility boundary
- A — A' Line of section corresponding to the geologic cross section in figure 3
- Tunnel-access groundwater site
- Groundwater sampling site with identifier
- ① Approximate center of underground fuel storage tank with identifier



Groundwater NVDOC is about 3 times higher than DRO at the sampled wells.

- Elevated NVDOC is evidence of partial biodegradation of the source hydrocarbons
- Partial transformation products might not pose a risk at low concentrations.
- But NVDOC might help to trace migration pathways.

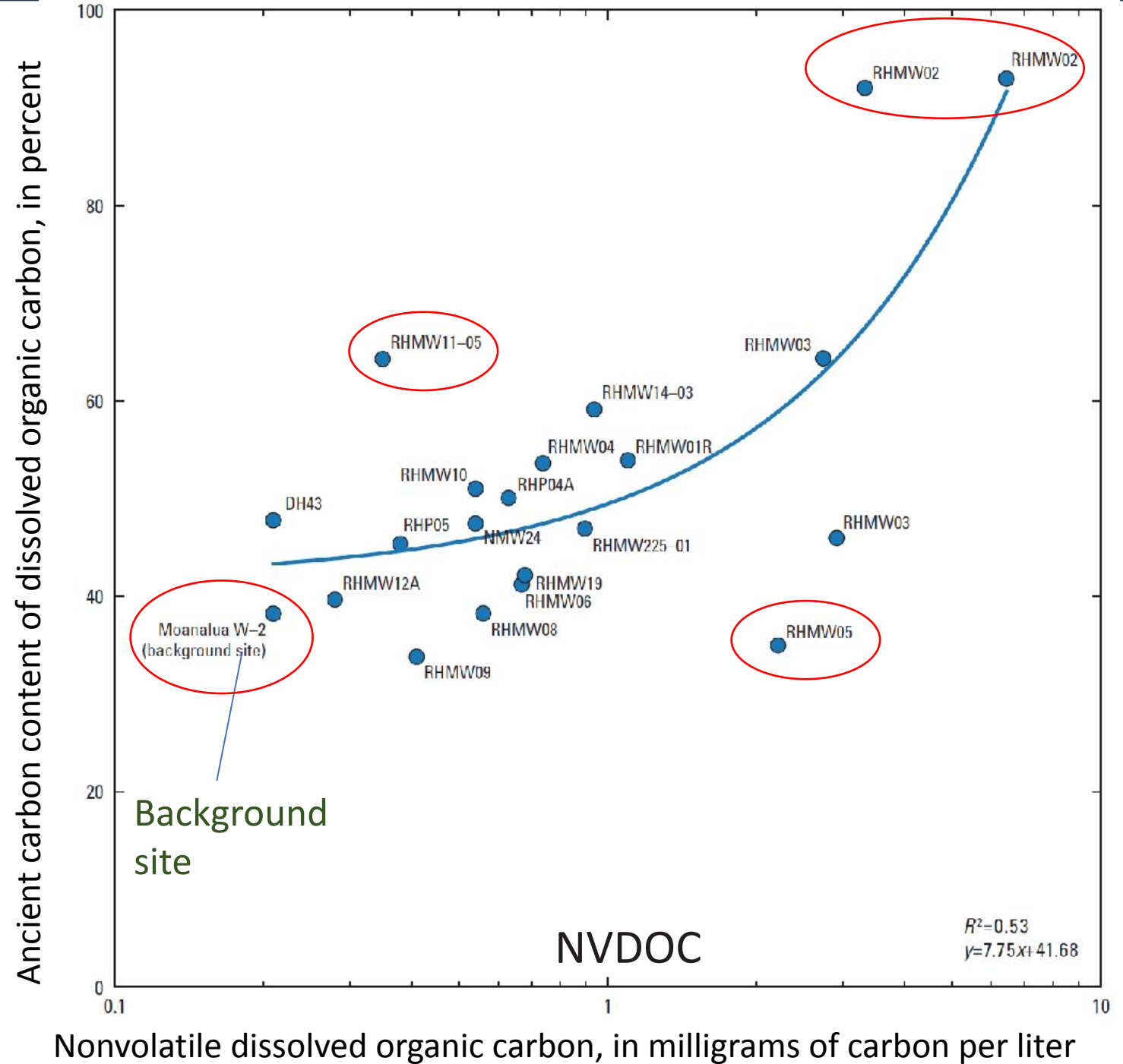


Trost et al., 2024

Ancient Carbon and NVDOC

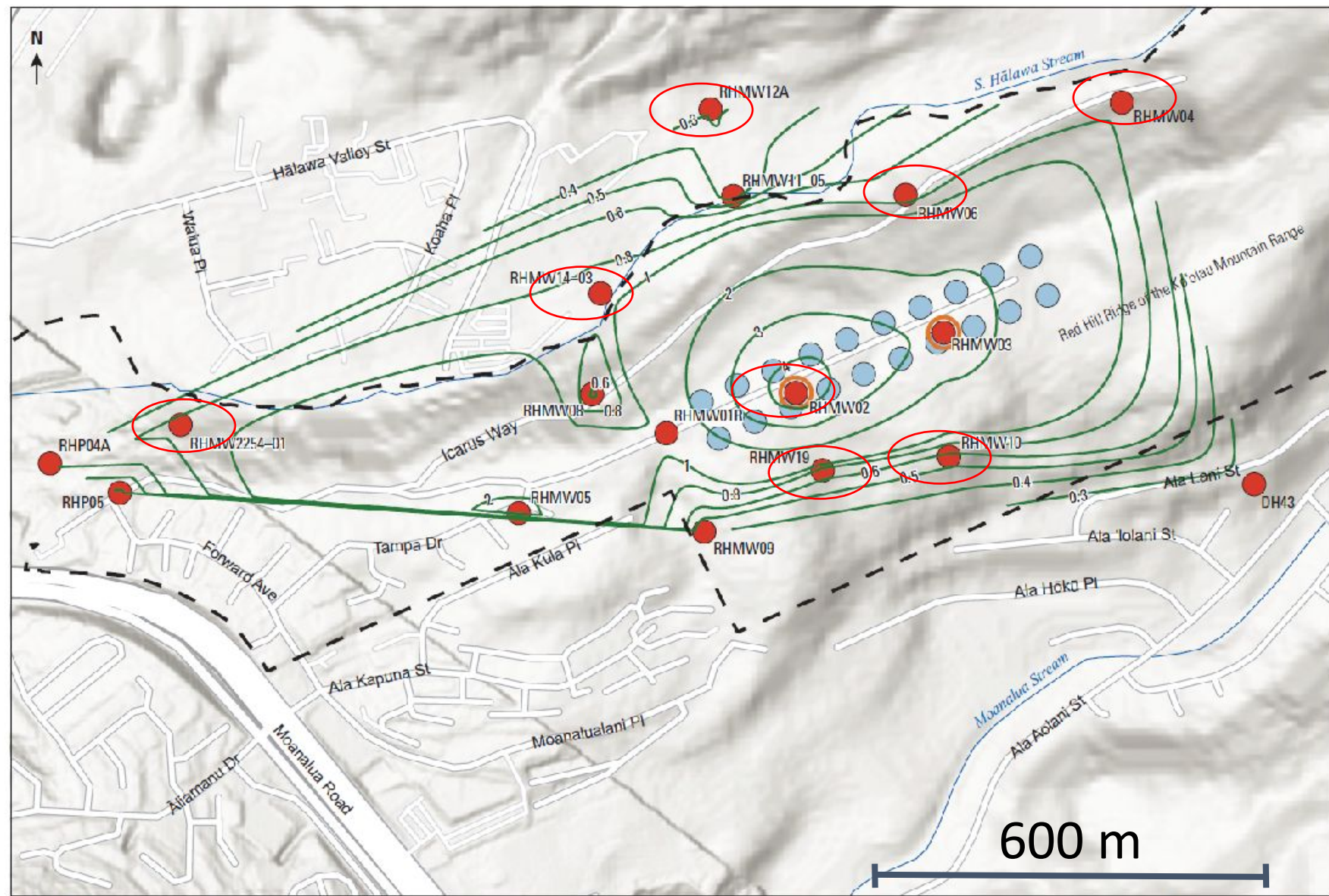
- Overall trend of increasing ancient C with increasing NVDOC
- RHMW02 had the highest NVDOC, DRO, and ancient carbon
- The background site, Moanalua W-2, had 38 percent ancient carbon
 - Suggesting a natural source of ancient carbon in the basalt aquifer
- RHMW05 has high concentrations of young NVDOC
- RHMW11-05 has especially old NVDOC but concentrations are low

^{14}C -NVDOC

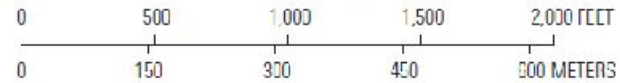


Groundwater NVDOC

- Background value is very low <0.3 mg/L
- Highest is at RHMW02 near 2014 release
- Elevated values:
 - both north and south of the tanks
 - at RHMW2254-01 located at Red Hill Shaft
- Values drop 10x in 200 m to south and in 300 m to north

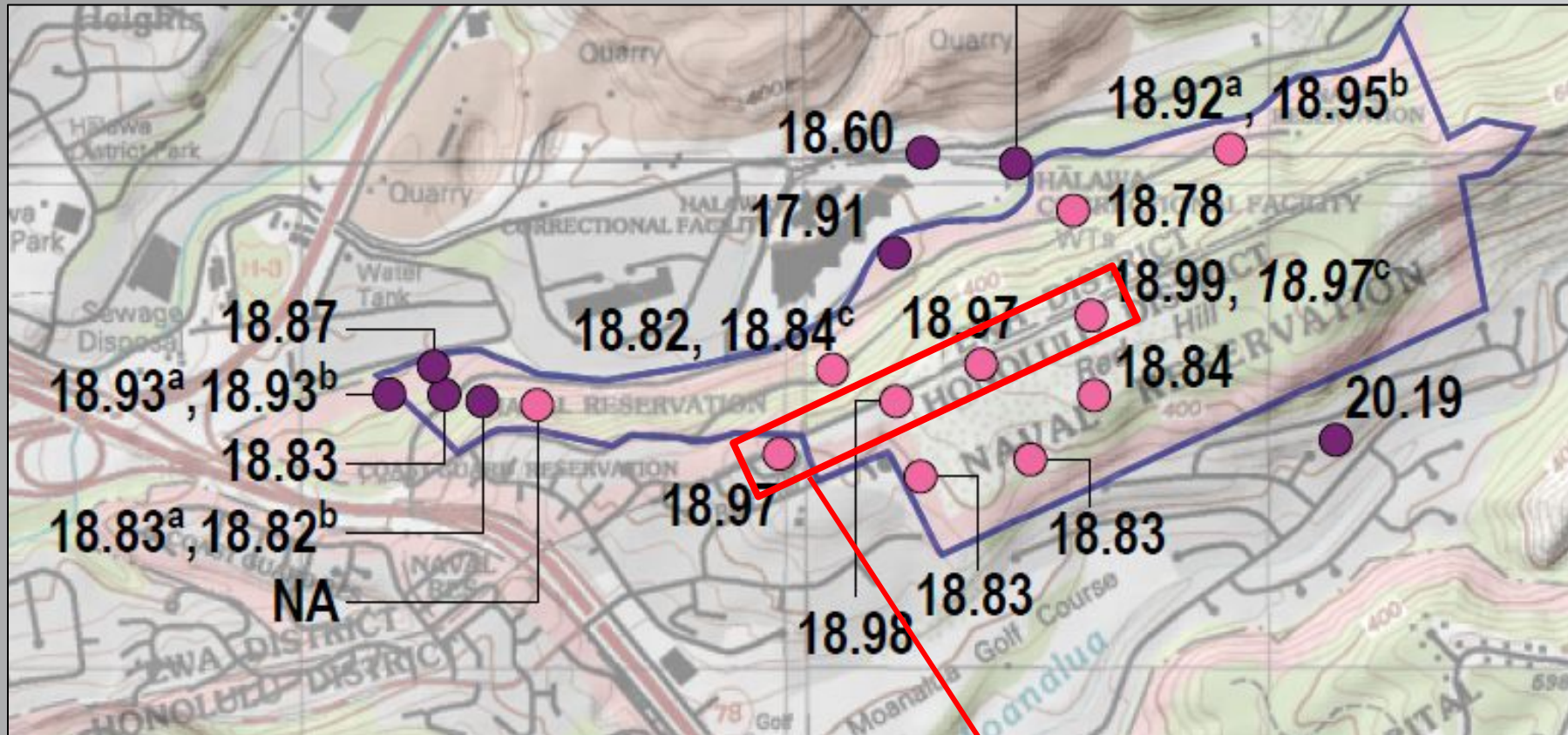


Base from U.S. Geological Survey digital data, various scales and dates
 Universal Transverse Mercator, zone 4 north
 North American Datum of 1933



EXPLANATION	
---	Red Hill Bulk Fuel Storage Facility boundary
—0.8—	Nonvolatile dissolved organic carbon, in milligrams per liter
○	Average of 2022 and 2023 samples
RHMW08 ●	Groundwater sampling site with identifier
●	Approximate center of underground fuel storage tank

Groundwater divide on the ridge

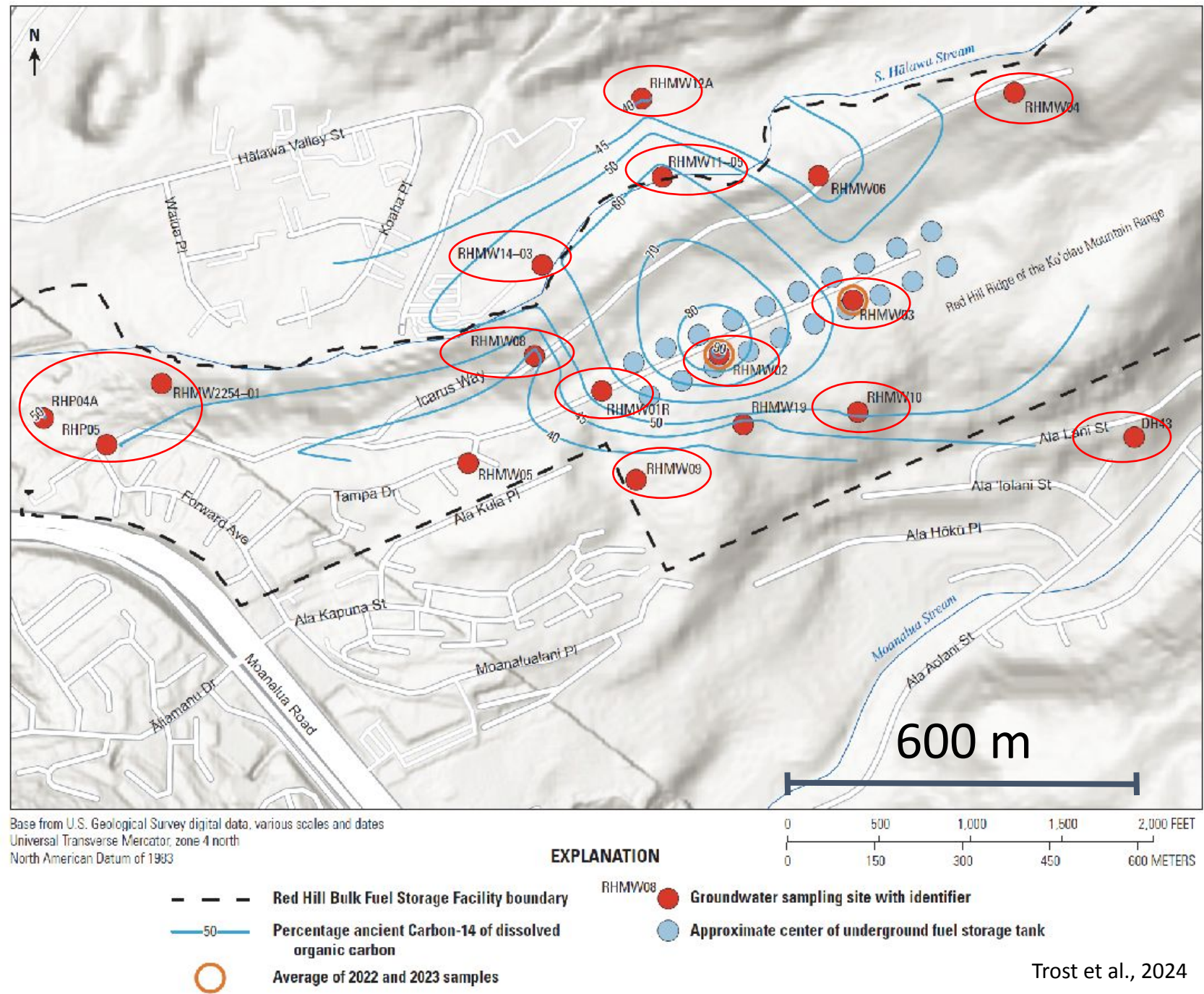


- Well is open or **screened** at the altitude of the measured water level
- Well is open or **screened entirely below** the altitude of the measured water level

Highest water levels observed in tunnel wells along the ridge. Water levels are lower to the north and south.

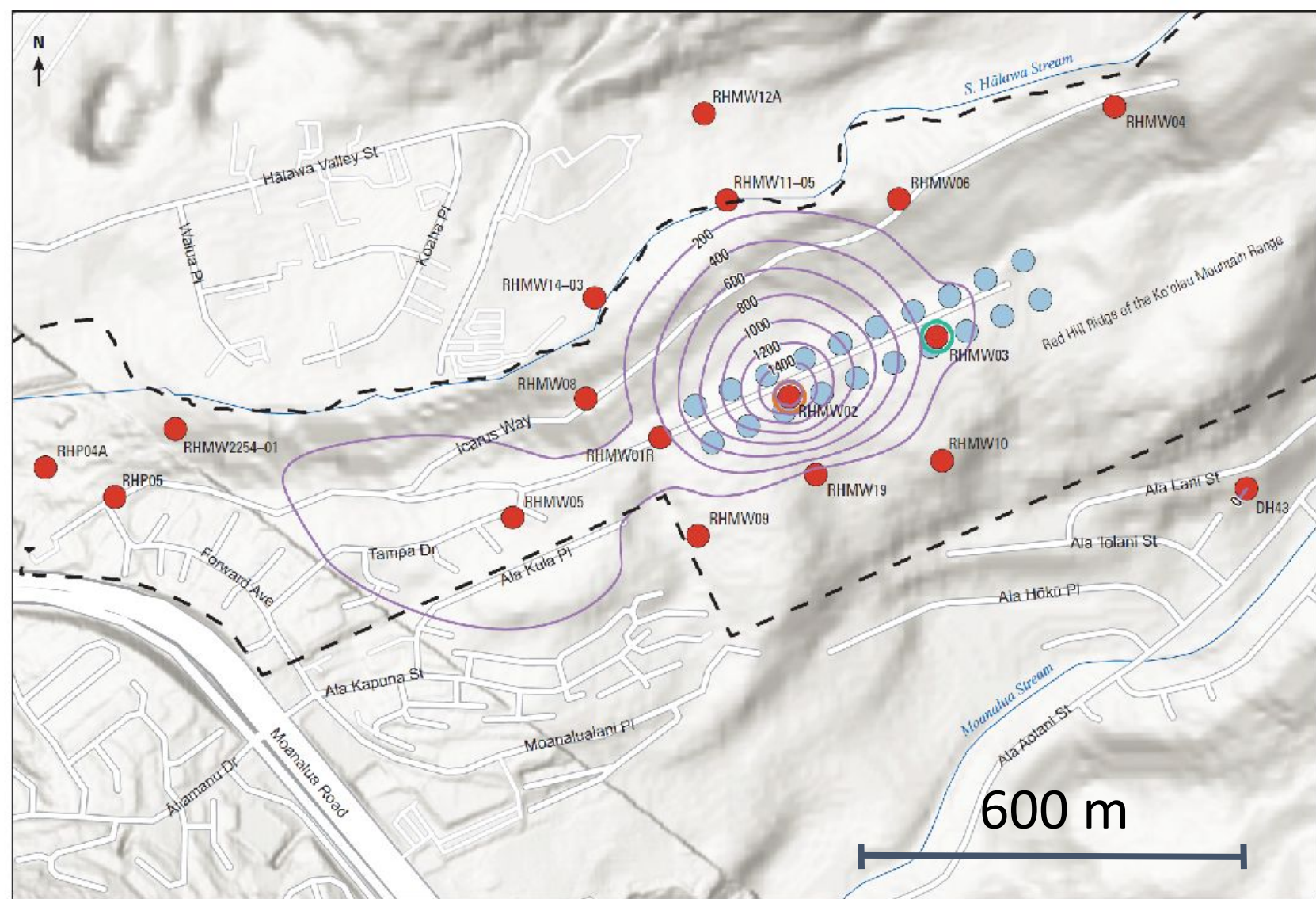
Percent ancient C in NVDOC (¹⁴C-NVDOC)

- Background is 38 percent
- Highest at RHMW02
- Near background at RHMW12A, RHMW09 and RHMW08
- Greater than 45 percent at RHMW2254-01, RHP04A, RHP05, RHMW03, RHMW01R, RHMW04, RHMW10, and DH43
- High values at deep wells RHMW14-03 and RHMW11-05 need more study



Diesel Range Organics (DRO)

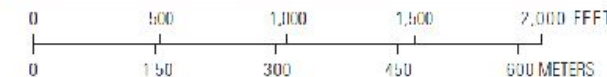
- Only 4 wells exceed the reporting limit of 190–220 $\mu\text{g/L}$
- Highest values were at RHMW02 (2,500 $\mu\text{g/L}$ 9/22; 1,100 $\mu\text{g/L}$ 1/23)
- With so many wells below the reporting limit, little insight is gained into migration



Base from U.S. Geological Survey digital data, various scales and dates
 Universal Transverse Mercator, zone 4 north
 North American Datum of 1983

EXPLANATION

- Red Hill Bulk Fuel Storage Facility boundary
- Diesel range organics concentration, in micrograms per liter
- Average of 2022 and 2023 samples
- 2022 sample only
- RHMW08 ● Groundwater sampling site with identifier
- Approximate center of underground fuel storage tank



Soil CO₂ measurements



Measuring efflux



Soil gas sampling for CO₂ concentration and carbon-14 content



Soil carbon trap

No ancient carbon detected in any soil surface sample
Surface soil CO₂ does not appear to be a reliable indicator of the source zone

Summary

Soil Gas Results

- No ancient carbon detected in any sample collected in 2022–23
- Surface soil CO₂ does not appear to be a reliable indicator of the source zone

Groundwater Results

- NVDOC might be a useful indicator of the contaminant zone
- Ancient C varies with NVDOC concentration suggesting a fuel source
- Background groundwater has 38 percent ancient C and about 0.2 mg/L NVDOC
- NVDOC is about 3 times DRO

References

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Thanks for your time

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Photo credit: U.S. Geological Survey

Extra Slides

Biodegradation indicators

NVDOC correlates with:

^{14}C -NVDOC, DRO, Fe, Mn

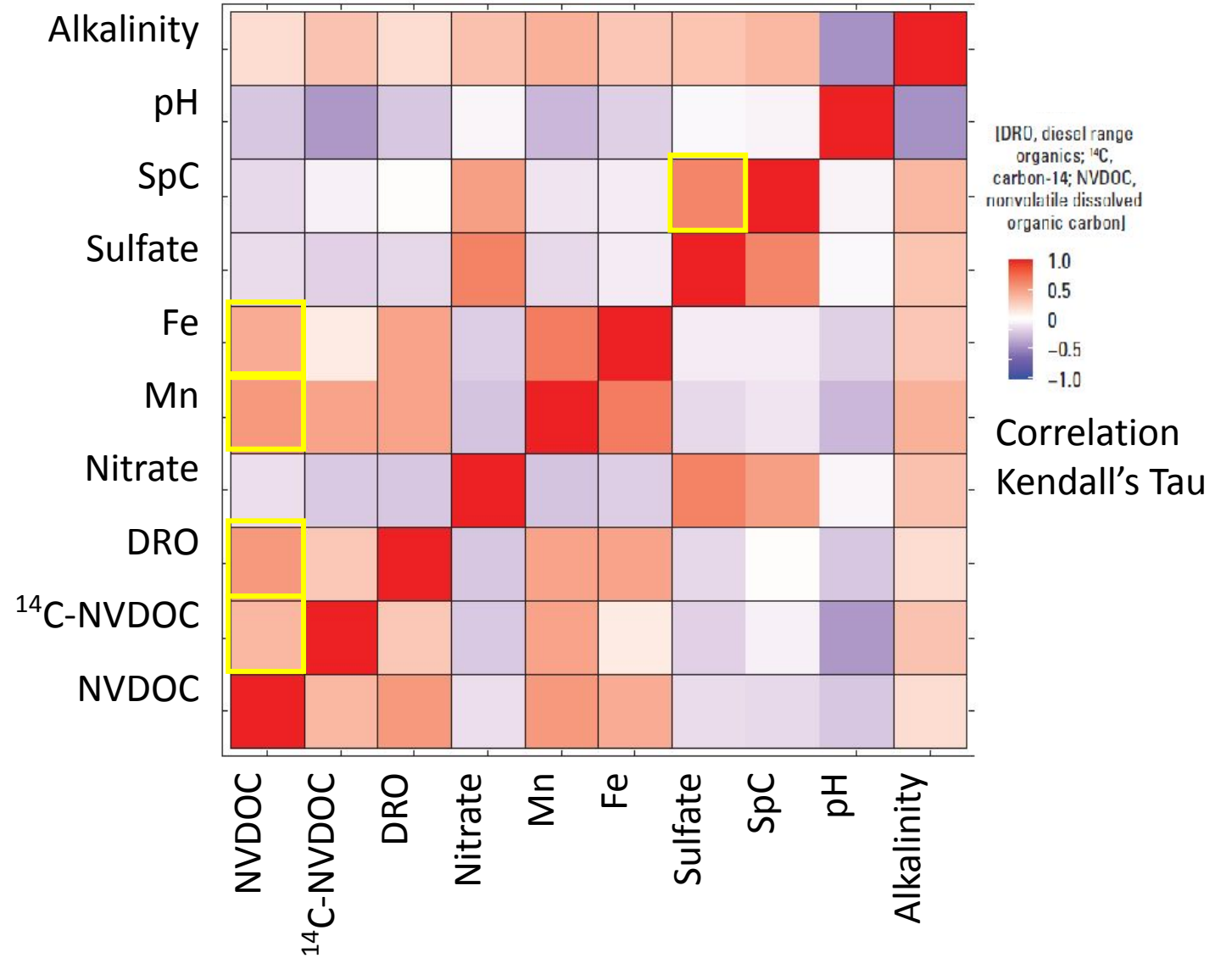
Fe and Mn reduction important

No significant correlation with:

Sulfate, Nitrate, Specific Conductance (SpC), pH, Alkalinity
Not good plume indicators

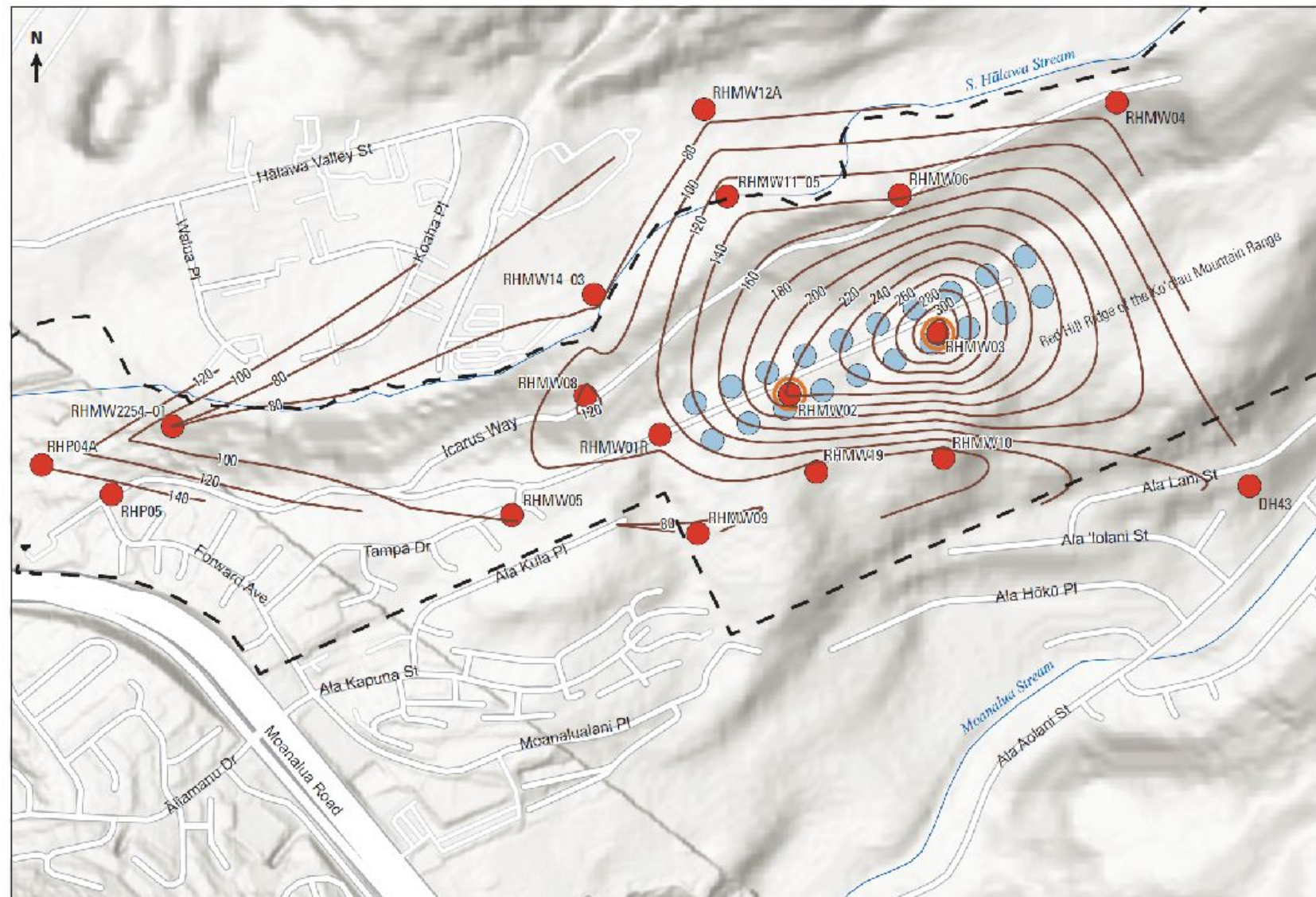
Sulfate correlates with SpC:

mixing with seawater may have a larger effect than biodegradation

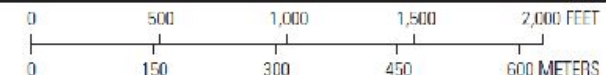


Alkalinity

- Alkalinity increases result from production of CO_2 during biodegradation
- Background values are 70–90 mg/L
- Highest values are at RWMW03 and RWMW02
- Elevated values are found north and south of the ridge and in the new peripheral wells
- Elevated values at DH43 consistent with past DRO detections



Base from U.S. Geological Survey digital data, various scales and dates
Universal Transverse Mercator, zone 4 north
North American Datum of 1983

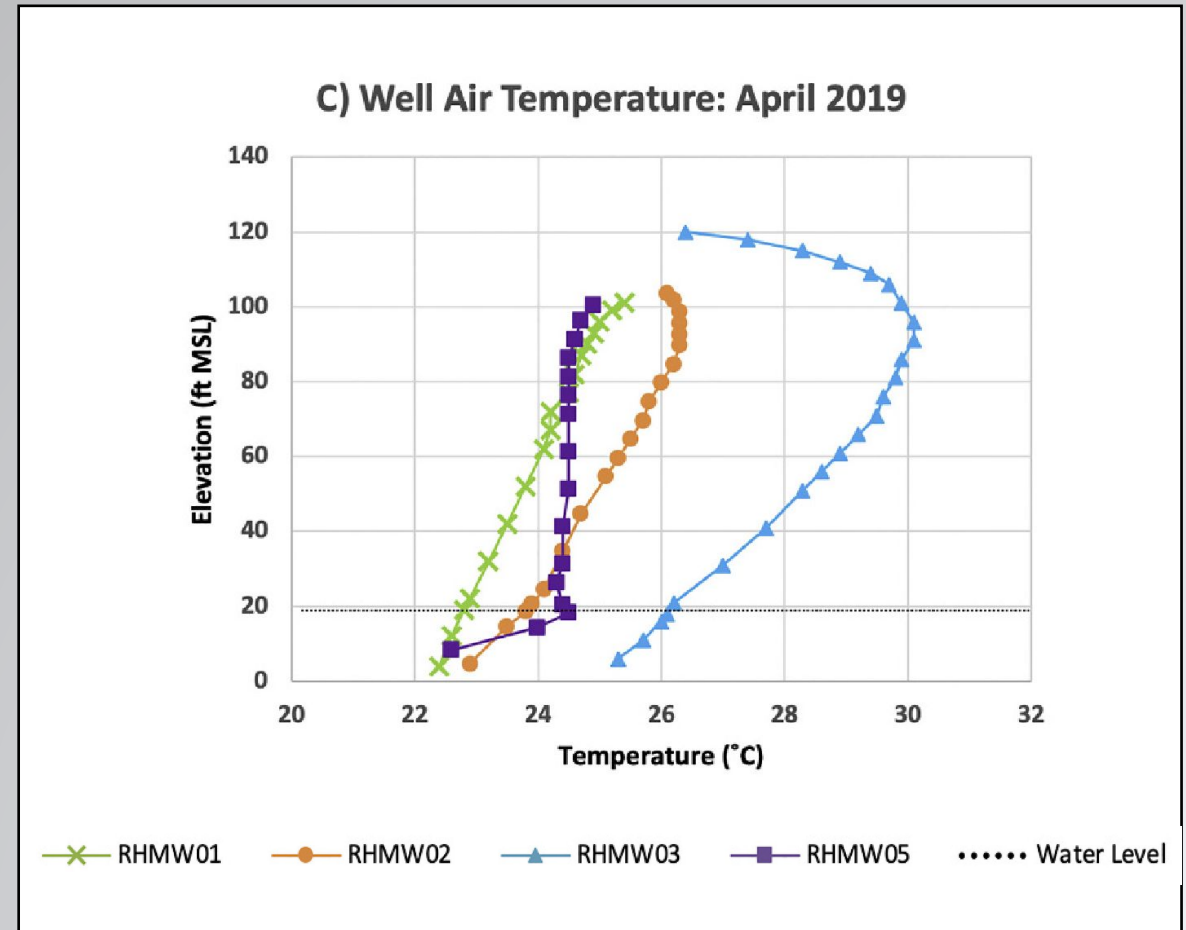


EXPLANATION

- Red Hill Bulk Fuel Storage Facility boundary
- 100— Alkalinity concentration, in milligrams per liter
- Average of 2022 and 2023 samples
- RHMW09 Groundwater sampling site with identifier
- Approximate center of underground fuel storage tank

Evidence of vadose zone biodegradation near RHMW03

- High concentrations of alkalinity and NVDOC but not DRO
- Elevated temperatures of 2.4–2.5°C near the water table (Mitchell and Oki, 2018)
- Elevated temperatures in the vadose zone (McHugh et al. 2020)



McHugh et al., 2020