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GROUNDWATER FLOW IN THE MOANALUA/RED HILL/HALAWA REGION: Evaluating Rates, Directions, and Contamination Risks

Mr. Robert Whittier and Dr. Donald Thomas

00:11 [Keri Kodama (host)]: All right. Hi, everyone. Welcome to this

00:16 third seminar in our WRRC spring seminar series. We have a general theme of Red Hill,

00:24 the Red Hill water crisis. And this week, Robert Whittier and Donald Thomas will be talking about

00:31 groundwater flow and the Moanalua/Red Hill/Hālawa region. Robert Whittier is a geologist with the

00:37 Hawaiʻi Department of Health Safe Drinking Water Branch and an affiliate faculty at UH Mānoa

00:44 Department of Earth Science and WRRC. And Donald Thomas is a member of the faculty at the Hawaiʻi

00:49 Institute of Geophysics and Planetology at UH, and serves as the Director of the Center for

00:55 the Study of Active Volcanoes at UH-Hilo. Without further ado, I'll turn it over.

01:00 [Robert Whittier (speaker)]: Well, thank you, Keri.

01:05 Here's the structure of our slides. We'll be talking about structures.

01:10 First, talk a little bit of a background, go over the problem statement, talk about the geologic

01:17 setting of the study area, and the structures that influence groundwater flow trajectories, and an

01:25 alternative approach to the general chemistry to evaluate groundwater flow trajectories,

01:31 and also the planed comprehensive regional geologic investigation to answer the currently

01:37 unanswered questions. Okay, for background, both Don and I have been involved in Red Hill for quite

01:43 some time. My first involvement was in 2006, working as a consultant for the Navy. And as

01:51 part of that work, I did the contaminant flow and transport model or contaminant transport modeling,

02:00 and also set up and executed a regional groundwater monitoring and aquifer testing

02:08 study. Then in 2014, of course, we had a release, and I was at the Department of Health at the time,

02:15 and got involved in the oversight end of Red Hill. And we also invited Don to assist us

02:23 due to his in-depth knowledge of Hawaiʻi hydrogeology and groundwater.

02:29 So here's the overarching question. And that is, how do we assess the risk of

02:35 contamination from any source in a realistic way? Specific to this problem is, for Red Hill,

02:42 how to assess the risk from free phase and dissolved phase petroleum contamination,

02:49 to groundwater and to public drinking water sources within the area.

02:54 And at this point in time, we can't state with certainty, the rate or direction of groundwater

03:00 flow, and thus, we can't state with certainty, the rate and direction that contamination will move.

03:07 Key to gaining this understanding is looking at the geologic structures that influence

03:13 groundwater and contaminant transport, which currently is incomplete.

03:20 So this diagram on the left actually shows our problem. We have

03:27 a potential source of fuel contamination, and hydrocarbon fuel is light relative to groundwater.

03:34 Also, it's immiscible in that it doesn't mix with water. So it's referred to as a Light Non-Aqueous

03:40 Phase Liquid. In small releases, we can retain the LNAPL or that free product phase within the

03:51 vadose zone, but due to recharge, we'll get contaminant migration of the dissolved

03:57 phase to the water table. In a large release, which is definitely a potential at the Red Hill

04:03 facility, we can get both the dissolved phase and the LNAPL phase down to the water table,

04:10 at which point the plume will spread. And structures that are present at Red Hill that exist

04:17 exert a significant control on the degree and direction of spreading.

04:24 And currently, how these structures influence groundwater flow and the resulting groundwater

04:31 flow trajectories beneath Red Hill and in the region are not well understood.

04:37 We borrowed this diagram from the Navy's conceptual site model for Red Hill. And it

04:44 actually shows our problem: we have 20 very large underground fuel storage tanks that are situated

04:52 within the rock of the Red Hill Ridge. Bottoms of which are about 100 to 150 feet above

05:00 the groundwater and that groundwater is a primary drinking water aquifer for the island of Oʻahu.

05:06 To the northwest, we have two—

05:11 we have a primary drinking water source and also to the southwest a primary drinking water source.

05:18 These two drinking water sources are shafts, which are basically tunnels excavated along the

05:25 water table, distribute the pumping over a large area, and reduce the risk of saltwater intrusion

05:35 resulting in chloride fouling of our drinking water source.

05:38 Unfortunately, the water table is where the LNAPL reside. So that increases the risk of

05:48 impactful contamination from any spill at Red Hill to these type of drinking water sources.

05:57 To the southeast, we have conventional wells.

06:03 And they draw their water from deeper in the aquifer, so less susceptible to petroleum

06:08 contamination but nevertheless need to be considered. We have the basalt, which I've talked

06:15 about previously, but also lower permeability structures, which we'll talk about in more detail:

06:22 saprolite and valley fill in between the ridges. And also at the toe of the Red Hill Ridge, 06:29 late stage volcanics which resulted in explosive eruptions

06:34 and the associated structures, subsurface structures, with those explosive eruptions.

06:43 So looking at a geologic map of the area, we have the Red Hill facility

06:48 to the northwest. And southeast, we have valleys which are filled with alluvial valley fill

06:56 and underlying saprolite, low permea—poorly permeable structures.

07:04 Also to the northwest we have several primary drinking water sources including the Hālawa shaft,

07:11 which again draws us water from right at the water table. Going mauka to makai,

07:20 or from mountain to ocean, we will encounter a

07:29 structure called caprock, which is a composite of marine deposits, beach deposits, that extend down

07:39 into the water table. Internally viewed as poorly permeable, but can have some highly permeable

07:47 sequences within that structure. Also is the late stage volcanics and associated tuff rings,

07:57 again, poorly permeable, and right at the toe of the Red Hill Ridge. If we look at the

08:07 groundwater elevations going from the southeast, to the northwest, starting here at Kalihi Valley,

08:14 they tend to step down going from ridge to ridge. This gives us a hydraulic potential

08:21 for groundwater flow and thus contaminant transport from the southeast to the northwest.

08:31 But the other explanation for the step down is the semi-compartmentalization for the valley fill. And

08:42 we also have light stage, volcanic lava flows overlying some of the valley fill in the Kalihi

08:51 and the Nuʻuanu Valley. So the relationship between groundwater and the valley fill and

08:59 saprolite sequence has been considered for quite some time. In 1942, Wentworth looked at the

09:09 relationship between the valley fill saprolite sequence and the underlying basalt and groundwater

09:18 and came up with two potential realizations since he didn't have boreholes to ground truth it. One

09:24 would be shown here as a—the shallowest extension of the valley fill into the

09:33 aquifer. And it shows that only in Moanalua Valley would we get any significant

09:41 extension of the valley fill into the aquifer. In the North Hālawa Valley and South Hālawa Valley,

09:48 very little extension of the valley fill saprolite into the aquifer. But he also

09:56 reasoned that if you look at the slopes of the valley walls and extended them downward, where

10:02 you get a much deeper intrusion of the valley fill saprolite, very deep in Moanalua Valley,

10:12 less steep but still significant in North and South Hālawa Valley. And this is at

10:17 a cross section at the 500 foot elevation along the axes of the various ridgelines.

10:32 Later, Mink in 1980 considered the effect that caprock may have on groundwater flow.

10:40 And he reasoned that caprock is generally a poorly permeable structure, and that it would

10:47 divert groundwater flow from a direct mauka-makai flow path to a flow path following the groundwater

10:57 elevation potential from Honolulu

11:01 to Pearl Harbor. And he estimated that minimal groundwater flow in this direction but about

11:07 10 to 15 million gallons per day across this boundary here from Honolulu into

11:17 Pearl Harbor. If that is correct, that has a—puts the ground drinking water sources to the northwest

11:27 at a significant risk to contamination originating at the Red Hill facility.

11:36 More widely accepted groundwater flow trajectories in this area is that, in many USGS publications,

11:44 that reason that the valley fill saprolite divide the Honolulu aquifer into

11:50 sub-aquifers or compartments, and that the general groundwater flow would be

11:58 in the mauka-makai direction, and this is as described by Hunt in 1996. But he added a caveat.

12:08 He said the effectiveness of these barriers would diminish going inland and that their

12:15 penetration into the underlying basalt would also decrease going inland.

12:20 So the Mink—we'll refer to as the Mink conceptual model and the Hunt conceptual

12:26 model are not necessarily mutually exclusive. If we look at, going down South Hālawa Valley,

12:36 look at the possible structures that the groundwater flow would encounter and the

12:40 possible directions of groundwater flow, we can see some very different

12:48 risk contamination scenarios. Groundwater flow is mauka-makai.

12:55 It will go from the permeable basalt and then encounter the

13:04 low permeability of the saprolite and the valley fill, and in some cases also encounter

13:10 the subsurface structures associated with the late stage volcanics. Finally encounter the caprock,

13:19 again generally viewed as being poorly permeable, but can have zones of high permeability,

13:26 such as limestone—reef limestone layers, and associated dissolution channels.

13:37 If we go from the southeast or the northwest, depending on where that groundwater

13:44 pathline originates, we can have an unimpeded pathway

13:51 from Pearl Harbor—or from Honolulu to Pearl Harbor, or increasingly impeded

13:58 flowpath where groundwater would have to flow beneath the saprolite valley fill sequence. So two

14:08 very contrasting risk implications depending on which groundwater flow scenario is most accurate.

14:20 If we look at groundwater elevations within the facility itself, and this

14:27 was groundwater elevations taken on December 23, and I have the year wrong, that'd be 2021.

14:36 We see that during a period when the Red Hill Shaft was shut off, as was done following the

14:44 November 20 release, that we have almost no groundwater gradient potential going down the

14:52 axis of the Red Hill Ridge, we have a 2 hundredths of a foot (0.02 foot) groundwater elevation drop

15:02 over a span of about 0.7 kilometers. That actually is within the realm of uncertainty of the

15:09 measurements. We do have a decreasing groundwater potential going to the northwest, which

15:19 is fairly significant, about 0.2 feet. That would imply groundwater flow in this direction. However,

15:30 if we look at the southeast side, we have an almost identical drop in groundwater potentially

15:37 going to the southeast. So it is very difficult to ascertain groundwater flow directions in Red Hill

15:46 based upon groundwater elevations and relative groundwater elevation potential alone.

15:54 So again, the depth of the valley fill, and the saprolite, which is one of the keys that

16:01 we need to understand groundwater flow trajectories within this area.

16:07 So to that end, the Navy working with Boise State University conducted a seismic survey

16:15 to image the contact between the valley fill and saprolite wedge and the underlying basalt

16:25 And so these line shows the transects that were done on South Hālawa Valley and North Hālawa

16:34 Valley, and my interpretation of the depth of penetration into the aquifer shown in percent of

16:44 the penetration into the—down to the—did point to the transition zone of the freshwater lens.

16:57 So, the red line is where we would first see the contact of the basalt saprolite interface

17:04 at the water table. Red line is that point at which that saprolite valley fill extends 50%

17:16 into the freshwater lens. See that we start seeing some protection right adjacent to the

17:30 tank farm. And we do see protection extending up to about even with the Hālawa shaft.

17:41 But this is very shallow intrusions down to about here is about the 25% into penetration

17:51 point down here, which is near the bottom end of the fuel facility and well below the

17:58 location of the Hālawa shaft. If groundwater flow is to the northwest then

18:06 there is a limitation to the protective nature of the saprolite valley fill.

18:13 Here is an actual transect—seismic transect that was taken right adjacent to

18:20 the Hālawa shaft and North Hālawa Valley. And it shows the saprolite valley fill contact

18:28 extending to about 20 feet below sea level or about 40 feet into the freshwater lens.

18:43 So the next structure that we need to consider is a late stage eruptions and the tuff rings.

18:52 And these are structures that are associated with a late stage volcanics located here at the toe

18:58 of the Red Hill Ridge and also extending into Moanalua Valley. For mauka-makai flow,

19:09 it does present a further barrier, but we could get flow around it. But the extent of that

19:19 resistance to groundwater flow depends on the nature of the structure beneath

19:24 the subs—beneath the surface of the—beneath the ground's surface and into the water table.

19:33 So here is a conceptualized cross-section of the

19:40 Salt Lake tuff ring complex

19:44 along this transect right here. So we have what we refer to as a diatreme, which is basically the

19:52 explosive event where all of this rock got ejected and then much of it fell back in. We have the

20:04 aerial deposits of the volcanic tuff ash on either side, but they are primarily surface structures.

20:14 The late stage eruptions actually require some sort of plumbing to get the magma up here into

20:21 the groundwater to result in that steam-generated explosive eruption. And that would probably be a

20:30 dike, another potentially vertical planar-type structure that would be a barrier to groundwater

20:38 flow. So to look at that, these structures have varying densities. We can look at the subsurface

20:47 density using gravity measurements. So DOH and— University of Hawaiʻi and DOH did a seismic study—

20:59 gravity study looking for gravity contrast. On the light end would be saprolite.

21:08 Tuffs are a little bit denser. Basalt would be more in the dense intermediate range. And finally,

21:15 dikes and other intrusives would be at the high end. Diatremes the—have not yet been defined.

21:26 And here was a result of that. The warmer colors indicate positive gravity anomalies or

21:35 denser subsurface structures. The cooler colors, negative density anomalies or

21:42 less dense subsurface structures. So the positive density anomalies for present,

21:48 directly underneath the Āliamanu Crater within the base of the Moanalua Ridge and Moanalua Valley.

21:59 The negative or less dense structures,

22:03 ironically, would be within the Salt Lake Crater, which is in contrast to Āliamanu Crater,

22:11 also within the southern part of South Hālawa Valley, and the lower part of the Red Hill Ridge.

22:21 So what does this mean? Means it provides possible evidence of dense structures and aquitards

22:29 here in the mauka-makai flow path. It also provides an alternate hypothesis for our

22:43 flat water table beneath the Red Hill facility.

22:50 So we looked at structures and it's not totally answered all of the questions.

22:54 So an alternative approach would be to look at the groundwater chemistry.

22:58 And this is something that I'm pursuing as part of my job at the University,

23:02 now looking at the overall risk of public drinking water sources to contamination.

23:12 So this is a multi step process. First look at what groundwater species are commonly

23:19 measured and use them as tracers. Establish their concentration in a natural setting as a baseline,

23:27 that would be the unimpacted recharge zones. Then model the chemical distribution in groundwater and

23:34 compare the model results with the measured data and look for zones of enrichment and depletion.

23:42 So we're looking at land use influence versus groundwater chemistry. For our

23:49 two conceptual models of groundwater flow, the mauka-makai flow would be under non-developed

23:54 land. So the chemistry should be very similar to that of the upslope recharge areas.

24:02 If we looked at Honolulu to Pearl Harbor, it's an urbanized area. So then we should

24:09 be seeing anthropogenic impact. Two preliminary tracers we've looked at is chloride, comes from

24:16 rainfall and dry deposition, anthropogenic source would be irrigation with groundwater,

24:23 and another natural source near the coast would be saltwater intrusion.

24:28 Nitrate results from atmospheric deposition and rainfall, the decay of organic matter,

24:36 which should be at a steady state in the upper recharge zones, and anthropogenic

24:43 sources would include fertilizers and wastewater. So, our goal here

24:49 is to compare—compare the site chemistry with that of upslope recharge areas of groundwater.

24:58 Looking at chloride. The approach we took was chloride mass balance

25:03 in that we have atmospheric rainfall deposited chloride. The rainfall will get evaporated,

25:14 increasing the concentration of chloride in the recharge water at a predictable rate.

25:20 And so we do a mass balance approach. We can then estimate the concentration of chloride

25:28 in the recharge and put that into a groundwater flow model. So, to validate this, we have a

25:38 climate station here, right outside of my office here at the upper Pearl City,

25:45 and do a water balance study and estimate recharge and also collect

25:56 the rainwater to get a chloride composition of rainwater and dry deposition. So when we did

26:04 our water balance salinity calculation, we got a recharge concentration of 25 milligrams per

26:13 liter. We also have a lysimeter for collecting soil water. So during periods of recharge,

26:20 collected soil water at 90 centimeters, and got 20 milligrams per liter, so very close agreement.

26:29 Put that into our groundwater model. Because not only do we have a climate station and lysimeters,

26:34 we have a well right outside of our office. So collect a sample from the well,

26:41 chloride is about 18-and-a-half milligrams per liter. The model chloride for that same

26:46 well is about 19.8 milligrams per liter. So we seem to have good agreement there.

26:54 So this map shows the distribution of rainfall and dry deposition chloride and recharge. The inset

27:07 shows the Red Hill area. And the arrows show our two conceptualized groundwater flow trajectories.

27:16 The average recharge concentration of chloride above the facility would be about 39 milligrams

27:25 per liter. So that means for mauka-makai flow, the groundwater should be less than 39 milligrams per

27:33 liter. But if we go from Pearl Har—Honolulu to Pearl Harbor, then we're flowing through areas of greater

27:46 chloride groundwater recharge. So then our groundwater chloride should be greater than

27:52 39 milligrams per liter. Now, we've put this in a groundwater model,

28:01 look at—map the results, but map them as excess chloride, which is a percentage of additional

28:11 chloride measured versus that, that the model predicted based on rainfall and dry deposition.

28:18 We validate that model using those wells that are in the conservation or primary recharge areas.

28:26 You got very—pretty good agreement with the model. So it does seem to work. And if we look

28:33 in the Red Hill region, we do see some wells that do—where the groundwater chlorides do agree with

28:43 that predicted by the model, but overall, we have significant excess groundwater chloride.

28:51 This would be inconsistent with mauka-makai flow. So the next question is, where does

29:00 that come from? We have a major pumping center. And my hypothesis would be that, that

29:09 pumping center is drawing chlorides from deep beneath it up into the freshwater lens.

29:16 But we have a series of wells that have multiple depth sampling points. And if we look at that,

29:26 chlorides in the water column versus the average of chlorides measured at the Red Hill Shaft, we

29:34 cannot account for what is pumped versus what is in the water column beneath the Red Hill facility.

29:46 The Red Hill Shaft chlorides vary from about 75 to 147 milligrams per liter

29:54 and that seems to vary positively with pumping in that as you increase pumping you go to

30:00 the higher chloride concentrations. So for not getting the chlorides from directly beneath,

30:07 where is it coming from? One possibility is that the—

30:15 we have pref—layering of our lava flows. The different sequences or

30:24 types of lava in those flows has very contrasting hydraulic properties. We have

30:36 clinker zones, which if they're unweathered would have very high hydraulic conductivity.

30:41 But we also have ʻaʻā layers which very massive lava,

30:45 very low hydraulic conductivity. So we would have a structured preferential flow path,

30:54 down tip of the lava flows, potentially extending into the transition zone.

30:59 So that would potentially result in groundwater being drawn up to what we've often thought of as

31:08 a skimming shaft at the water table surface. The implications for Red Hill would include

31:17 the capture zone that extends much further downslope than would typically be modeled.

31:24 Also would be much broader. But one of the more critical points would be that this would be much—

31:33 the Red Hill Shaft would be much less efficient at capturing shallow groundwater contamination.

31:43 Finally, nitrate as a anthropogenic tracer, and go quickly over that. In 2006,

31:54 Helton et al. found an inverse relationship between rainfall and leachable nitrate-nitrogen

32:01 in the forest setting of East Maui. We looked to see if that was also applied

32:08 throughout other islands, throughout the state, and found a good correlation—

32:13 inverse correlation between rainfall and nitrate concentration in the wells if you do a

32:22 rainfall weighted average of rainfall along the flow path. So

32:27 again, we looked the at, we modeled the nitrate, and mapped it as a percent exceedance

32:36 of the measured versus the modeled. In the Red Hill region, we find that we have actually some

32:43 depletion, some agreement with the model, but then some zones of significant excess nitrate.

32:53 So it's two very different patterns of nitrate with different flow trajectory implications.

33:00 So what this brings us to is that chloride concentrations observed are inconsistent with the

33:06 mauka-makai flow trajectory, and actually more consistent with the alternative Honolulu-Pearl

33:13 Harbor. Nitrate story is more nuanced, and that is due to potentially biodegradation of

33:21 fuel hydrocarbons, which will reduce the nitrate in the groundwater as the indigenous microbes

33:31 break down the fuel and hydrocarbon contamination. We will continue to work with nitrates and nitrate

33:38 isotopes to refine our interpretation. And at this point, I will turn it over to Don and let him—

33:49 shift the screensharing to him. And he will talk about what additional work we're going to do.

33:57 [Donald Thomas (speaker)]: So, Bob has talked about data that we all

34:04 have, have gathered over the last several years to better understand this system. But as he has said

34:12 many times that there is still a great deal more that we need to do and to learn about this entire

34:21 system before we will be able to accurately estimate risks associated with releases of

34:29 contaminants into the groundwater here. And so we put together a program of planned studies that we

34:38 would like to accomplish to help us answer some of these critical questions. Very briefly, I'll go

34:45 into more detail here momentarily. What we want to do is better to find these major structural

34:51 features: the valley fills, the diatremes, the other large scale structures within the Red

35:00 Hill region that have very substantial effect on groundwater transport, and how contaminants are

35:08 likely to move. We also want to better document and characterize sort of the intermediate scale

35:14 features within the basalt ridges. The pāhoehoe, the ʻaʻā, the clinker, and the soil and clay features will

35:23 have significant impacts on how both groundwater moves as well as LNAPL will move through this

35:29 system. We want to document the interaction of fuel with basalt. The fuels are hydrophobic, and

35:39 they will react differently with the basalts than water typically does. And so we intend to develop

35:48 a better understanding of how that interaction will impact how that fuel migrates from

35:55 the vadose zone—from the unsaturated zone, into the water table. We want to characterize

36:02 the natural and pumping-induced flow rates and directions at a variety of scales in this region.

36:09 And with that data, we'd like to populate a 3D geologic model with the site-specific data,

36:18 apply some geostatistical analysis to what we see there geologically

36:23 to develop a really detailed conceptual site model. And then use that conceptual site model

36:30 to drive the development of a new—numerical flow model, both for the LNAPL, for the fuels,

36:37 as well as for groundwater. And use our existing dataset of so-called synoptic data,

36:44 water level data, and tracer data to validate that numerical flow model. So I'll talk in more

36:51 detail now about each of these types of studies and what we hope to do and hope to accomplish.

36:57 First thing we want to do is image the valley fill and saprolite wedges. We know that the

37:03 valley fill and saprolite are much less permeable than the basalts. We would like to—

37:13 they are also heavily altered and they respond to seismic waves quite differently from the basalt

37:21 itself. There's a technique that's been used on Oʻahu called ambient surface wave tomography. It

37:28 is a seismic—passive seismic method. It was successfully used in southeast Oʻahu

37:37 looking at the the sediment fill and basalt in the Sandy Beach region by Niels Grobbe and his

37:48 colleagues, and was was quite successful at it. The technique employs natural seismic activity, or

37:56 seismic wave activity is generated actually by waves impacting on the shoreline, as well as

38:03 anthropogenic seismic noises that is created by traffic and quarry operations and similar types

38:10 of what we call seismic noise, and allows us to develop a map of seismic velocities

38:19 over a range of depth slices. This is a result of Niels Grobbe's team

38:28 out near Sandy Beach, and each of these images is a horizontal slice

38:36 through the geology of the area, and allowing them to identify the seismic velocity and then infer

38:47 that the zones where the seismic velocities are higher are the zones of more pristine basalts,

38:55 and differentiate those from the lower seismic velocities which are likely sediments.

39:03 We would like to apply this technique here in the North Hālawa Valley and South Hālawa Valley to

39:11 develop a very detailed picture of how deeply incised those valleys were, and how deep the

39:21 alluvium and saprolite is able to penetrate into the water table and affect groundwater flow.

39:30 Again, this idea we have and one of the things that I wanted to mention too is that having wells

39:40 into these features will allow us actually to ground truth this interpretation.

39:47 And there are a number of wells, there will be additional wells drilled in this region,

39:51 that will allow us to really much better characterize both the saprolite and valley fill

39:58 intervals as well as in the vicinity of the diatremes of these late stage volcanics.

40:07 The other technique that we want to apply is additional gravity surveys and try to

40:15 better image the intrusive lavas that are associated with the Salt Lake Tuff Ring Complex.

40:22 Bob has already showed this image indicating that we have higher density material up in—excuse me—

40:34 up in this region, and also extending over here

40:39 and under the Moanalua Valley as well as partially under Red Hill Ridge.

40:47 And our intention is to expand these, the survey area, and increase the density of seismic stations

40:57 so that we can get better resolution. One of the things I wanted to point out

41:02 is that in these gravity anomalies, the solutions are non-unique, there are a number of different

41:14 conceptual models for these intrusive bodies

41:18 that will satisfy the same dataset. By increasing the number of data points,

41:23 we can narrow those down. We will also investigate using this passive seismic

41:31 surveys over the region of these high density features to try to better image those as well.

41:43 The third step in defining these major structural features is to compile all of the existing and new

41:49 well core data. We have a number of wells that have been drilled in this region. This shows an

41:56 array of wells, the ones with the kind of the light blue labels—these are existing wells

42:04 that have been drilled using a technology called continuous coring. And so we have

42:10 actual geologic samples over the entire depth of the wells here that have been drilled.

42:18 We also are in discussion with the Navy on drilling some additional wells in this region

42:25 that will really give us a much more detailed data set that we can compile into

42:38 the models—the geologic models from this region that will give us much better insight into how the

42:48 groundwater flow will interact with these different lava types.

42:54 Now, let me move on. So we want to characterize the intermediate scale features within this area

43:01 as well. And what do I mean by intermediate scale? I'm talking about the individual lava flows. This

43:07 is an image taken from a recent USGS publication that gives us kind of a conceptual idea of

43:17 what the lava flow sequence looks like. We have the ʻaʻā flow units that can be several meters

43:26 thick and up to 10 and 20 meters wide. And these flow units are typically surrounded by ʻaʻā clinker. And

43:36 within this sequence, we also have pāhoehoe lavas.

43:40 And groundwater flow through these individual features can be quite different.

43:48 So, our intent here is to try to better image these different flow units using electrical

43:56 resistivity tomography (ERT) and audio-magnetotelluric (AMT) surveys. And we will be looking specifically

44:05 at the individual ridges in this area. We should be able to image and distinguish the

44:11 weathered clinker zones from the ʻaʻā cores and from the pāhoehoe flow intervals as well.

44:19 The area in which we would conduct these surveys is along Red Hill Ridge. This is a view downward

44:26 on Red Hill Ridge. The tanks themselves are down here. They would make it impossible to apply this

44:33 technique below the tanks, because this is an electrical method and that—the steel tanks would

44:42 disrupt the signal that we would hope to gather there. But further up the ridge,

44:49 we feel like that information will give us considerable detail on the array of

44:56 pāhoehoe and ʻaʻā and clinker zones that we have buried within the ridge below the tanks and down

45:04 into the water table. Likewise over here on the Hālawa Ridge just above the quarry operations.

45:17 Another aspect of characterizing these intermediate scale features,

45:20 and really what we're trying to accomplish with this characterization,

45:24 is to identify where flow can occur and try to develop an understanding of what the scale

45:30 of that flow would be. And so, we will conduct a sequence of measurements, directly measuring

45:40 exposed lava flow units and identifying the transmissive features in those flow units.

45:50 We can do that using exposures inside of tunnels. There are a number of tunnels that have have been

45:56 cut into the ridges surrounding Red Hill. And where the interior walls of those tunnels are

46:04 exposed we can document cooling joints, in the ʻaʻā flow units, the void spaces

46:11 in the ʻaʻā clinker zones. We also have exposed quarry faces. The Hālawa quarry

46:20 has been very generous in allowing us to come in and inspect the faces of the the quarry in

46:28 areas. This work, some of this work has already begun. Dr. Scott Rowland, who is with the faculty

46:34 at the University of Hawaiʻi, has mapped in this case, these are the clinker zones. We have

46:44 lava flow interfaces here and although you can't see it very well in this image—

46:49 if you look at this image, he's also mapped the cooling joints, 46:53 where fractures have bisected the ‘a‘ā core units and can—developing a statistically

47:04 significant inventory of the distribution of these fracture units;

47:12 determining what their fracture apertures are, we will be able to model how fuel is able to

47:21 pass through the vadose zone, the unsaturated zone, on its way down to the water table, and

47:29 actually develop some models for that, to be able to broadly understand how fuel does

47:37 interact with these features in the subsurface and work its way down towards the water table.

47:46 And finally, another method that we are going to investigate is—there is a well logging technique

47:53 called borehole televiewer, where we can actually go in and image the exposed walls

48:00 of an open borehole and image not only the— this is a core taken from a borehole. This is a

48:08 borehole televiewer image, not of the core itself, but of the borehole walls.

48:14 And we can image the clinker zones. We can image the fractures and document the frequency of these

48:22 fractures, what their orientation is, and their apertures, and also input that into our model.

48:30 So the next series of studies is to document the fuel and basalt interactions. What we want

48:36 to do is assess the retention rate of fuel by different basalt lithologies. What I’m saying

48:45 here is that when you say pour a gallon of fuel onto the—to a basalt surface or a soil surface,

48:54 that underlying soil, some of it will adsorb and hold on to that fuel. Likewise,

49:01 the basalt will hold on to some of that fuel. And so a spill of a certain size, as Bob mentioned

49:07 earlier in the presentation, may not even make it to the water table. And so what we want

49:13 to do is understand how much fuel is retained in the vadose zone, and how large a fuel release

49:21 would actually make it down to the water table and for this LNAPL plume on top of the water table.

49:31 And this will mostly involve laboratory work and we’ll be using weathered and unweathered

49:38 samples of the massive ‘a‘ā, the ‘a‘ā clinker, and the pāhoehoe to do the studies,

49:46 and looking at the wet and dry because the the

49:49 level of moisture will also affect the rate of retention of the basalt for the fuel.

49:57 Ultimately, what we hope to do then is assess the rate

50:00 of transport through massive and fractured ‘a‘ā core lavas and do

50:08 modeling of fracture apertures and fracture frequencies to determine how that fuel is moving.

50:15 And we know that is a very complex— complex process. This is an image

50:20 taken from a study in a hardrock environment elsewhere, but you can see the fuel distribution

50:27 is nowhere near—in the red and blue is nowhere near contiguous. It’s a very scattered and

50:34 torturous pathway that that the fuel does follow through these fractured hardrock environments.

50:41 So it will be a combination of laboratory studies as well as modeling.

50:46 In the next set of studies, we'd like to characterize water flow under pumping and

50:51 non-pumping conditions. This is something that, we hope by taking direct measurements of water flow

51:00 in some of the existing wells, they can provide us with at least an initial very site specific

51:08 information on water flow and water flow rates and water flow trajectories that we can then

51:14 use to develop a tracer test, a larger scale tracer test, that will give us a reason—regional

51:22 indication of how groundwater flows. So the first step in that is conducting in well measurements

51:28 of particle tracks, this is a technique where we can drop an instrument into a well,

51:35 either open hole or in the screened interval that allows water to pass through the well laterally.

51:43 And the technique allows us to not only determine the rate of flow, the velocity of

51:51 particles that are imaged in the flow system, we can also determine the direction.

51:59 So this is in the—this is showing data gathered from a specific well

52:07 in the open hole section, and then in a screened well, where there's only a

52:11 short section open to study. And they show very similar results. Those results then,

52:19 are plotted up in what's called a rose diagram. And although we don't expect any individual well

52:28 to tell us what the regional flow direction is, by measuring these flow directions, in a

52:35 broad sequence of wells in this region, we feel that the preponderance of evidence

52:41 will give us some information of what the rate of flow is and the overall direction of flow.

52:53 Also, as part of this work, we want to expand Bob's analysis of the natural tracers

53:01 to include ions, the ion concentrations, such as the chloride, the other ions, the isotopic

53:09 composition of the water and the dissolved ions, that are both from natural products

53:19 as well as anthropogenic contaminants that are already present in the water.

53:24 And again, the idea is that water under urbanized areas has distinctly different

53:32 chemical compositions and isotopic composition than water coming in from more pristine regions.

53:40 And with all of that data, then as guidance, we will plan to design and execute a dye tracer

53:47 study where we would inject the dye tracer into a carefully selected well, and then monitor

53:54 wells that, again, our preponderance of our data suggests is the direction of water flow.

54:02 And finally, one of the things that we have not done yet is try to inventory the

54:09 amount of water that is flowing within this region and is discharging into Pearl Harbor.

54:17 Because that ultimately would be the destination of this mauka-to-makai flow. And this, this would

54:25 be following work that Eric Attias and colleagues did offshore of West Hawai‘i. What they were able

54:33 to do is use an electrical geophysical method to image the electrical conductivity below the sea
54:40 floor and identify a layer of freshwater saturated rock as well as an area where
54:49 that, whatever that confining layer was that was responsible for that deeper freshwater,
54:55 allows it to come to the surface. So he was able to actually image the flow of water through
55:03 the ocean bottom up into the overlying saltwater water column.
55:10 And so, we would like to attempt some of these surveys within Pearl
55:15 Harbor. All of these are of course subject to agreement by the Navy to allow us to come in
55:21 and be able to conduct these surveys without interfering with their normal operations.
55:27 One of the techniques that has been mentioned that we have discussed
55:31 is the so-called self-potential method. This was used in that southeast Oʻahu study. It did show an
55:39 indication of direction of flow of water in that region. However, this is an electrical method. And
55:49 within the region that we're working, there is a tremendous amount of buried electrical conductors,
55:54 the pipelines, the tanks. And all of these will have an effect on the signal that is
56:01 surveyed using these self-potential surveys. And so although we will attempt it, we don't
56:06 have high expectations that we'll be able to get very reliable data from that exercise.
56:15 The next step in these studies will be to integrate the well log data into physical results.
56:22 And what I mean by this, we want to put this into a 3D
56:29 visualization model. This is an example of what can be done. These are actually
56:40 a visualization of the geology in the areas surrounding the fuel tanks
56:48 within Red Hill. When the fuel tanks were being constructed,
56:53 they had geologists go in and map every single lava flow and describe every single lava flow
57:01 in the walls of the cavity that was excavated prior to the installation of the tanks.
57:09 And so, we could put that into a three dimensional visualization
57:16 and apply appropriate geostatistical methods to extend and infill the intermediate
57:24 scale structures, where we don't have that site-specific data. And this is another example
57:30 where that original dataset was modeled to show the extent of pāhoehoe and ʻaʻā and clinker
57:42 units within this system. And what we can do with that model then is to
57:49 make a sort—at-will, various slices through this system and define the different flow units
58:00 and their ability to allow groundwater and LNAPL to flow within this region.
58:11 Ultimately, the goal of this effort though, is to use that
58:16 three dimensional visualization to develop a comprehensive conceptual site model
58:21 based on the most detailed geophysical and ground truth data and statistical modeling that we can

58:26 generate. And then that CSM, that conceptual site model, will be the starting point for

58:33 subsequent numerical models. And those numerical models will include an LNAPL transport model,

58:40 a numerical model for modeling groundwater flow. The LNAPL transport model will be

58:48 specific to the vadose, the unsaturated zone, the numerical flow model will apply to groundwater

58:54 flow through this region, and ultimately then, that will form the basis for a contaminant fate

59:00 and transport model. As I mentioned earlier, the intent is that once that model—and we don't

59:07 develop these models in a vacuum—once we develop the models, we then validate those models using

59:15 measured water levels over extended period of time for natural flow conditions as

59:21 well as under pumping conditions. And then with that, we should be able to

59:29 make much better estimates of groundwater flow within this region, compare those against

59:38 also the dye tracer test, and come up with the best possible model we can.

59:43 So, in closing what I am trying to sort of say in summary here is that this is a depiction

59:52 of the flow model that was developed by the contractor for the Navy. It shows these very

60:02 linear so-called particle tracks from beneath the tanks down towards Red Hill Shaft. This is

60:12 looking at these data in map view from above. And this is looking at a cross section of that

60:20 flow. So a very narrow flow path being followed by particles in the water as they migrate down

60:30 towards Red Hill Shaft. We want to transition that to one that recognizes the complexities

60:38 of fluid flow through this extraordinarily complex geologic system.

60:45 And will more accurately portray what happens when a contaminant is released within this region,

60:56 and how it would spread and travel both horizontally and vertically.

61:01 And finally, I would add a postscript. And this is in anticipation of a question that

61:09 I've actually been asked, "Well, if the tanks are going to be shut down, why are you

61:14 going to do all of this work?" And my answer to that question is what we don't know about

61:21 Red Hill hydrogeology, we also don't know about most of O'ahu's hydrogeology. We hope that the

61:29 work that we're going to do here will serve as a template and a stimulus to expand our efforts

61:38 to better understand how contaminants do move within the basalt formations here on O'ahu.

61:46 And what we can do to minimize the risks to our really vital drinking water resources on

61:54 the island. With that, I thank you and we can begin to take questions. Thank you very much.

62:02 Transcribed by https://otter.ai