On the Hunt for High-Level Groundwater: Tutuila, American Samoa

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Objective:

Assess the development potential of dike-impounded water in tropical volcanic island settings using a numerical model calibrated with natural spring and seep elevations.

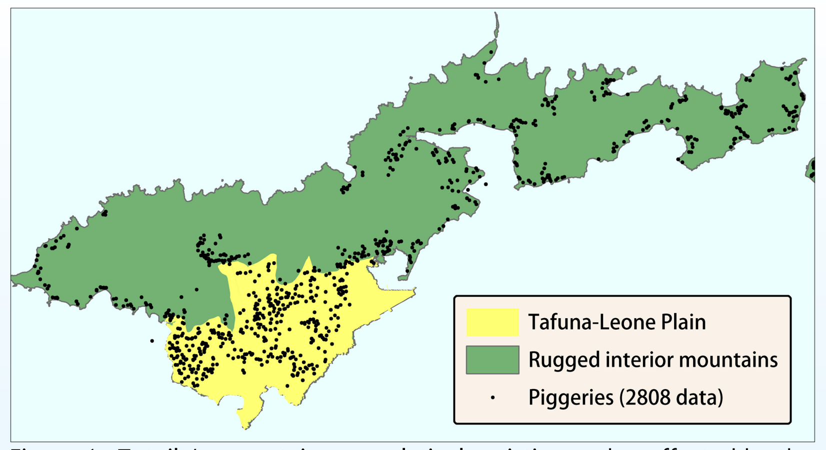

Figure 1: Tutuila's mountains are relatively pristine and unaffected by the anthropogenic contaminants that are prevalent on the Tafuna-Leone plain.

Introduction:

On the island of Tutuila, in the territory of American Samoa, the sustainability of groundwater resources is in question. In the Tafuna-Leone Plain (Fig. 1), septic tanks, cesspools and piggeries lie proximal to the population's primary drinking water wells in a highly permeable unconfined aquifer[1]. The alternative to continued water development in the contamination prone plain is to assess the potential of high-level groundwater resources (Fig. 2). Existing groundwater studies have not yet modeled these resources as a separate system[2]. In American Samoa drilling costs are high and utilities have tight budgets, so it is imperative for water managers to be equipped with accurate groundwater models prior to subsurface investigation. Model calibration is difficult, as there are no monitoring wells on Tutuila, and no production wells within high level aquifers. We present a novel method for model calibration based on field observations of natural hydrologic features and water sample geochemistry.

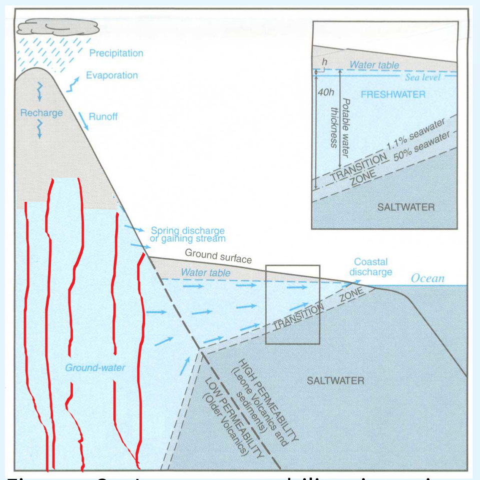
Figure 2: Low permeability intrusions such as dikes (red) can impound groundwater to higher elevations than those in basal lens aquifers. This dike impounded groundwater can either percolate slowly through the subsurface or it may discharge as a spring or seep where the water table intersects the land's surface. (Modified from Izuka, 2007)

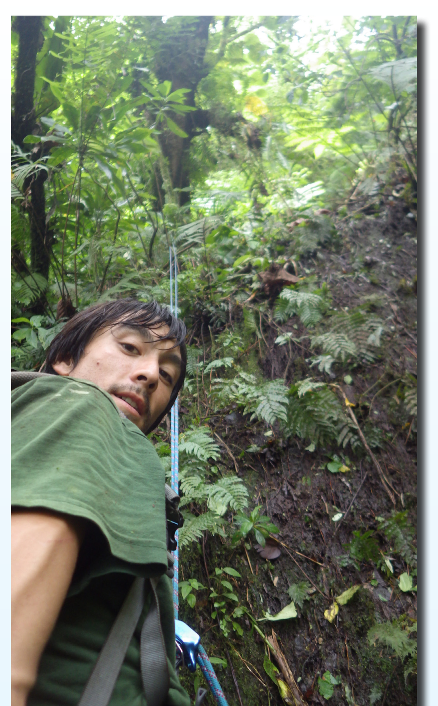
Figure 3: Calibration points were mapped by ascending running streams until the terminus was reached or by accessing ridgelines and descending into likely drainages.

Field Methods:

Perennial springs & seeps are generally understood to be expressions of the local water table and can therefore be used to calibrate groundwater head elevations (Fig. 3). Once found, springs were identified by their geomorphology and sampled for radon gas where feasible (Fig. 4), to test if springs represented true groundwater discharge, as opposed to recent rainwater. GPS coordinates were later used to extract high accuracy elevations from a 1 m resolution DEM.

Radon is generally not present in surface water or precipitation, however, it is easily dissolved into groundwater via recoil and diffusion from aquifer material. Significant quantities of ^{222}Rn indicates recharge waters have been in aquifer pore spaces long enough for Rn concentration to increase by an order of magnitude or more (Fig. 5).

Modeling Methods:

Spring elevations were used as known head elevations for calibration of a steady-state MODFLOW model. Within the Malaeimi watershed, flux out to drains was routed back into the model via mountain front recharge at the applicable cells. Once calibrated, the model was used to run hypothetical water development scenarios to calculate sustainable yields for each unit. Two hypothetical well-cells were placed at -3 to -50 MSL depth, in the outer caldera unit and the inner caldera unit (Figs. 6 & 7).


Figure 4: Radon grab samples were taken with a gas tight piezometer and hand-pump to minimize dissolved gas evasion. Samples were analyzed on a RAD H20 radon gas detector the same day as collection.


Figure 10: Offline production well. Static water levels were used for model calibration.

Figure 11: Pig at wellhead. Direct evidence of threats to groundwater sustainability (despite being a friendly pig).

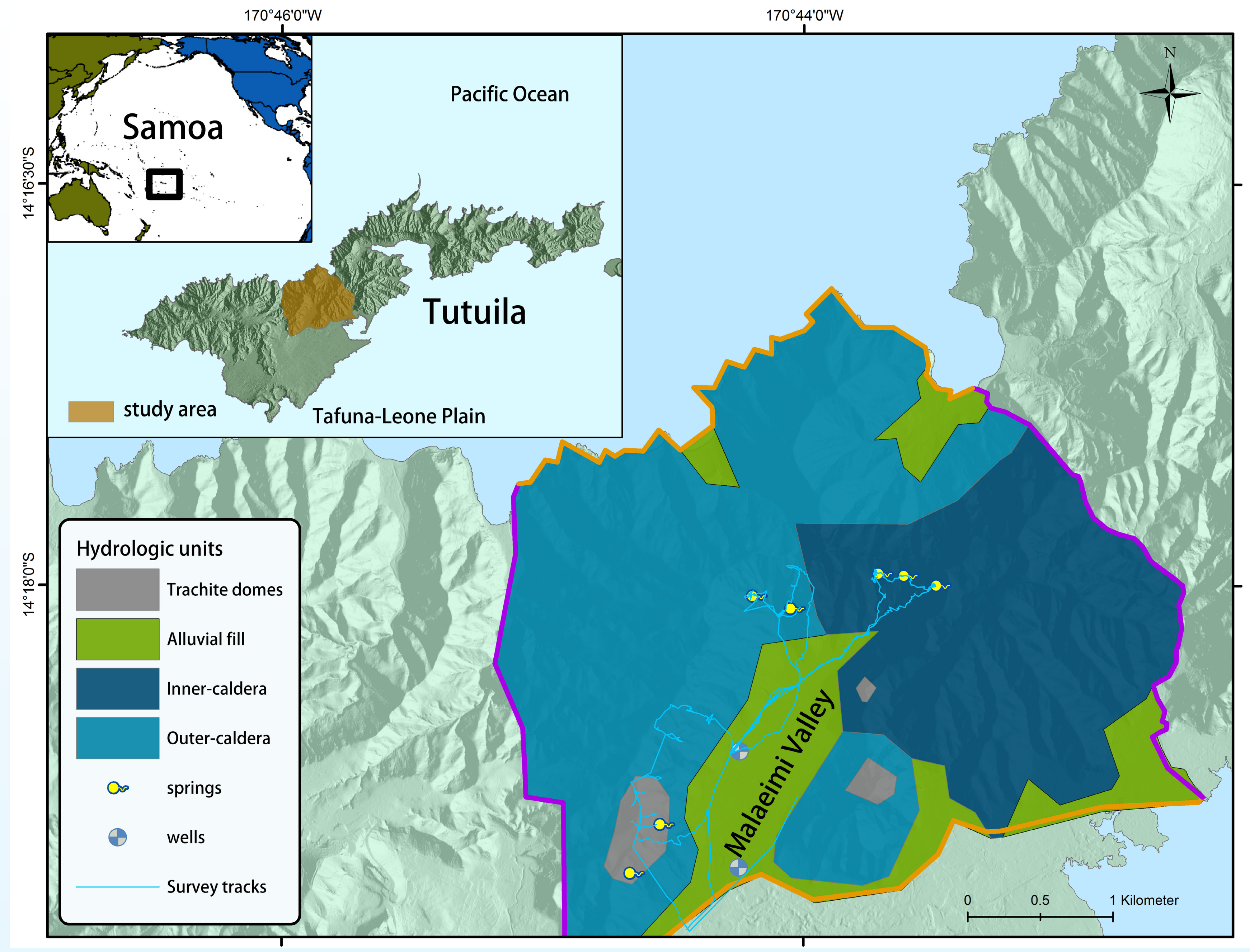

Figure 6: Boundary conditions and hydrologic units used in groundwater model. Orange boundaries represent zero MSL specified head and purple boundaries are assigned specified head values which correspond to elevations of stream valley bottoms.

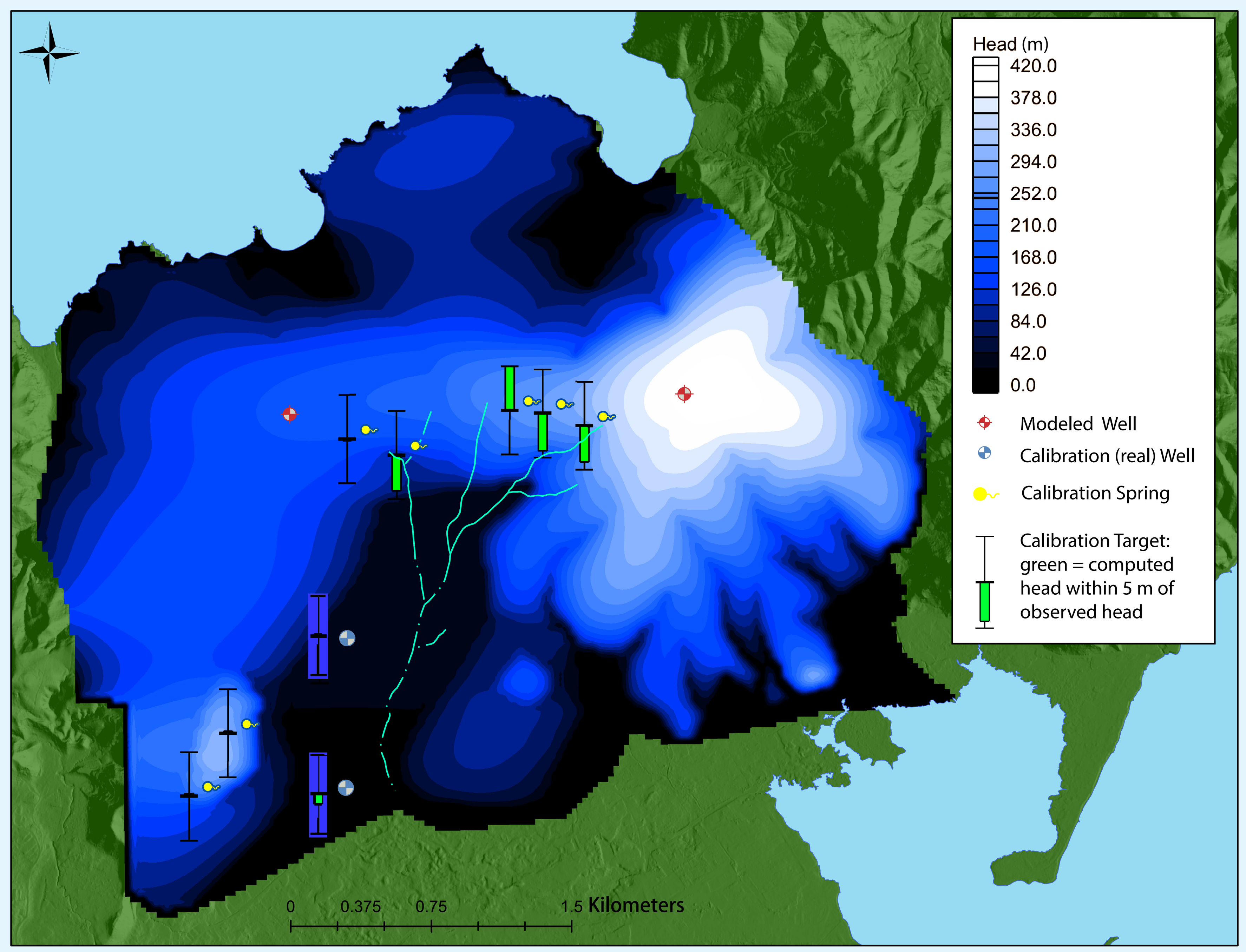

Figure 7: Modeled groundwater head elevations in meters above MSL. Model was calibrated with 7 springs and 2 observation wells. Also shown are locations of two hypothetical pumping wells.

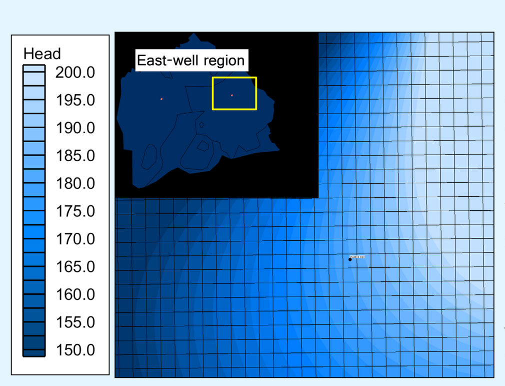
Figure 9a.
East-well, inner caldera region of model. Prior to modeled pumping.

Whole model grid size is 28 X 28 m by 5 layers. Bottom of layer 5 truncated at 40x starting head elevation.

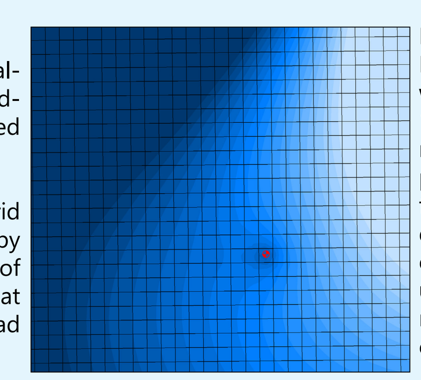
Figure 9b.
Modeled East-well pumping at 14.9 $m^3 \cdot d^{-1}$, the max sustainable pump rate (MSR) for the inner caldera unit. In the outer caldera unit MSR = 69.9 $m^3 \cdot d^{-1}$, per well-cell unit.

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Results:

Successful model calibration (Fig. 7) required the use of a horizontal anisotropy factor (K_{E-W} / K_{N-S}) of 10:1. This simulates dike orientations that lie parallel to the east-west trending rift zone[3]. The inner caldera unit shows a higher max drawdown to pump-rate ratio (Fig. 8), a result of lower hydrologic conductivity. The hypothetical outer caldera well has a pump rate-to-drawdown-ratio (3.2 m^2d^{-1}) that is comparable (4.2 m^2d^{-1}) to a real outer-caldera well located in the same geologic unit (no real inner-caldera wells currently exist on Tutuila). Criteria for sustainable yield is based on a maximum reduction of water table elevation by 22 m, the largest currently accepted production well drawdown in the American Samoa Power Authority system (Table 1). For context, the largest water user on the island, Starkist Tuna, places a 1 MGD stress on the system. To sustainably meet the tuna cannery's needs from this high level groundwater alone would require the installation of horizontal wells or Maui-type shafts covering equivalent of 54 of these well-cells in the outer-caldera unit or 253 cells in the inner-caldera unit.


Figure 12: Tutuila's Mountains are as steep as they are aesthetically pleasing.

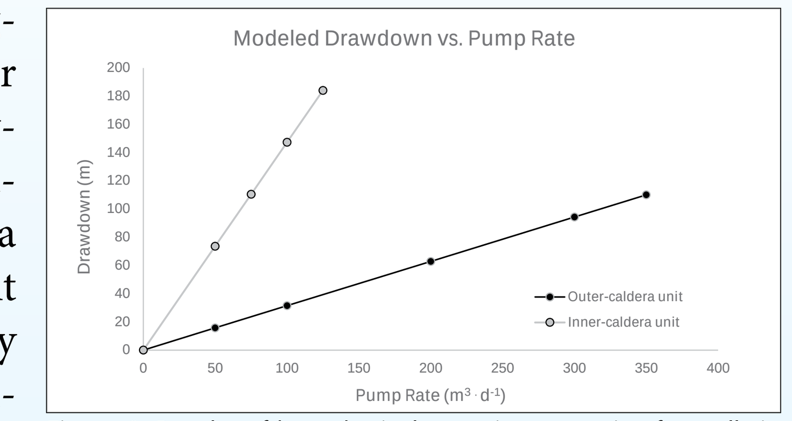

Figure 8: Results of hypothetical pumping scenarios for wells in two geologic units. Modeled wells were pumped at 50 to 300 m^3 d^{-1} or until well-cells went dry.

Well test results	Outer-caldera (W)	Inner-caldera (E)
Modeled hydraulic conductivity	0.12 (m/d)	0.01 (m/d)
Horizontal anisotropy	0.1	0.1
Vertical anisotropy	50	50
Pumprate to drawdown ratio	3.2	0.68
Acceptable** drawdown	22 m	22 m
Max sustainable pumprate	69.9 $m^3 \cdot d^{-1}$	14.9 $m^3 \cdot d^{-1}$
Streamflow results		
Historical stream baseflow[4]	490 $m^3 \cdot d^{-1}$	734 $m^3 \cdot d^{-1}$
Modeled stream baseflow	1163 $m^3 \cdot d^{-1}$	1800 $m^3 \cdot d^{-1}$
Historical flow ratio: E over W	1.50	
Modeled flow ratio: E over W	1.55	

**explanation in text

Table 1: Hypothetical well test results and streamflow comparison between units.

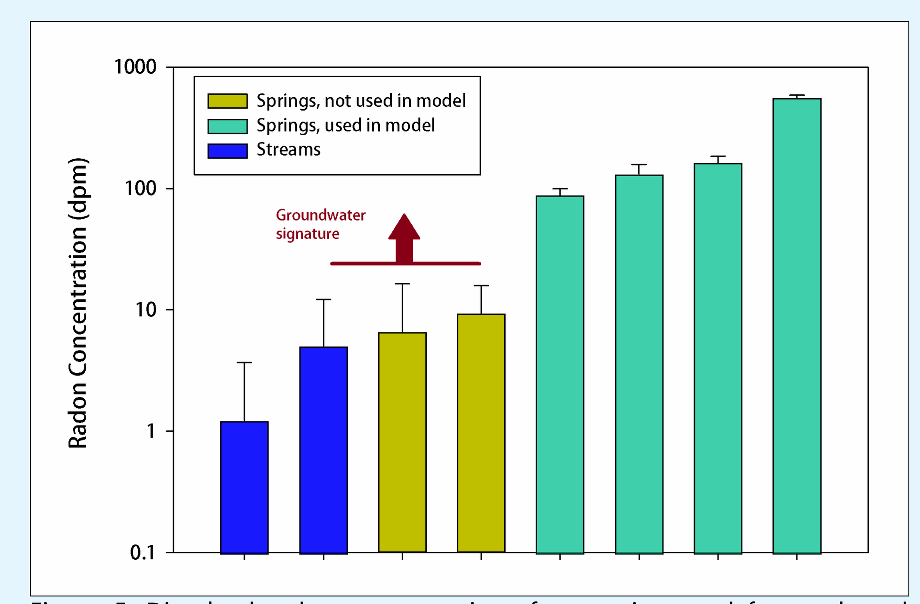

Figure 5: Dissolved radon concentrations from springs and from selected surface water samples for comparison. Radon concentrations in groundwater are generally an order-of-magnitude higher than those found in surface water or precipitation.

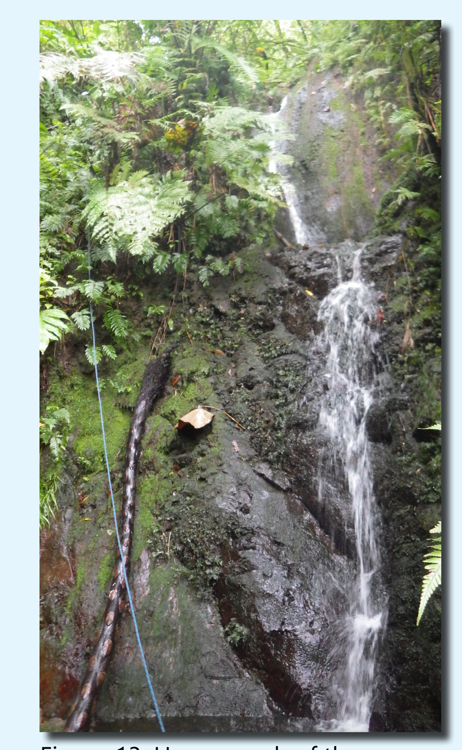
Figure 13: Upper reach of the eastern fork of Malaeimi stream.

Conclusions:

1) Development of high-level groundwater in Tutuila's outer-caldera unit will result in higher production yield and lower head drawdown than water development in the inner-caldera unit.

2) Natural hydrologic features can be useful in developing and calibrating models that may serve as tools for future water resources exploration in volcanic island terrains.

References:
1. Eyre, (1989). USGS Water-Resources Investigations Report: 94-4142
2. Izuka, et. al.(2007). USGS Scientific Investigations Report: 2007-5167
3. Walker & Eyre, (1995). "J. of Volcanology & Geothermal Res. 69.3 241-254
4. Wong, (1995). USGS Water-Resources Investigations Report: 95-4185