An Isotopic and Microbiological Tracer Approach to Assessing Recharge Mechanisms in Surface Water Affected Wells on Tutuila, American Samoa

Christopher Shuler[1,2]*, Marek Kirs[2], Henrietta Dulai[1,2], Craig R. Glenn[1,2], Randel DeWees[3], and Aly El-Kadi[1,2].
[1]Dept. Geology and Geophysics, [2]Water Resources Research Center; University of Hawaii, 96822. [3]American Samoa Community College, 96799 Email: *cshuler@hawaii.edu

Background

Part of the water supply on Tutuila, the territory's main island, is subject to one of the longest boil-water-advisories in U.S. history. Turbidity and bacteria spikes during heavy rainfall events show many of the island's most productive wells (Fig. 1) receive groundwater under the direct influence of surface water (GUDI). However, it's unclear whether surface water reaches the wells through improperly sealed well casings (Fig 2-A), or through the aquifer matrix itself (Fig 2-B).

Here these hypotheses are examined with environmental tracers over seasonal and event-based timescales to constrain recharge timing and material transport from surface to production well pump. Tracers include the isotopic composition of water (δ^2H & $\delta^{18}O$), microbial indicators (*Escherichia coli* & total coliform (TC)), and physical tracers such as turbidity.

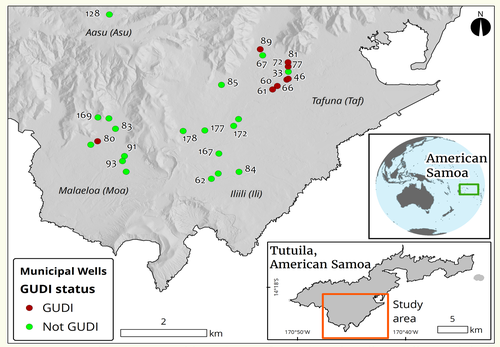


Figure 1: Study region and locations of municipal wells. Wells are labeled by ID number and are color coded by U.S. Environmental Protection Agency (US-EPA) determined GUDI status.

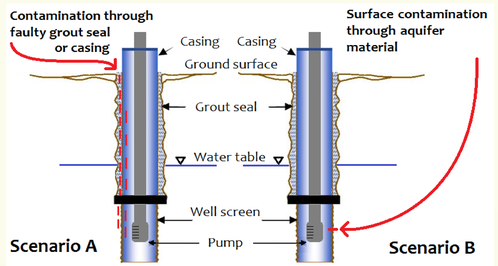


Figure 2: Hypothesized flow paths of surface contamination in GUDI wells. **Scenario A** depicts surface contaminated water (*indicated by red lines*) traveling through poorly sealed grout or well casing, while **Scenario B** shows how contaminated water may reach a properly sealed well through highly permeable aquifer matrix.

δ^2D & $\delta^{18}O$ in precipitation and groundwater

Methods – Water samples for δ^2H & $\delta^{18}O$ analysis were collected monthly at six groundwater wells and at four precipitation sampling locations outfitted with cumulative precipitation collectors (Fig. 3).(1)

Results – δ^2H & $\delta^{18}O$ values in precipitation show clear seasonal variability. In comparison, well waters show little variation throughout the year or between different sites, and consistently match an average mixed composition of water from different seasons (Fig. 4).

Significance– Low seasonal variability in groundwater δ^2H & $\delta^{18}O$ values shows that regional scale recharge occurs on longer than seasonal timescales. This suggests the water recharged during heavy-rainfall events constitutes a relatively small volume of the total recharge.

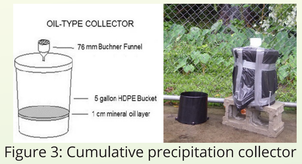


Figure 3: Cumulative precipitation collector

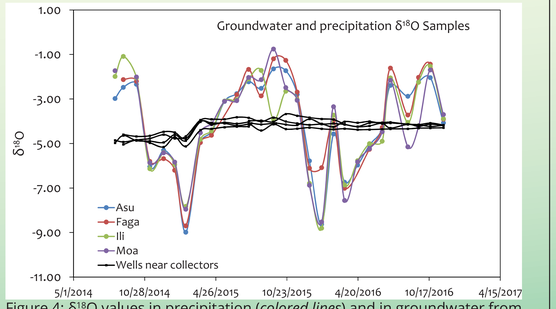


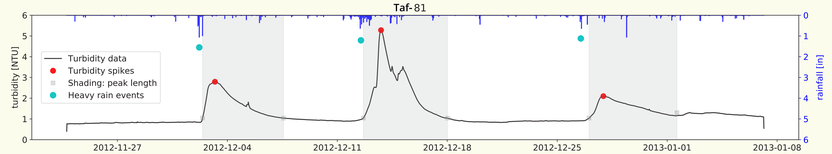
Figure 4: $\delta^{18}O$ values in precipitation (*colored lines*) and in groundwater from wells located near precipitation collectors (*black lines*).

Turbidity response to rainfall events

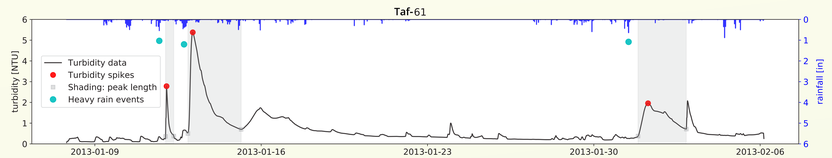
Method – Rainfall and turbidity data originally collected by U.S. EPA for GUDI well designation was reanalyzed. Turbidity data was filtered to identify peaks that correlated with heavy rain events.

Result –GUDI wells showed faster and more dramatic turbidity response to rainfall, whereas non-GUDI wells maintained low turbidity levels overall (Fig. 5). Tafuna GUDI well turbidity spikes started 3 - 24 hours (mean = 17.6 hrs.) after rain event peaks, and lasted between 1.5 – 11 days (mean = 4.7 days).

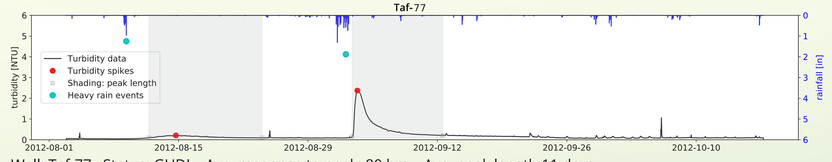
Significance – Turbidity spike duration indicates event water remains in the aquifer for multiple days after rainfall, suggesting it originates from an area with more storage than the material around a well annulus. Additionally, the response time of turbidity spikes is consistent with expected groundwater velocities in the Tafuna Aquifer material(4, 5). Surface water infiltration through casings would be expected produce a faster response, similar to surface runoff peaks in streams, which occur within minutes to hours of heavy rain. This supports the hypothesis that surface water reaches wells through permeable aquifer material.



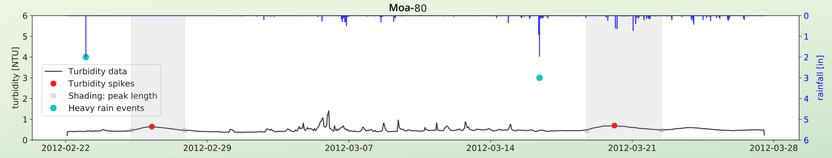
Well: Taf-81, Status: GUDI, Ave. response to peak: 29 hrs., Ave. peak length: 5.5 days



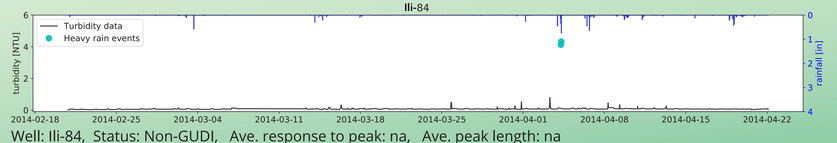
Well: Taf-61, Status: GUDI, Ave. response to peak: 12 hrs., Ave. peak length: 36 hrs.



Well: Taf-77, Status: GUDI, Ave. response to peak: 80 hrs., Ave. peak length:11 days



Well: Moa-80, Status: GUDI, Ave. response to peak: 2.5 days, Ave. peak length: 3 days



Well: Ili-84, Status: Non-GUDI, Ave. response to peak: na, Ave. peak length: na

Figure 5. Turbidity [NTU] (*black line)* in wells vs. heavy rain events (*cyan points)*. Rain events of < 0.33 inch/hr. were ignored and turbidity spikes without preceding rain events were not analyzed (*red points show peaks; grey boxes show durration)*.

Microbial tracers in groundwater

Methods - GUDI and non-GUDI wells were sampled monthly and during high-rain events for TC and *E. coli*. In groundwater, these bacteria indicate low aquifer-filtration capacity(2) and short travel times, as sub-surface *E. coli* die off rates can be >50% per day(3).

Results – Non-GUDI wells had insignificant TC levels and no *E. coli* detections, whereas GUDI wells consistently showed TC and *E. coli* presence. Monthly samples showed no seasonal trend. However, *E. coli* counts correlated with 48 hour rainfall totals (Fig 6). Rain event sampling indicated *E. coli* spikes occur during events, but persist marginally past 72 hours (Fig. 7).

Significance – Rapid *E. coli* response suggests surface water recharge occurs on very short timescales, (<48 hours). Order-of-magnitude *E. coli* concentration discrepancies in adjacent GUDI wells shows the source may be heterogeneous or contribute variable amounts of water to different wells.

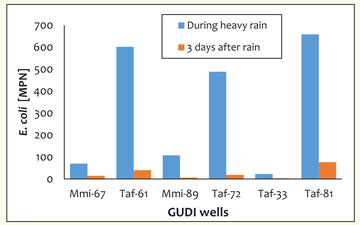


Figure 7: Heavy rain event *E. coli* sampling at GUDI wells. Two sample times were selected, during a heavy rain event (4 inches of rainfall in previous 48 hours) (*blue bars*), and 11 days later (*orange bars*) during a period of low 48 hour rainfall (0.07 inches).

Figure 8: American Samoa Community College student interns and faculty assisted with sampling and analysis.

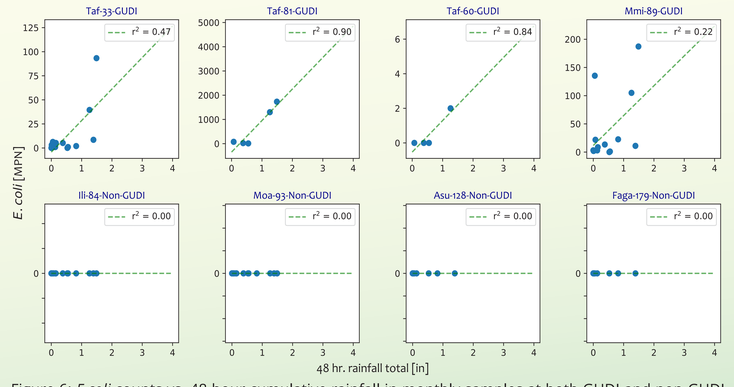


Figure 6: *E.coli* counts vs. 48 hour cumulative rainfall in monthly samples at both GUDI and non-GUDI wells. Green lines represent liner best fit of the rainfall-*E. coli* relationship. r^2 values generally indicate fair correlation. The rainfall-TC relationship (not shown) was similar; however, r^2 values were generally lower (0.3, 0.88. 0.6 and 0.1 for wells 33, 81, 60, and 89 respectively).

Conclusions

- **Rapid recharge of surface water occurs quickly, within 3 – 48 hours of heavy rainfall**
- **Turbidity travel time points towards aquifer material over faulty casings as the primary transport medium for surface water**
- **Tafuna Aquifer material does not provide sufficient filtration and holding time to remove microbes from groundwater.**
- **Results suggest abandonment of the Tafuna Well Field is recommended over rehabilitation of existing wells.**

Acknowledgements

Fa'afetai Tele Lava to the people and agencies who made this work possible:

American Samoa Power Authority
Utu Abe Malae, Danielle Mauga, Taylor Savusa, Katrina Mariner, & operations staff

American Smaoa EPA
Jason Gambatese & Tim Bodell

American Samoa Community College
Randy DeWees, Kelley Anderson-Tagarino, Rocco Tinitali, Hugh Fuimaono, Janet and Mona Chang.

And Scot Izuka & Joe Fackrell

Support for this work was provided by:
The Water Resources Research Institute Program, Pacific RISA and the U.S. EPA Region IX Making a Visible Difference Program

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