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

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Background

Don't drink the tap water in American Samoa. Why? 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 at least eight 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 (^{2}D&^{18}O), microbial indicators (*E. coli* & total coliform (TC)), and physical tracers such as turbidity.

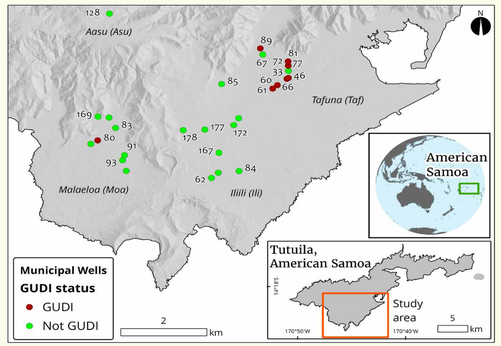


Figure 1: Study region and locations of municipal wells. Wells are labeled by ID number and are color coded by U.S. Environmental Protection Agency (US-EPA) determined GUDI status.

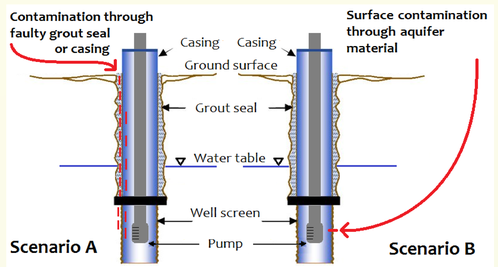


Figure 2: Hypothesized flow paths of surface contamination in GUDI wells. **Scenario A** depicts surface contaminated water (indicated by red lines) traveling through poorly sealed grout or well casing, while **scenario B** shows how contaminated water may reach a properly sealed well through highly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

^{2}D & ^{18}O in precipitation and groundwater

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

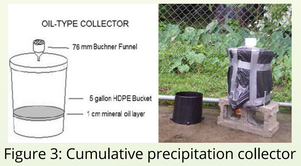


Figure 3: Cumulative precipitation collector

Results – ^{2}D&^{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– Groundwater ^{2}D&^{18}O signatures indicate the aquifer contains a fairly consistent mixture of wet and dry season precipitation. This suggests regional scale recharge is not exceptionally rapid. Therefore heavy-rainfall event recharge makes up a small proportion of the production stream and clearly reaches wells from a localized source, either through casings or originating in the aquifer near to the wells.

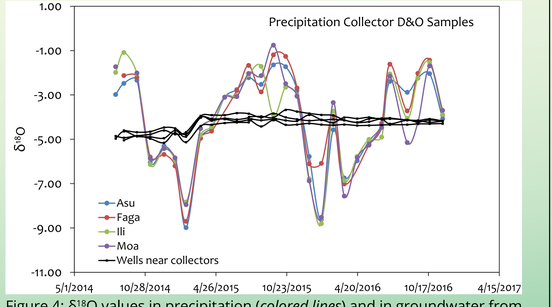


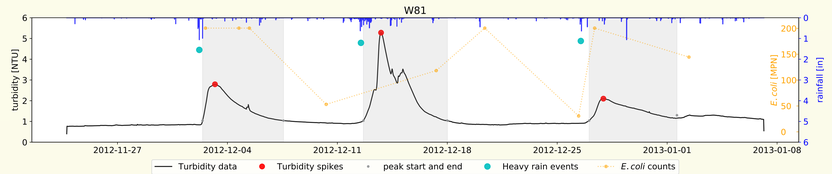
Figure 4: $\delta^{18}O$ values in precipitation (*colored lines*) and in groundwater from wells located near precipitation collectors (*black lines*).

Turbidity response to rainfall events

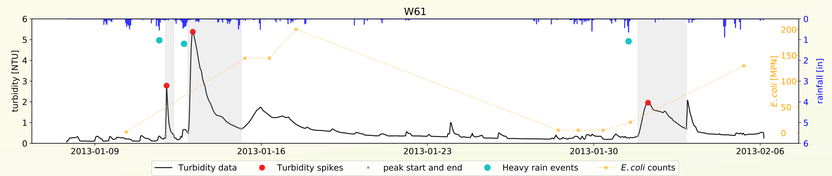
Method – US-EPA provided rainfall, *E. coli,* and turbidity data, originally collected for GUDI well designation. Turbidity data was filtered and reanalyzed to identify peaks that correlated with heavy rain events.

Result –Tafuna wells generally 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).

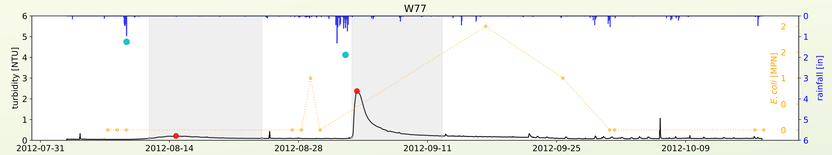
Significance – Turbidity spike duration indicates event water remains in the aquifer for days after rainfall, suggesting it originates from an area with more storage than the material around a well annulus. Additionally, the response time of turbidity spikes is consistent with expected groundwater velocities 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.



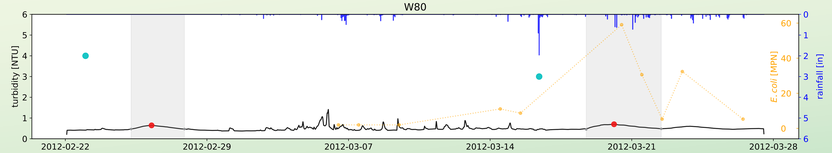
Well: Taf-81, Status: GUDI, Max turbidity: 5.3 [NTU], Ave. response to peak: 29 hrs., Ave. peak length: 5.5 days



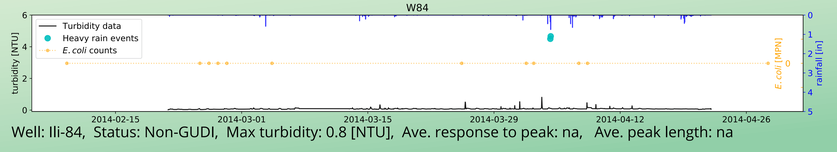
Well: Taf-61, Status: GUDI, Max turbidity: 5.4 [NTU], Ave. response to peak: 12 hrs., Ave. peak length: 36 hrs.



Well: Taf-77, Status: GUDI, Max turbidity: 2.4 [NTU], Ave. response to peak: 80 hrs., Ave. peak length:11 days



Well: Moa-80, Status: GUDI, Max turbidity: 1.5 [NTU], Ave. response to peak: 2.5 days, Ave. peak length: 3 days



Well: Ili-84, Status: Non-GUDI, Max turbidity: 0.8 [NTU], Ave. response to peak: na, Ave. peak length: na

Figure 4. Plots of turbidity [NTU] (*black line)* vs. heavy rain events (*cyan points),* and *E, coli* counts (*orange points*). Events with rain rates below 1 inch/3 hrs. were ignored and turbidity spikes without preceding rain events were not analyzed.

Microbial tracers in groundwater

Methods - GUDI and non-GUDI wells were sampled monthly and during high-rain events for TC and *E. coli*. Samples were analyzed with Colilert-18® tests in Quanti-Tray®/2000 format. 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* levels correlated with 48 hour rainfall totals (Fig 6). Rain event sampling indicated *E. coli* spikes occur during events, but persist only marginally past 72 hours (Fig. 7).

Significance – Rapid *E. coli* response suggests some 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.

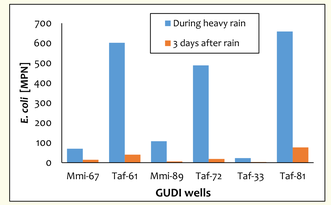


Figure 7: Results of heavy rain event E. coli sampling at GUDI wells. Two sampling times were selected, during a heavy rain event (4 inches of rainfall in previous 48 hours on 4-11-2016) (blue bars), and 11 days later during a time with a low 48 hour rainfall total (0.07 inches) (orange bars).

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

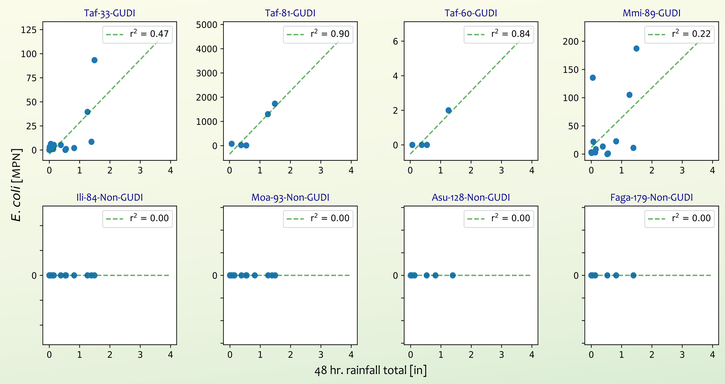


Figure 6: Plots of *E.coli* concentrations vs. 48 hour cumulative rainfall from monthly samples at both GUDI and non-GUDI wells. Green lines represent liner best fit of the rainfall-*E. coli* relationship. r^2 values generally indicate fair correlation. The rainfall-TC relationship (not shown) was similar. 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

- **Surface water recharge occurs quickly, within 3 – 48 hours of heavy rainfall**
- **Turbidity travel times suggests 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.**
- **Abandonment of the Tafuna Well Field is recommended over rehabilitation of existing wells.**

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