



Electrical Conductivity and Major Cation Concentrations in Municipal Water from Tutuila Island, American Samoa

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Abstract

Residents of Tutuila Island's central villages have come to expect a safe, reliable supply of municipal water. As of 2012, all villages were connected to the central distribution system. But some people do not use this as their source of drinking water citing taste, odor, or concern of contaminants as reasons. This study was conducted to determine whether water quality varied across the island. In August 2012 we collected 20 tap water samples from villages throughout Tutuila Island and tested their electrical conductivity (EC) and concentrations of calcium, magnesium, potassium, and sodium. We found that municipal water from Western Tutuila and from villages on the north shore had low EC, indicating low levels of dissolved solids. This was confirmed by correspondingly low cation concentrations. Samples from villages located on the south shore of Eastern Tutuila, however, had relatively high EC values ranging from 2.5 to 3.3 mS cm⁻¹, with correspondingly high levels of cations. Samples from Central Tutuila had EC levels and cation concentrations between these two extremes. Because dissolved solids can impart a taste to water, its quality does indeed depend upon the sources of municipal ground water supplying the villages.

Introduction

With abundant rainfall of up to 200 inches (5000 mm) annually, American Samoa enjoys a regular and reliable source of pristine water. Far from major industrial pollution, both surface and ground water serve as sources of drinking water for its residents. The local water utility, the American Samoa Power Authority (ASPA), uses deep, encased wells as the exclusive source for the municipal water system (Fig. 1). Yet some villages serviced by ASPA continue to rely to some extent on small reservoirs constructed on streams for drinking water (Fig. 2). During periods of intense rainfall, the American Samoa Environmental Protection Agency (ASEPA) would issue boil water notices in the local media for villages that rely on these reservoirs, owing to high total coliform and fecal coliform counts. Mayors were advised to initiate cleaning activities in the watershed and water catchments to minimize the contamination. Few such problems had ever been encountered for the municipal ground water supply until November 2001.

During routine monitoring by ASEPA, five of 60 municipal water samples showed the presence of total coliform bacteria (*Samoa News*, 20 NOV 2001). In-

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Figure 1. One of ASPA's 53 ground water wells. Wells are encased in concrete and may be as deep as 300 ft (90 m), requiring pumps of 30 to 40 hp (22 to 30 kW) to draw water to the surface. A 6% solution of sodium hypochlorite in the yellow drum is injected into the distribution system to disinfect the ground water as it reaches the surface.

adequate dosage of chlorine injection into the distribution lines was the suspected cause (*ibid.*) Although coliform bacteria were found in more than 5% of 60 samples taken, consumers were assured that no corrective action was required on their part, that is, no boil water notice was issued.



Figure 2. A reservoir built on a stream to supply villagers with water. These were typically built long before the municipal distribution system reached a village. Residents continue to rely upon them as a source of drinking water.

Bacterial contamination in the municipal water supply resurfaced four years later (*Samoa News*, 14 APR 2005). ASPA's survey teams identified illegal cross-connections of village water to ASPA's water system and leaks in the distribution pipes as the causes. To counter the bacterial contamination, chlorine injection was increased at the affected sites. Again, no boil water notice was issued.

That year we distributed a 37-question survey, developed by the Pacific Island Water Quality Team, to a convenience sample of 50 people to document public awareness, attitudes, and actions toward water quality in American Samoa³. Every one of the respondents listed "clean drinking water" as being either extremely or very important.

The first boil water notice issued for residents connected to the municipal water line occurred a year later. Interruption of chlorine injection at one of the disinfection stations resulted in excessive coliform contamination of the distribution system (*Samoa News*, 15 DEC 2006). Department of Education officials instructed the School Lunch Program to provide students with extra bottles of water to discourage them from drinking tap water (*Samoa News*, 19 DEC 2006). The boil water notice was lifted the next day (*Samoa News*, 20 DEC 2006). While a faulty chlorine injector (Fig. 1) may have allowed coliform bacteria into the distribution system, the primary problem was human and animal waste contamination of ground water.

In April 2003, a laboratory-confirmed case of leptospirosis was diagnosed in a 39-year-old construction worker in American Samoa. This was the first confirmed human case of the disease acquired in American Samoa⁴.

Leptospirosis is a bacterial disease caused by *Leptospira interrogans*. Rats, dogs, and pigs are typical carriers of this bacteria. They release it in their urine. The bacteria enter a person either through cuts in the skin or by accidentally drinking water containing it.

In 2005, a 38-year-old male admitted to the Intensive Care Unit at LBJ Tropical Medical Center, died two days after showing symptoms indicative of leptospirosis (*Samoa News*, 11 May 2005). The previous year six individuals were reportedly infected, resulting in two deaths (*ibid.*). Studies conducted in 2004⁴ and in 2010⁵ found that over 15% of the Territory's popu-

3 <http://ag.arizona.edu/region9wq/index.htm>.

4 Winger K. Leptospirosis: a seroprevalence survey on American Samoa. 2004. Atlanta, GA. Centers for Disease Control and Prevention, 2004. <http://www.botany.hawaii.edu/basch/uhnpscesu/pdfs/sam/Winger2004AS.pdf>.

5 Lau CL, Skelly C, Smythe LD, Craig SB, and Weinstein P. Emergence of new leptospiral serovars in American Samoa—ascertainment or ecological change? *BMC Infectious Diseases* 2012, 12:19. doi:10.1186/1471-2334-12-19.

lation had been exposed to the bacteria, mainly to the *Leptospira* serovar associated with pigs.

Widespread public outcry demanded enforcement of a law requiring piggeries to be set back at least 50 ft (15 m) from a stream or a building used for human habitation (*Samoa News*, 23 SEP 2005; Fig. 3). Despite initial opposition by some members of the Fono, ASEPA began an aggressive campaign in August and November 2006 to enforce the law. By the end of 2007, its efforts resulted in the closure of 69 non-compliant piggeries, and [with assistance from the USDA Natural Resource Conservation Service EQIP program] 57 others were able to bring their piggeries into compliance (*Samoa News*, 15 APR 2008).



Figure 3. A non-compliant piggery discharging its waste directly into a stream. Prior to ASEPA's efforts to enforce the law disallowing such practices, the vast majority of piggeries were in violation. They lacked proper waste disposal systems. Most housed less than a dozen mature pigs. But some contained over a hundred pigs ranging in age and size from young piglets to breeding stock.

In 2008 the American Samoa Soil and Water Conservation District hosted the first Territorial Soil and Water Conservation Day (*Samoa News*, 24 OCT 2008). One of the most popular exhibits was presented by ASPA's Water Division. It stressed the importance of preventing illegal cross-connections of village surface water supplies with the municipal ground water distribution system and of repairing leaky toilets, one of the worst water wasters in the home (*ibid.*).

In addition to pig waste, another major source of coliform and fecal bacteria is human waste. Most of the heavily populated villages are served by ASPA sewer lines. Starting at Coconut Point, through Nu'uuli and Tafuna, to Futiga is one line. Another runs from Fatumafuti to the tuna canneries in Atuu and about half way up the road in Pago Pago Val-

ley⁶. Elsewhere, homes and businesses have either septic tanks, cesspools, or pit privies that allow waste to percolate into the soil to reach and contaminate ground water.

The USEPA set December 1, 2009, as the deadline for enforcement of a new Ground Water Rule that required source monitoring for bacterial contamination⁷. It is estimated that half of ASPA's 53 wells contain bacteria⁶. The Malaeimi watershed is a major source of ground water. It has ten wells within one square mile (2.6 km²) that produce 1,900 gallons (7,190 L) per minute³. Three of these wells and seven others at Fagaima are contaminated (*Samoa News*, 10 SEP 2010). As a consequence, public institutions that are supplied by these wells, such as schools, are required to install costly filtration systems before tap water can be used for drinking.

Owing to the new rule, ASPA again issued a boil water notice in March 2010 (*Samoa News*, 20 AUG 2010). ASPA shock chlorinated the wells, but positive bacterial samples kept the boil water notice in effect into August 2010. ASPA predicted that it would take at least two years to change the water infrastructure and correct the problems that led to contamination of the ground water (*Samoa News*, 10 SEP 2010). Correcting the problems would not only require funding, but also dealing with land and right-of-way issues which could be time consuming (*ibid.*). Otherwise, violation of the Ground Water Rule would result in a penalty of \$10,000 per day (*Samoa News*, 21 SEP 2010).

Students attending schools in affected areas were asked to bring bottled water, since the Department of Education had no budget for purchasing bottled water. And the USDA, which funds the School Lunch Program, allowed only the purchase of milk and juice, not water (*Samoa News*, 10 SEP 2010.).

ASEPA soon reported that ASPA would receive \$14 million in federal funds to address the water infrastructure problem as well as extend the sewer system (*Samoa News*, 21 SEP 2010). And with funding from two separate awards from the US Department of Interior for \$1.43 million and \$571,052, ASPA broke ground to bring potable water to the three remaining villages not on the municipal distribution system—Fagalii, Maloata, and Fagamalo (*Samoa News*, 25 APR 2011). ASPA was also working to remove cesspools and old septic tanks and replace them with new ones (*Samoa News*, 19 JUL 2011). They also increased monitoring of chlorine levels to ensure bacteria were being destroyed (*ibid.*). Through these efforts, villages were being removed from the boil water notice piecemeal. By November 2011, only villages in Central Tutuila from Iliili to Leloalua were still

6 American Samoa 309 Program Assessment and Strategy. Memorandum No. 11. Townscape, Inc. September 8, 2010. mail@townscapeinc.com.

7 Ground Water Rule: A Quick Reference Guide. Revised March 2010. EPA-816-F-08-029. www.epa.gov/safewater.

under the boil water notice (*Samoa News*, 04 NOV 2011).

Throughout the 2010/2011 school year, ASPA provided coolers and 5-gallon (19 L) bottles for use by both private and public schools in order to ensure at least one 12-ounce (350 ml) serving of water per child per day (*Samoa News*, 04 AUG 2011). At the beginning of the 2011 school year, the American Samoa Department of Education had encouraging news that the USDA would allow the School Lunch Program of provide potable water to schools (*ibid.*; Fig. 4).



Figure 4. American Samoa Department of Education (ASDOE) School Lunch Program (SLP) water truck. With USDA approval, the ASDOE SLP delivers water, purified by a local bottled water vendor using reverse osmosis, to both public and private schools.

Methods and Materials

During the week of 20-24 August, 2012, we distributed 1-L polyethylene bottles to fellow staff who live in widely dispersed villages on Tutuila Island and asked that they fill the bottles with tap water from their homes. Where sampling gaps occurred, we collected tap water from homes of relatives or friends and from two stores and an elementary school.

As samples were returned, we determined their electrical conductivity (EC) using a Hanna Instruments Portable Multi-Range Conductivity/TDS Meter, Model 8733, calibrated at 25°C with a 12.88 mS cm⁻¹ solution of potassium chloride, as recommended in the user's manual.

The following week we determined the concentrations of calcium, magnesium, potassium, and sodium cations using a Buck Scientific Atomic Absorption/Emission Spectrophotometer. Calcium, magnesium, and potassium concentrations were determined by absorption at wavelengths of 422.7 nm, 202.6 nm, and 769.9 nm, respectively. Sodium concentration was determined by emission at 589.0 nm. Samples whose absorption or

emission reading exceeded the concentration of the highest standard were diluted with distilled water until their reading was within range for interpolation. Standard curves for absorption were linear, while the sodium standard curve was quadratic.

Water hardness was computed from the separate determinations of calcium and magnesium using the formula⁸:

$$\text{mg CaCO}_3/\text{L} = 2.497 (\text{Ca, mg/L}) + 4.118 (\text{Mg, mg/L})$$

Total dissolved solids⁸ (TDS), dried at 180° C, were determined on a subsample of tap water collected from the same sites during April 2012.

Results and Discussion

The 20 samples of tap water were divided into three classes based on their electrical conductivity (EC) levels (Fig. 5). EC is the ability of water to carry an electric current. This ability depends upon the number and type of ions dissolved in the water. EC is an indirect measure of the total dissolved solids (TDS) in water⁸. Therefore, TDS can easily be calculated using the formula in Fig. 6.

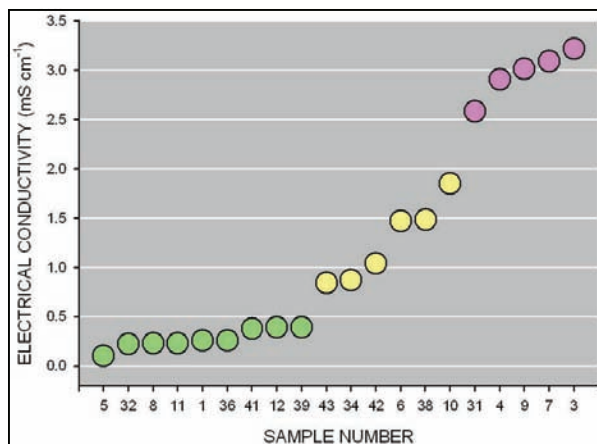


Figure 5. Electrical conductivity (EC) of 20 municipal water samples collected throughout Tutuila Island during 20 to 24 August, 2012. Sample numbers were arbitrarily assigned to collection bottles.

Samples with the lowest EC values had very little dissolved solids that could impart a taste. These were color-coded green. Samples with the highest EC values were highest in TDS. They were color-coded red. And samples whose EC values fell between these two extremes were color-coded yellow. EC and other parameters tested are given in Table 1.

Table 1. Electrical conductivity (EC), concentrations of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), and computed hardness for 20 municipal (ASPA) tap water samples taken throughout Tutuila Island during 20 to 24 August, 2012.

Sample	Village	mS/cm	Concentrations in mg/L (or ppm)				calculated Hardness	EC level
		EC	Ca	Mg	K	Na		
5	Fagamalo	0.10	0.02	3	1.1	6	12	Low
32	Sailele	0.22	0.04	5	2.1	10	21	
8	Vatia	0.23	0.03	5	1.9	12	21	
11	Pago Pago	0.23	0.05	5	3.1	14	21	
1	Masefau	0.26	0.03	5	2.3	11	21	
36	Malaeimi	0.26	0.03	5	7.0	18	21	
41	Leone	0.38	0.16	18	7.1	21	75	
12	Poloa	0.39	0.08	5	6.9	23	21	
39	Taputimu	0.39	0.16	18	7.2	22	75	
43	Tafuna	0.84	0.15	26	9.6	422	107	Medium
34	Aoloau	0.87	0.18	28	16.7	320	116	
42	Vaitogi	1.04	0.21	26	8.6	618	108	
6	Nu'uuli	1.47	0.26	30	13.2	890	124	
38	Fagatogo	1.48	0.26	30	13.6	1013	124	
10	Tula	1.85	2.42	106	4.8	450	443	
31	Aua	2.58	1.90	124	5.4	320	515	High
4	Auasi	2.91	1.78	124	7.0	971	515	
9	Alofau	3.01	1.68	120	7.9	1330	498	
7	Fagaitua	3.09	2.05	130	6.3	569	540	
3	Lauli'i	3.22	2.17	131	6.7	601	545	

8 Clescerl LS, Greenberg AE, and Eaton AD (eds.) Standard Methods for the Examination of Water and Wastewater. 20th Ed. 1998.

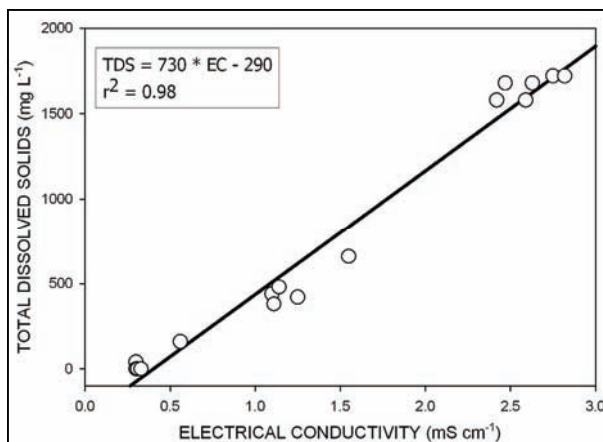


Figure 6. A plot of Total Dissolved Solids (TDS) with Electrical Conductivity (EC) shows their linear relationship.

Sodium (Na) and magnesium (Mg) were the dominant cations in the samples (Table 1). Calcium (Ca), magnesium, and potassium (K) are important for human health. Small amounts of these minerals are added to some imported bottled water to enhance taste. They come from the weathering of rock and soil.

Sodium, too, is an important mineral that also comes from the breakdown of rock and soil. However, excessive sodium in the diet is correlated with high blood pressure, or hypertension, in some individuals.

These four cations, or positively charged ions, are balanced by an equal quantity of negative charge supplied by negatively charged ions, or anions. An earlier, more comprehensive examination of Tutuila Island's ground water, found bicarbonate to be the dominant anion⁹.

A comparison of EC levels (Fig. 5) with the amount of calcium and magnesium, expressed as calcium carbonate equivalent, or CaCO_3 , and sodium reveals that the samples with lowest EC values had little of these cations dissolved in them (Fig. 7). For samples with medium and high EC values, the relationship between EC and cation concentration is more complex.

Samples 6 and 38, for instance, with medium EC values, have about the same level of dissolved cations as samples 7 and 3, with high EC values. They differ, though, in that the two medium EC samples have significantly more sodium cations relative to calcium carbonate equivalent, whereas the two high EC samples have about equal amounts of sodium and calcium carbonate equivalent. This near equal ratio of sodium to calcium carbonate equivalent holds for all six high EC samples. And the predominance of sodium to calcium carbonate equivalent holds for all medium EC

9 Eyre, PR. Ground-Water Quality Reconnaissance, Tutuila, American Samoa, 1989. U.S. Geological Survey. Water-Resources Investigations Report 94-4142. Honolulu, HI. 1994.

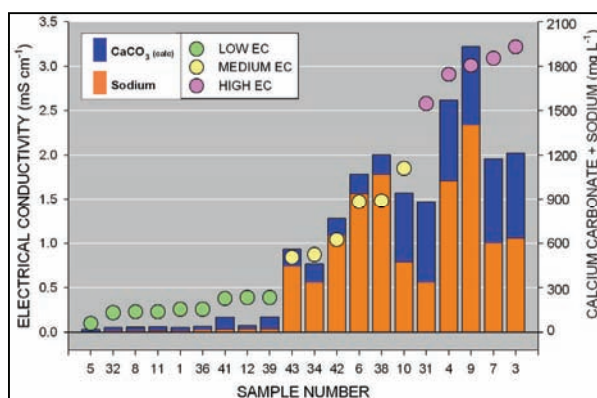


Figure 7. Comparison of EC values to the amount of calcium and magnesium, expressed as calcium carbonate equivalents, and sodium.

samples except for sample number 10. This sample shows a nearly identical sodium to calcium carbonate equivalent ratio as sample number 31, yet the latter sample's EC is significantly greater.

All four cations are also found in seawater. The major ions in seawater are, from greater to lesser concentration in milligrams per liter (mg L^{-1}): chloride, sodium, magnesium, sulfate, calcium, and potassium⁸. The ratios Na:Mg:Ca:K are, approximately, 27:3:1:1. A comparison of the ratio of sodium to magnesium, for all 20 tap water samples and for seawater shows a considerable addition of sodium cations in all the samples of medium EC values, except for sample number 10 (Fig. 8). These unusually high values cannot be accounted for by seawater intrusion alone, unless some unknown mechanism is removing magnesium as, perhaps, by precipitation. But this is unlikely.

For instance, the solubility constants for calcium carbonate and for magnesium carbonate are, respectively, 4.8×10^{-9} and 1.0×10^{-5} . However, the earlier report by Eyre⁹ found only bicarbonate, chloride, and

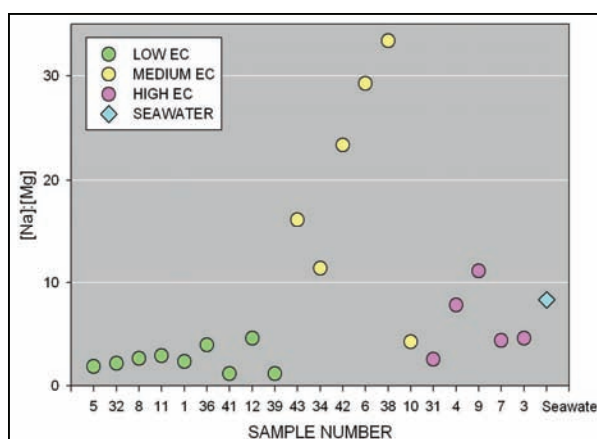


Figure 8. Ratios of sodium to magnesium for the 20 tap water samples. This ratio, i.e., 9:1, is also shown for seawater.



Figure 9. Location of tap water samples taken 20 to 24 AUG 2012 on Tutuila Island, American Samoa. Numbers and colors correspond to the sample numbers and color-codes used elsewhere in this report but the colors are intensified for clarity.

sulfate anions. Calcium and magnesium salts of these anions are soluble. At the pH of ground water, i.e., slightly acidic owing to dissolved carbon dioxide, bicarbonate is the overwhelmingly dominant equilibrium species for aqueous solutions of carbon dioxide. Therefore, the unusually high Na:Mg ratios for the tap water samples of medium EC values must be due to an exogenous source. We speculate that this source is sodium hypochlorite used to disinfect the wells by shock chlorination.

A second anomaly seen in Fig. 8 is the lower-than-seawater ratios of Na:Mg for all tap water samples with low EC values and for 4 of the 5 high EC value samples. If the ratios of Na:Mg for samples with low EC values can be attributed to natural dissolution of soil and rock, then a much greater amount of this same dissolution might be occurring in wells supplying villages along Tutuila Island's south-eastern shore (Fig. 9). Alternatively, seawater intrusion might be taking place in these wells, but a corresponding amount of magnesium must be added to account for a Na:Mg ratio less than that of seawater. A possible source of this magnesium may be olivine, $(Mg,Fe)_2SO_4$, an easily weathered mineral found in basalts such as those forming the Samoan archipelago. Without further evidence, though, this suggested accounting for the lower-than-seawater ratios of Na:Mg in these tap water samples must remain as speculation.

Samples with low EC values were predominantly from Western Tutuila and the north shore of Eastern Tutuila. Samples from three villages bordering Pago Harbor—Fagatogo (38), Pago Pago (11), and Aua (31)—show that their tap waters run the spectrum from low to high EC values. The EC results for tap water sampled in August 2012 were consistent with results obtained from samples collected in April 2012, with two exceptions: In April, Aoloau (34) had a low EC value while Tula (10) had a high EC value. Cation concentrations were not determined on samples collected in April.

The hardness values from Table 1 may be of particular interest to consumers. All water begins as soft water falling as rain with little or not dissolved solids. As an excellent solvent, water dissolves minerals from soil and rock, making it “hard.” The degree of hardness is expressed as calcium carbonate equivalents. (See the equation on p 4.) Water with a hardness value less than 17.1 mg $CaCO_3$ per liter is classified as soft (Table 2). Only one of our samples (No. 5) fell into this classification.

Table 2. A basic water hardness scale. The EPA does not establish standards for hardness in drinking water, since it poses no risk to human health.

Water Hardness Scale	
mg/L	Classification
less than 17.1	Soft
17.1 - 60	Slightly Hard
61 - 120	Moderately Hard
121 - 180	Hard
over 180	Very Hard
http://www.waterhardnessscale.com	

The consequences of hard water for consumers are that soaps and detergents do not suds easily and leave a ring at water level in sinks and tubs. The effectiveness of soaps and detergents is diminished as well. Both the bathtub ring and loss of effectiveness are due to calcium and magnesium binding with the soaps and detergents and precipitating.

Phosphates were often added to laundry detergents in order to bind the calcium and magnesium cations instead of allowing them to bind to the detergent. Since being banned by the EPA in laundry detergents sold in the United States, manufacturers have solved this problem using eco-friendly additives. Ironically, sodium chloride—the “salt” in seawater—can act as a water softener.

Acknowledgements

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