

The Chemical Composition of Hawaiian Rainfall

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Abstract

Measurements of the chemical constitution of rain in the Project Shower area showed that the ammonia and nitrate content is very low, and that the total salt content decreases inland to extremely low values on the upper slopes of the volcanoes.

1. Introduction

During the operation of Project Shower rainwater samples were collected and analysed for various constituents. It was thought that this would add some information relevant to the cloud physics research done by other groups and also that it would shed some light on important geochemical problems, especially on those related to the nitrogen cycle in nature. The work was consequently carried out along three lines, namely:

1. Estimations of the total salt content in rainwater.
2. Determinations of ammonia and nitrate in rainwater.
3. Detailed analyses of some representative rains.

Further, the sampling should be done in such a way as to get variations both in space and time.

2. Technical details

Daily samples of rainwater were collected in pineapple cans used for recording rainfall in the investigation area. These cans were coated inside with a plastic lacquer, which was found to be very resistant, and were thus suitable for the purpose. The position of the cans are seen on the Location Map at the end of this monograph. Only the Saddle Road and Kulani Road cans, which were read

daily, were used for sampling of precipitation. The Kulani Road is gravel and the analyses sometimes showed rather strong influence presumably from dust. The Saddle Road samples are therefore much more reliable, as this road was paved.

Inspection of the cans was made on a routine basis every morning. Normally it took about two hours to complete the inspection along the Saddle Road (inspected in the order 1—25, 76, 78) and about the same time on the Kulani Road (inspected in the order 60—64, 32—44, 88—91, 78). If there had been any precipitation it was measured in a measuring cylinder and transferred to a polyethylene bottle. The sides of the can were rinsed as far as possible, with the rainwater before it was transferred to the polyethylene bottle. If there had been no precipitation the cans were washed with distilled water to prevent any accumulation of settled salt particles in fair weather periods. It was found that the amounts of salts which settled during a 24-hour period were very small, except very near the coast line where they could be quite noticeable.

On some occasions rainwater samples representing short time intervals were collected by means of a so-called rain scoop, which consisted of a stainless steel funnel of 0.5 m² area, equipped with windscreen wipers for rapid drainage along the inside of the funnel. These samples will be referred to as rain scoop

samples and were collected by the Woods Hole group and myself, mainly on places along the Saddle Road.

The analytical work was done at Brewer's Crop Log Laboratory in Onomea, a little village a few miles north of Hilo near the coast. This was a good laboratory. The temperature varied between $+23^{\circ}\text{C}$ and $+27^{\circ}\text{C}$ in the daytime. The rainwater samples were brought there in the morning and when the temperature had reached $+25^{\circ}\text{C}$ (within half a degree) the electrical conductivity was determined on most samples if the volume was great enough. Na was determined by use of a spectrophotometer belonging to the laboratory (Beckman model DU with flame equipment and photomultiplier attachment hydrogen-oxygen flame). In the beginning the pH was estimated by a Beckman pH-meter (model G with glass electrode belonging to the Hawaiian Sugar Planters' Association in Honolulu). Later the pH meter broke down and as it was difficult to get it repaired the pH determinations had to be abandoned.

On some samples ammonia and nitrate were determined. The procedure, which was quite tedious, was as follows. The ammonia was distilled off in an all-glass apparatus and estimated by addition of Nessler's reagent and subsequent measurement of the colour intensity in a balanced photoelectric instrument belonging to the laboratory. In the residue nitrate (and nitrite) was reduced by Devard's alloy to ammonia, distilled off and estimated in the same way as the ammonia nitrogen.

Some samples were concentrated in the laboratory to small volumes and kept in small polyethylene bottles. They were brought back to Stockholm and analysed at the Institute of Meteorology for K, Mg, Ca, Cl and SO_4 .

Glassware for the analytical work and chemicals were provided by the Pineapple Research Institute, Honolulu, and other necessary equipment was provided by the Brewer's Crop Log Laboratory.

The daily samples were collected by Mr. T. Hayashi, of the Pineapple Research Institute who also assisted in the analytical work. I am greatly indebted to him for his careful sampling and reliable assistance in the laboratory.

3. Results

The analytical results together with other appropriate data are given in tables 1—4. The position is indicated by symbols which are found on the Location Map. The amounts of "sea salts" given in tables 1 and 2 have been estimated from the electrical conductivity, using a dilution series of sea water as a standard. The sea water sample used for this was collected about 10 miles off Hilo. The description "sea salt" does not imply that the composition of rainwater is exactly that of appropriately diluted sea water, but is probably the best estimate of the total salt content in these rainwater samples based on a single determination. Whenever Na was determined this is also given in tables 1 and 2. In sea water the amount of sea salts is very close to $3.25 \times \text{Na}$. From tables 1 and 2 the "sea salt" estimated from the electrical conductivity is always equal to or greater than $3.25 \times \text{Na}$ except in some samples with a very low electrolyte content.

Table 1 gives the "sea salt" and Na contents of the daily samples from the Saddle Road and the Kulani Road and table 2 gives the same for the rain scoop samples. Cans of even number on the Saddle Road were not inspected after October 20—21 except on November 2—3. In all other cases in table 1 a blank in the P column means that the can was inspected but that no precipitation had fallen.

Noticeable in table 1 is the very rapid decrease in the salt concentrations inland. On some occasions the rain which fell on the higher slopes was practically distilled water. The general salt level and the rate of decrease of salt inland seem also to vary from day to day.

In table 3 the results of the ammonia and nitrate determinations are shown for some of the daily Saddle Road samples. The low concentrations as well as the uniformity of concentrations inland are remarkable.

Finally table 4 shows the main constituents of some composite daily samples from the Saddle Road and some rain scoop samples from the Club 299. In order to get sufficient volumes for analysis the samples had to be grouped. The distances given as well as the heights above sea level refer to the midpoint in each group. The relative composition when

Table 1 Chemical data on Daily Rainwater Samples from the Saddle Road and the Kulani Road

Can No	Oct. 19—20			Oct. 20—21			Oct. 25—26			Oct. 26—27			Oct. 27—28		
	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l
Saddle Road															
76													16.1	7.4	
78													18.0	6.2	
1	18.2	6.9	1.4	28.7	17.2	4.39	53.8	1.2		24.5	7.9		27.2	2.4	
2	19.6	6.0	1.2	37.5	15.6	3.93									
3	19.8	5.9	1.16	38.2	15.3	3.82	58.6	.7		36.2	4.6		29.4	1.4	
4	19.7	6.0	1.15	37.5	15.1	3.90									
5	20.7	5.2	.84	51.1	13.7	3.29	61.0	.3		39.9	2.5		30.7	1.0	
6	19.0	4.2	.76	52.2	11.6	2.50									
7	18.9	3.4	.62	56.3	11.0	2.41	55.5	.3		31.8	1.8		22.5	.7	
8	18.9	2.5	.52	54.9	10.2	2.15									
9	18.0	2.4	.59	62.1	9.1	1.87	43.0	.0		25.6	1.1		18.5	.4	
10	18.9	1.6	.30	52.9	8.7	1.54									
11	16.1	1.3	.26	47.6	8.0	1.38	32.7	.0		22.9	.6		10.7	.3	
12	14.1	1.2	.24	42.9	6.5	1.03									
13	14.3	1.1	.26	39.9	6.3	.98	26.5	.0		17.3	.1		5.9	.1	
14	11.4	.8	.23	36.4	5.1	.73									
15	10.5	.8	.17	32.6	4.3	.59	22.1	.0		15.9	.0		4.0	.0	
16	8.7	1.7	.16	32.4	3.3	.47									
17	8.3	1.1	.21	26.8	2.9	.44	16.6	.0		11.3	.0		1.1	.0	
18	6.5	.7	.21	24.7	2.9	.41									
19	8.3	.6	.19	28.2	2.2	.36	15.0	.0		9.2	.0		.8	.0	
20	3.9	.5	.21	22.4	1.9	.29									
21	5.3	.5	.18	20.2	2.0	.29	13.4	.0		7.3	.0		1.1		
22	5.0	.7	.18	19.9	2.0	.29									
23	4.3	.8	.16	18.2	2.0	.29	11.7	.4		6.0	.1		.3		
24	2.1	.4	.18	10.3	1.8	.29									
25	4.5	.6	.11	13.9	2.0	.36	10.0	.6		4.6	.2		.3		
Kulani Road															
60							42.6	1.8		17.3	8.0		24.6	5.3	
61							53.9	1.2		20.0	10.2		33.4	3.0	
62							49.8	1.2		21.9	9.1		23.9	2.9	
63	No cans on Kulani Road						39.3	1.6		24.7	7.9		22.2	4.5	
64							31.0	1.5		30.2	6.5		20.5	2.8	
32	in operation until						34.5	1.2		36.6	5.6		21.0	2.3	
34	Oct. 25—26						29.0	1.8		57.7	4.2		23.1	2.3	
36							27.0	.5		44.8	1.8		17.3	.5	
38							27.1	.4		39.4	1.2		14.0	1.2	
40							25.0	.2		27.6	.7		9.8	.0	
42							20.5	.0		21.8	.2		9.5	.1	
44							15.7	.0		16.2	.1		5.2	.2	
88															
89															
90										Cans 88—91 not in operation					
91										until Nov. 6—7					
79															

Table 1 (Cont'd)

Can No	Oct. 28—29			Nov. 2—3			Nov. 6—7			Nov. 7 3 hr. run			Nov. 9—10		
	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l
Saddle Road															
76	.0						39.2	7.2					3.8	16.5	
78	.0						43.1	6.5					3.2	11.1	
1	2.7	15.0	3.85	2.3	26.1	7.2	78.5	.7					11.0	3.4	
2				.6	37.0	11.5									
3	4.4	10.5	2.09	4.3	24.5	7.0	83.9	.3		5.7	6.5		9.9	1.6	
4				8.4	16.6	4.9									
5	4.8	8.7	1.74	8.9	13.1	4.0	86.6	.3		10.9	2.5		10.1	2.7	
6				5.4	10.0	2.9									
7	8.7	5.0	.73	6.4	6.9	1.6	66.2	.2		6.8	1.9		9.6	4.5	
8				6.4	5.1	1.2									
9	6.1	1.6	.28	9.2	2.3	.5	60.6	.1		8.2	.5		6.3	3.3	
10				4.7	2.1	.5									
11	5.5	.7	.15	4.0	1.1	.7	60.6	.6		6.5	.3		6.2	4.0	
12				2.7	2.1	.7									
13	5.3	.1	.10	1.6	2.9	.5	19.1	.0		4.1	.3		5.6	2.0	
14				1.2	2.1	.4									
15	6.8	.0	.10	1.3	4.8	.9	13.2	.0		3.4	1.1		4.1	1.2	
16				.7		.6									
17		.0	.09				9.8	.5		1.9	1.4		3.4	.2	
18	2.5														
19		.3	.06				11.8	.0					3.8	.0	
20	2.7														
21		.0	.08				10.2	.0					2.2	.1	
22	1.6								8						
23	.2		.20				10.6	.1					2.7	.1	
24															
25	.0						7.8	.2					2.6	.3	
Kulani Road															
60	1.7	35.8	8.4	.5		11.1	49.0	3.2		.1			8.7	3.9	
61	4.2	10.8	3.3	2.4	53.5	8.5	56.9			.5			7.7	6.7	
62	4.2	12.2	3.7	4.9	15.4	2.7	50.6	1.6		1.1	10.7		9.2	5.1	
63	2.8	23.3	6.2	.5		10.0	56.0			3.6	9.6		6.5	3.6	
64	3.1	14.4	4.2	.3		13.0	57.5	1.1		9.8	5.0		8.7	3.7	
32	6.5	11.8	3.6	1.5	36.3	11.1	48.5	3.1		8.8	3.4		7.2	6.4	
34	8.2	7.0	1.24	2.7		9.5	52.0	1.9		11.3	2.0		9.0	3.7	
36	6.9	2.3	.57	7.4	9.6	2.6	46.9	.4		8.2	1.2		9.3	2.2	
38	8.2	.5	.27	9.8	3.0	1.0	32.8	.4		5.7	1.2		9.3	2.2	
40	5.2	.3	.13	4.2	1.8	.5	27.5	.1		4.9	1.2		8.5	1.5	
42	7.0	.1	.11	1.1	3.1	.8	17.4	.1		3.6	1.1		7.7	1.2	
44	8.6	.2	.00	.1			9.9	.2		3.5	.3		5.9	.5	
88							24.5	1.2		6.0	1.2		5.7	.1	
89							7.4	.3		4.4	.3		4.9	.3	
90							13.0	1.3					4.8	1.2	
91							3.0								
79															
Remarks										Precipitation up to 1100 hrs. on Nov. 7			Inspection runs begun at 1100 hrs. and 1400 hrs.		

Table 1 (Cont'd)

Can No	Nov. 22—23			Nov. 25—26			Nov. 26—27			Nov. 27—28			Nov. 28—29		
	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l
Saddle Road															
76							¹ 34.1	5.6	1.1	107.7	2.9	.80	97.6	.1	
78				9.7	7.6	2.1				112.5	2.6	.82	108.5	.0	
1				12.6	2.6	.7	4.0	4.4	1.1	56.9	1.2	.38	57.4	.0	
2															
3	.4		10.0	12.7	6.3	1.4	1.4	9.9	3.2	37.0	.8	.31	42.9	.0	
4															
5	.3		15.2	16.8	8.7	2.5	1.3	16.3	4.5	19.8	1.2	.34	31.2	.0	
6															
7	.5		10.1	17.5	3.7	.9				8.0	2.4	.62	27.7	.0	
8															
9	.7		4.9	16.7	3.4	.8				4.5	2.7	.75	28.5	.0	
10															
11	.3		7.9	13.4	1.6	.5				2.1	3.5	1.01	22.2	.0	
12															
13	.5		4.2	9.7	.8	.3				1.0		1.09	18.9	.0	
14															
15				8.1	.4	.1				.9		1.51	21.1	.0	
16															
17				5.0	.2	.1							Missing		
18															
19				5.0	.1	.1							16.2	.0	
20															
21				3.5	.3	.1							13.5	.3	
22															
23				2.9	.3	.2							10.1	.3	
24															
25				.8		1.1							14.0	.4	
Kulani Road															
60							12.5	7.7	1.5	170 +	2.7	.82	170 +	.0	.0
61							20.1	8.2	1.7	170 +	1.8	.64	170 +	.0	.0
62							25.0	6.8	1.8	170 +	1.2	.55	170 +	.0	.0
63							18.3	12.3	3.2	153	1.2	.45	148	.0	.0
64							13.8	8.3	1.8	127	1.2	.41	121.4	.0	.0
32							15.6	13.0	1.8	97.7	1.1	.30	97.1	.0	.0
34							13.7	7.7	1.8	85.8	1.2	.40	80.4	.0	.0
36	2.6		5.2				14.8	6.0	1.7	65.2	.7	.38	73.0	.0	.0
38	.1		10.8				14.9	6.1	1.8	45.6	.7	.29	82.7	.0	.0
40							14.1	2.7	.8	40.2	.8	.31	63.3	.0	.0
42	8.0		6.5				12.0	1.4	.4	33.5	.8	.25	43.7	.0	.0
44							8.4	2.6	.6	32.8	.8	.26	34.0	.0	.0
88							8.4	.8	.3	32.7	.8	.31	26.7	.0	.0
89							6.1	1.5	.4	15.9	.5	.21	26.7	.0	.0
90							3.4	1.6	.4	5.7	.7	.21	26.7	.0	.0
91							3.1	1.5	.3	1.51	.2		17.0	.0	.0
79													4.5		
Remarks															

¹ Includes also Nov. 25—26

Table 1 (Cont'd)

Can No	Nov. 29—30			Nov. 30 2 hr run			Nov. 30—Dec. 1			Dec. 1—2			Dec. 2 2 hr run		
	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l
Saddle Road															
76	3.9	19.7	5.60				16.3	19.5	6.21	22.3	16.5	5.07			
78	4.0	18.2	4.76				13.6	20.4	6.47	22.8	13.1	4.45			
1	10.1	10.1	3.10				20.8	9.9	3.14	35.8	17.1	5.60	tr.		
2															
3	16.4	12.4	3.81				25.8	9.3	2.90	49.4	14.3	4.54	4.1	18.5	6.19
4															
5	16.6	10.3	3.17				15.2	8.3	2.69	74.2	9.3	2.92	18.5	9.8	2.85
6															
7	14.1	8.0	2.15				17.6	10.4	3.17	78.7	7.7	2.11	18.1	2.8	.96
8															
9	14.6	5.7	1.65				18.5	9.9	3.06	70.7	4.4	1.21	8.5	5.1	1.33
10															
11	15.2	5.6	1.55	.2		8.02	18.6	8.9	2.70	67.5	2.3	.71	7.6	2.3	.50
12															
13	9.9	3.8	1.05	.9		3.10	17.8	6.7	1.95	51.6	1.2	.35	4.6	.7	.14
14															
15	12.7	3.5	.96	2.1	4.4	1.20	17.6	5.3	1.45	37.8	.7	.20	3.8	.2	.06
16															
17	2.5	6.9	1.78	2.4	2.4	.71	14.0	3.8	1.00	22.3	.6	.10	2.3	.2	.06
18															
19	4.0	1.4	.40	2.0	1.7	.40	10.7	3.4	.85	20.6	.3	.10	2.2	.0	.05
20															
21	3.6	1.3	.31	.6		.36	5.0	3.5	.90	14.7	.2	.07	2.2	.0	.04
22															
23	4.0	.7	.25	.3		.71	5.1	3.6	1.00	10.3	.3	.06	1.3	.2	.05
24															
25	4.3	2.4	.68	.1		.96	3.2	5.3	1.43		.4	.17	1.1	.3	.10
Kulani Road															
60	15.8	8.4	2.61				16.2	17.4	6.16	16.7	14.8	4.96	tr.		
61	13.6	7.7	2.42				25.0	15.0	4.84	22.6	13.2	4.42	.5		8.04
62	19.6	6.3	1.98				29.4	13.8	4.42	30.7	11.4	3.72	.6		7.55
63	13.6	7.1	2.15	All empty			27.0	11.1	3.58	34.4	12.0	3.97	.3		9.00
64	14.7	7.5	2.20				28.0	11.6	3.66	33.9	12.0	3.89	1.6	22.1	7.31
32	15.8	7.5	2.21				25.9	11.6	3.72	36.2	12.3	4.10	3.8	15.4	5.12
34	13.6	9.0	2.60				24.1	11.5	3.69	38.6	10.9	3.41	3.8	15.4	5.12
36	18.5	6.7	1.95				29.7	8.8	2.34	50.9	6.9	2.26	6.8	9.7	2.94
38	14.7	6.4	1.46				27.2	6.7	1.96	60.8	6.9	2.10	7.0	3.1	1.04
40	13.8	4.6	1.25				26.3	5.7	1.72	59.0	3.7	1.03	5.5	1.3	.40
42	13.5	3.4	1.05				26.6	5.0	1.40	42.9	1.5	.42	3.5	1.0	.32
44	12.0	2.7	.80				17.5	4.4	1.20	27.2	.8	.32	2.4	.2	.14
88	Missing									153.3	1.8	.55	Missing		
89	7.6	1.7	.56							134.0	1.7	.55	2.3	.3	.14
90	4.6	1.2	.40							124.2	1.3	.41			
91	3.8	1.2	.35							126.1	1.2	.31			
79															
Remarks	Precipitation collected once at 0800 and again at 1400, samples combined except No 76 and 78, which represent morning sampling only			Inspection runs begun at 1400 and 1600			Precipitation from 1600 Nov. 30 to 1400 Dec. 1			Precipitation from 1400 Dec. 1 to 1400 Dec. 2			Inspection runs begun at 1400 and 1600		

Table 1 (Cont'd)

Can No	Dec. 2—3			Dec. 3 2 $\frac{1}{2}$ hr run			Dec. 3—4		
	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l	P mm	Salt mg/l	Na mg/l
Saddle Road									
76	45.9	12.3	3.45				tr.		
78	58.4	15.0	2.80				tr.		
1	47.0	5.2	1.42				4.0	12.6	3.69
2									
3	57.8	3.9	.95				4.9	6.8	2.16
4									
5	59.5	3.0	.75	3.0	8.2	2.21	9.0	7.3	1.95
6									
7	67.7	1.7	.43	2.2	4.5	1.10	6.9	5.7	1.50
8									
9	70.9	.7	.17	4.2	1.6	.36	6.5	4.8	1.07
10									
11	54.5	.3	.06	3.3	.3	.07	5.2	2.1	.52
12									
13	40.4	.0	.04	2.3	.2	.10	3.7	.8	.25
14									
15	30.4	.0	.04	2.0	.0	.03	3.4	.2	.07
16									
17	19.8	8.0	.03	1.4	.1	.10	2.0	.8	.16
18									
19	21.5	5.0	.02	1.0		.10	2.8	.2	.09
20									
21	16.8	8.0	.02	.7		.10	1.5	.8	.15
22									
23	13.3	.0	.01	.3		.03	.7		.15
24									
25	10.7	.0	.01				.5		.52
Kulani Road									
60	31.6	9.4	3.00	10.9	5.6	1.29	.3		
61	56.9	7.4	2.10	9.8	4.6	1.20	.1		
62	60.0	6.8	2.95	8.7	5.0	1.40	2.3	15.8	5.01
63	73.1	5.1	1.50	7.1	3.4	.90	3.2	14.8	4.50
64	77.5	3.7	1.25	6.8	2.6	.57	2.7	13.6	3.91
32	80.5	2.8	.84	5.5	1.3	.35	4.6	10.3	2.91
34	84.6	2.4	.72	4.7	.7	.24	6.8	9.0	2.32
36	87.5	.7	.32	2.7	.3	.15	8.4	6.4	1.70
38	75.3	.3	.15	2.1	.3	.10	11.5	3.8	.95
40	63.8	.2	.15	1.6	.3	.10	12.0	1.2	.26
42	49.3	.0	.04	1.4		.06	7.5	.2	.19
44	37.1	.0	.05	.5		.06	3.8	.3	.10
88	34.1	.0	.02	1.3		.11			
89	28.7	.0	.10	1.3	.3	.12			
90	21.7	.0	.07	tr.		.98			
91	17.9	.0	.07						
79	7.5	.0	.06						
Remarks	Precipitation from 1600 Dec. 2 to 1300 Dec. 3			Inspection runs begun at 1300 and 1530			Precipitation from 1530 Dec. 3 to 1530 Dec. 4		

Table 2. Data on Rain Scoop Samples Collected in Hawaii 1954

Hour	Collection Time in Minutes and Seconds	P mm	Salt mg/l	Na mg/l	Hour	Collection Time in Minutes and Seconds	P mm	Salt mg/l	Na mg/l
Oct. 20. Club 299					Oct. 26. Saddle Road, 2,750 ft				
1750	2'	.38	28.0	7.7	1050	4'9"	.072	4.3	.53
1752	2'	.29	28.6	7.8	1130	3'21"	.104	4.9	.80
1801	2'	.05	38.7	10.3	1232	1'53"	.126	2.8	.32
1804	6'	.08	35.7	9.7	1343	3'5"	.036	8.2	
1811	2'	.31	33.3	9.2	1348	2'	.060	6.2	1.08
1815	1'	.26	28.3	7.7	1350	2'5"	.066	8.8	1.82
1816	3'	.18	43.7	11.2	1352	1'45"	.082	7.6	1.31
1819	4'	.18	37.5	11.2	1354	1'25"	.080	5.9	.76
1823	3'	.46	29.7	8.5	1356	1'20"	.080	6.2	.88
1826	12'	.29	33.9	9.8	1357	1'30"	.066	5.2	.77
1838	8'	1.32	18.1	4.9	1358	1'10"	.082	3.3	.48
1846	4'	1.60	15.7	4.3	1359	0'55"	.066	5.0	.58
1850	8'	.60	24.3	6.8	1400	0'55"	.082	4.5	.61
1858	14'	.34	18.1	4.9	1401	0'55"	.080	3.4	.80
1945	11'	1.10	17.3	6.1	1402	0'43"	.096	3.7	.50
Oct. 20. Saddle Road, 2,750 ft					1403	0'45"	.106	3.2	.43
1357	4'	.150	14.8	2.92	1432	2'47"	.090	3.6	.53
1801	2'30"	.204	10.5	1.63	1442	2'13"	.134	2.5	.40
1803	2'	.192	5.7	.63	1459	4'24"	.096	2.7	.36
1806	2'35"	.170	12.3	2.17	1505	4'20"	.104	2.1	.33
1815	2'	.196	9.5	1.49	1522	0'37"	.104	2.9	.41
1817	2'	.178	6.7	.82	1524	0'44"	.110	2.4	.31
1819	2'	.152	3.2	.40	1533	2'22"	.140	2.5	.46
1821	2'15"	.140	3.7	.49	1550	5'4"	.066	6.5	
Oct. 21. Same Place					1637	5'24"	.130	2.7	.43
1649	4'20"	.076	20.0	5.22	Oct 26. Saddle Road, 5,520 ft				
1654	1'20"	.134	13.3	3.32	1523	6'	.052	3.2	.36
1655	1'25"	.150	9.6	2.02	1530	7'	.042	1.5	.16
1657	1'15"	.220	10.0	2.17	1535	5'10"	.034	1.4	.11
1658	0'56"	.224	7.3	1.16	1548	13'	.024		.26
1659	1'20"	.156	8.0	1.33	1559	10'30"	.034	2.0	.23
1701	4'	.112	10.9	2.51	1606	7'	.036	1.9	.10
1707		.066	14.6	3.70	1610	6'	.072	.5	.05
1741	1'20"	.106	9.9	2.10	1612	2'	.076	.6	.08
	0'40"	.206	7.7	1.29	1614	2'	.066	3.6	.41
1744	0'40"	.158	6.3	.87	1617	2'10"	.054	4.9	.54
1745	0'45"	.154	4.3	.56	1619	2'30"	.042	5.2	.57
1746	0'55"	.158	3.3	.51	1622	3'15"	.024		.90
1747	1'	.240	2.5	.37	Nov. 2. Saddle Road, 2,750 ft				
1748	1'30"	.086	3.8	.57	1523	4'	.128	7.5	1.46
1752	0'40"	.284	2.9	.42	1534	4'	.158	7.0	1.46
Oct. 25. Club 299					1545	5'	.164	6.0	1.30
2221	4'	.186	25.2		1608	2'30"	.146	4.5	1.03
2224	3'	.102	8.2		1612	2'	.084	3.5	.75
2228	2'	.400	4.9		1617	2'30"	.114	2.7	.65
2230	2'	.436	4.8		1622	4'	.078	4.6	1.06
2232	2'	.600	1.8		1632	4'	.058	5.8	1.40
2234	2'	.520	.7		1657	5'	.084	8.6	2.38
2236	2'	.200	1.0		1709	7'	.096	9.4	2.46
2238	10'	.090	3.0		1718	4'	.084	6.8	1.96
					1724	4'	.094	6.0	1.50
					1730	5'	.084	5.0	1.39
					1747	13'	.124	5.6	1.40
					1755	8'	.118	3.3	.81

Table 2 (Cont'd)

Hour	Collection Time in Minutes and Seconds	P mm	Salt mg/l	Na mg/l	Hour	Collection Time in Minutes and Seconds	P mm	Salt mg/l	Na mg/l
Nov. 2. Saddle Road, 4,500 ft					1320	3'	1.060	1.5	.20
1553	2'30"	.040		1.26	1323	3'	1.800	1.2	.14
1556	1'30"	.050		.39	1325	2'	.660	.9	.16
1558	1'30"	.066		.26	1328	3'	.300	2.3	.30
1600	1'30"	.044		.26	1331	3'	.270	3.3	.42
1601	1'30"	.028		1.08	1334	3'	.500	.2	
1603	2'	.022		1.23	1336	2'	.800	1.3	.20
1606	3'	.016		.88	1340	4'	1.320	1.3	.20
1613	6'	.008		3.14	1345	5'	1.100	1.2	.37
1617	4'	.016		1.66	1350	5'	.320	4.2	.68
1630	6'	.018		.50	1357	7'	.260	7.3	1.42
1636	7'	.024		.31	1400	3'	.060		
1647	11'	.014		.30	1417	9'	.220	6.3	1.36
1700	14'	.008		.39	1435	6'	.160	5.8	1.06
1727	4'	.016		.27	1450	6'	.140	6.0	1.03
1730	3'	.016		.21	1500	10'	.006		
1736	5'	.012		.18	Nov. 7. Saddle Road, 3,500 ft				
1742	5'	.016		.14	1135	0'52"	.176	2.6	.27
1748	6'	.024		.13	1153	2'6"	.266	2.0	.25
Nov. 6. Saddle Road, 2,000 ft					1155	0'43"	.118	1.8	.20
1630	22'				1200	0'44"	.300	1.0	.11
1643	11'	.012		.17	1208	1'12"	.060	1.9	.21
1706	13'				1216	0'57"	.096	2.5	.31
1715	4'	.012		.10	1320	1'18"	.060	3.2	.47
1720	5'	.020		.12	1322	0'57"	.068	1.8	.25
1731	11'	.010		.06	1327	1'1"	.098	.3	.07
1736	5'	.016		.16	1329	1'15"	.094	.5	.07
1742	6'	.020		.08	1337	0'51"	.154	.1	.07
1746	4'	.024		.09	1346	2'	.032		.21
1751	5'	.046		.08	1359	1'18"	.132	1.0	.15
1757	6'	.020		.04	1402	1'3"	.118	1.2	.15
Nov. 7. Saddle Road, 2,000 ft					1410	1'3"	.078	2.3	.30
1037	4'	.320	3.4	.57	1421	1'1"	.132	2.2	.30
1044	6'	.040	6.1	1.00	1425	0'45"	.124	2.3	.30
1052	4'	.250	4.0	.55	1436	1'	.064	1.2	.20
1057	4'	.020			1438	1'10"	.052	2.0	.25
1154	7'	.006		4.54	1541	8'	.016		2.16
1158	4'	.110	7.2	1.27	Nov. 30. Saddle Road, 2,000 ft				
1200	2'	.040	7.8	1.08	1747	1'15"		17.5	4.73
1202	2'	.110	4.9	.87	1748	2'		18.5	5.20
1204	2'	.006			1751	1'10"		12.3	3.35
1238	2'	.064	14.9	3.09	1753	1'15"		6.8	1.80
1242	4'	.060	9.9	2.34	1754	1'25"		6.8	1.70
1243	1'	.150	4.5	.70	1756	2'		11.0	3.97
1247	4'	.040	10.0	1.87	1758	2'25"		10.0	2.71
1251	4'	.008			1800	1'25"		6.7	1.80
1301	3'	.060	11.9	2.90	1802	1'40"		9.4	2.71
1304	3'	.150	8.1	1.84	1804	2'20"		15.4	4.60
1306	2'	.190	5.7	1.05	1806	2'10"		19.7	6.05
1309	3'	.050	7.3	1.39	1809	3'10"			13.4
1312	3'	.500	3.8	.60	1812				
1314	2'	.540	3.4	.51	1815	5'			18.80
1315	1'	.270			1818	5'20"			22.40
1316	1'	.060							
1317	1'	.310	1.9	.27					

Table 2 (Cont'd)

Hour	Collection Time in Minutes and Seconds	P mm	Salt mg/l	Na mg/l	Hour	Collection Time in Minutes and Seconds	P mm	Salt mg/l	Na mg/l
Dec. 2. Saddle Road, 2,000 ft					1652	1'10"	.066	10.9	2.65
1455	0'47"	.268	20.7	6.56	1654	1'10"	.078	9.4	2.50
1544	3'17"	.064	34.4	10.44	1657	1'35"	.052	11.9	3.29
1546	1'17"	.550	8.4	2.38	1659	2'55"	.050	11.4	3.49
1548	0'57"	.126	11.0	3.50	1702	0'35"	.230	6.8	1.81
1550	0'25"	.404	6.6	1.80	1703	0'26"	.278	(30.6)	.40
1552	0'25"	.410	5.5	1.47	1704	0'25"	.410	1.2	.31
1555	1'38"	.194	14.2	4.23	1705	0'40"	.446	1.2	.25
1557		.070	19.7	6.11	1706	0'30"	.348	.7	.16
1601	2'	.050	36.8	10.17	1715	0'55"	.074	5.1	1.10
1609	5'52"	.010	n.d.	n.d.	1717	1'	.084	5.0	1.10
1644	1'6"	.184	19.6	6.19			.288	2.7	.64
1647	1'27"	.104	13.8	4.19	Dec. 3. Saddle Road, 2,000 ft				
1649	1'34"	.120	13.6	4.18	1516	2'34"	.084	14.2	3.45
1654	3'43"	.048	21.3	6.43	1520	2'	.128	9.5	2.16
1702	0'47"	.340	13.2	4.10	1525	4'	.076	13.7	3.09
1704	0'50"	.156	10.0	2.93	1530	3'30"	.068	15.4	4.23
1708	2'32"	.026		7.19	1540	3'	.112	12.2	3.01
1714	3'6"	.060	22.8	6.66	1543	2'10"	.144	8.4	2.02
1722	2'3"	.150	7.4	1.96	1546	1'	.328	3.9	.90
1729	3'	.040	14.2	3.20	1550	2'	.396	4.6	1.00
Dec. 2. Saddle Road, Can 13 position					1553	2'	.356	1.8	.22
0918	1'8"	.066	3.7	.68	1602	2'	.072	2.3	.36
0920	0'46"	.046	3.8	.51	1607	7'20"	.080	4.3	.56
0922	1'33"	.070	2.7	.51	1618	3'	.148	4.0	.70
0924	1'46"	.092	2.7	.55	1627	3'	.130	2.3	.25
0926	0'57"	.130	1.6	.30	1640	6'30"	.062	6.8	1.04
0928	1'23"	.134	1.2	.19	1657	4'	.122	11.1	3.00
0930	1'18"	.104	1.8	.31	Dec. 3. Saddle Road, 2,750 ft				
Dec. 2. Saddle Road, 2,750 ft (a.m.)					1442	2'14"	.040		1.38
0955	1'16"	.090	14.2	4.31	1445	1'32"	.086	5.0	1.10
0957	1'9"	.176	6.6	1.52	1448	2'	.064	4.6	.90
0958	0'42"	.120	4.4	1.05	1450	1'15"	.062	2.2	.40
1001	0'53"	.100	3.4	.78	1451	0'52"	.094	2.2	.56
1002	0'29"	.228	2.2	.54	1457	0'47"	.088	2.7	.51
1004	1'37"	.240	2.1	.45	1459	1'17"	.040		.71
1006	0'63"	.074	1.8	.60	1503	2'13"	.096	5.0	.99
Dec. 2. Saddle Road, 2,750 ft (p.m.)					1507	2'6"	.048	5.0	1.22
1516	1'57"	.068	29.9	8.99	1621	6'54"	.044		1.70
1518	1'35"	.068	23.7	7.10	1636	4'57"	.038		3.31
1522	2'24"	.032	29.6	8.74	1639	1'19"	.064	6.3	1.51
1527	4'30"	.044	32.4	10.00	1642	1'33"	.062	2.7	.59
1537	1'1"	.064	22.7	6.55	1644	1'37"	.070	1.4	.35
1634	1'30"	.110	12.1	3.55	1648	2'26"	.086	1.1	.18
1636	0'40"	.126	11.0	2.80	1651	2'15"	.094	1.4	.41
1650	0'30"	.110	9.7	2.40	1653	1'57"	.072	2.2	.42
					1656	1'54"	.062	1.8	.52
					1659	2'52"	.058	2.2	.49

Table 3. Ammonia and Nitrate Nitrogen concentrations in Hawaiian Rainfall.
Concentrations in micrograms per litre; precipitation (P) in mm.

Can No.	Oct. 19—20			Oct. 20—21			Oct. 26—27			Oct. 27—28			Oct. 28—29			Nov. 2—3			Nov. 7 1100—1400		
	P	H ₃ N— —N	NO ₃ — —N	P	H ₃ N— —N	NO ₃ — —N	P	H ₃ N— —N	NO ₃ — —N	P	H ₃ N— —N	NO ₃ — —N	P	H ₃ N— —N	NO ₃ — —N	P	H ₃ N— —N	NO ₃ — —N	P	H ₃ N— —N	NO ₃ — —N
76	18.2	60	5	24.5	18	18	16.1	36	18	16.1	36	18	2.3	52	57						
78	19.6	62	2	36.2	37.5	76	18.0	28	<14	27.2	22	<14	4.4	46	46	2.7					
1	19.8	63	3	37.5	37.5		29.4						4.4	46	46	4.4	2.7				
2	19.7	62	5	39.9	18	<14	30.7	18	<14	4.8			4.4	46	46	4.4	2.7				
3	20.7	62	4	31.8	18	<14	22.5			8.7	38	32	4.8	46	46	4.4	2.7				
4	19.0	60	3	54.9	18	<14	18.5	18	<14	6.1			8.7	38	32	4.4	2.7				
5	18.9	58	1	25.6	18	<14	10.7	18	<14	5.5	42	32	6.1	46	46	4.4	2.7				
6	18.0	58	2	22.9	16	<14	5.9			5.3	34	28	6.1	46	46	4.4	2.7				
7	18.9	58	1	17.3	16	<14	4.0			6.8			6.8	37	37	3.4	3.4				
8	18.0	58	2	15.9	16	<14	32.4			2.5	38	30	2.5	38	30	2.5	38				
9	18.9	60	2	11.3	18	<14	26.8			2.7			2.7	20	20	1.6	1.6				
10	16.1	60	2	24.7	18	<14	28.2			1.6			1.6	20	20	1.6	1.6				
11	14.1	64	3	22.4	16	<14	20.2			1.6			1.6	20	20	1.6	1.6				
12	14.3	62	4	20.2	16	<14	19.9			1.6			1.6	20	20	1.6	1.6				
13	11.4	56	3	7.3	16	<14	18.2			1.6			1.6	20	20	1.6	1.6				
14	10.5	76	6	6.0	16	<14	10.3			1.6			1.6	20	20	1.6	1.6				
15	8.7	76	6	4.6	16	<14	13.9			1.6			1.6	20	20	1.6	1.6				
16	8.3	66	3	26.8	18	<14	26.8			1.6			1.6	20	20	1.6	1.6				
17	6.5	66	3	24.7	18	<14	28.2			1.6			1.6	20	20	1.6	1.6				
18	8.3	62	3	22.4	16	<14	20.2			1.6			1.6	20	20	1.6	1.6				
19	3.9	62	3	19.9	16	<14	18.2			1.6			1.6	20	20	1.6	1.6				
20	5.3	66	3	18.2	16	<14	10.3			1.6			1.6	20	20	1.6	1.6				
21	4.3	66	3	13.9	16	<14	13.9			1.6			1.6	20	20	1.6	1.6				
22	2.1	66	3	10.3	16	<14	10.3			1.6			1.6	20	20	1.6	1.6				
23	4.5	66	3	13.9	16	<14	13.9			1.6			1.6	20	20	1.6	1.6				
24	4.5	66	3	13.9	16	<14	13.9			1.6			1.6	20	20	1.6	1.6				
25	4.5	66	3	13.9	16	<14	13.9			1.6			1.6	20	20	1.6	1.6				

Table 4. Chemical composition of Hawaiian rains.

Height above sea level in feet	Distance from sea in km	Prec. in mm	mg. l ⁻¹								pH	Remarks
			Na	K	Mg	Ca	H ₂ N— —N	NO ₃ — —N	Cl	SO ₄ — —S		
1325	6.3	18.9	1.28	.10	.41	.41	.06	< .01	2.43	.29	5.2	Saddle Road samples Oct. 19— Oct. 20. Heights and distances averages of several.
1725	8.1	19.8	1.16	.09	.34	.35	.06	< .01	2.03	.26	5.2	
2100	9.7	19.8	.80	.10	.35	.30	.06	< .01	1.61	.20	5.2	
2700	12.4	18.6	.58	.06	.23	.15	.06	< .01	1.12	.21	5.4	
3680	15.9	15.9	.27	.05	.21	.12	.06	< .01	.53	.11	5.5	
5550	29.3	6.6	.19	.04	.15	.18	.06	< .01	.28	.08	5.7	
30	1.0		5.46	.37	.92	.47	.08	.05	9.63	.64	4.8	Saddle Road and Club 299 samples Oct. 20—Oct. 21. Heights and dis- tances averages of several.
1620	7.6		3.80	.19	.87	.67	.08	.05	6.87	.53	4.9	
2630	12.3		2.09	.14	.51	.44	.07	.05	4.62	.29	4.9	
4080	19.4		.98	.09	.60	.49	.07	.02	2.49	.27	5.0	
5330	25.8		.40	.06	.41	.27	.06	< .01	1.12	.10	5.2	
Hour	Sampl. time											
1752	2'	.38	7.7	1.21	2.22	2.64	.07	.07	13.9	.88	6.3	Samples taken at Club 299 (a) general sample for the whole period (b) precipita- tion the following night.
1813	2'	.31	9.2	1.26	2.12	1.13	.11	.09	15.5	1.00	6.3	
1826	3'	.46	8.5	.99	1.93	.88	.11	.05	15.0	.85	5.7	
1838	12'	.29	9.8	.86	3.04	2.08	.11	.05	16.8	1.26	5.4	
1846	8'	1.32	4.9	.64	1.37	1.49	.10	.00	8.9	.65	5.1	
1850	4'	1.60	4.3	.24	.79	1.10	.08	.00	5.2	.23	5.1	
1858	8'	.60	6.8	.62	1.64	.76	.10	.05	12.0	.98	5.1	
1956	11'	.34	4.9	.44	1.16	.42	.08	.05	8.0	.67	5.1	
(a)		7.44	6.3	.40	.94	.36	.08	.05	10.7	.69	4.8	
(b)		2.00	2.9	.24	.83	.87	.08	.05	5.7	.46	5.2	

compared to sea water using Na as a reference differs from sea water significantly. Generally there is an excess of Ca, Mg, K, SO₄ and sometimes Cl, apart from ammonia and nitrate. Further the pH is lower than would be expected by mere dilution of sea water. It can also be shown that on an equivalent

basis there are more cations than anions. This means that there must be some unknown anions present in noticeable concentration. Except for ammonia and nitrate which are very low, the Hawaiian rainwater does not differ basically from rainwater collected near the Swedish west coast.