

Precipitation and Fog Sulfate Concentrations
on Robinson Crusoe Island, Chile

by

Pilar Cereceda¹ and Robert S. Schemenauer²

1. Geography Institute
Catholic University of Chile
Casilla 306, Correo 22
Santiago, Chile
2. Environment Canada
4905 Dufferin Street
Downsview, Ontario
Canada M3H 5T4

Report SC94-02 Prepared for
The World Meteorological Organization
Geneva, Switzerland

28 March 1994

Summary

This brief report summarizes measurements of fog and precipitation sulfate concentrations made on Robinson Crusoe Island, which is located in the Juan Fernandez Archipelago off the coast of Chile, and is provided in recognition of WMO's support for the field work. The samples were collected in August 1993 and October 1993. The sulfate concentrations are compared to those for rain in the urban area of Santiago, Chile, to fog chemistry on the coast of Chile, to precipitation chemistry measured on Amsterdam Island in the southern Indian Ocean, and to precipitation chemistry measured on Bermuda in the North Atlantic.

The work was a joint project of the Catholic University of Chile and Environment Canada, with support from WMO. Total funding for the field work in 1993 was approximately \$6000 US.

The samples collected with the fog sampler on Robinson Crusoe Island (RCI) were too few in number (3) to analyze and also contained some drizzle; therefore, the initial discussion will be limited to the precipitation samples. The mean H^+ concentration in the 16 drizzle and rain samples was $3.49 \mu\text{eq L}^{-1}$, which is a pH of 5.5. This is very close to the theoretical value for water in equilibrium with atmospheric CO_2 (5.6). The mean SO_4^- concentration for these samples was 1.11 ± 0.79 ppm as compared to 13.2 ± 11.9 ppm for five samples collected in Santiago, Chile. The mean percent of excess sulfate in the RCI precipitation samples was 34.3% and in the Santiago city samples 95.9%. A pH value of 5.45 has been reported for Amsterdam Island in the southern Indian Ocean for precipitation. Non sea salt SO_4^- concentrations on Amsterdam Island were 0.1 ppm as compared to 0.34 ppm on RCI. Sulfate concentrations in coastal fog in north central Chile have averaged 9.12 ± 9.96 ppm, of which 89% or 8.12 ppm is excess SO_4^- . In addition, pH values as low as 3.46 have been reported in the coastal fog.

The mean SO_4^- concentrations in precipitation on Robinson Crusoe Island are about an order of magnitude lower than in fog on the Chilean coast and in precipitation in the Chilean capital of Santiago. The RCI samples also have a much lower percentage of excess sulfate. This limited sample set supports the idea that the island is indeed a 'remote' location free of major anthropogenic influences. It also supports the hypothesis that the Humboldt Current, which flows between the island and the mainland, may be a biological source region for the SO_4^- measured in the downwind continental fog and precipitation.

Project Title: The Role of Oceanic Emissions of Sulfur on Fog and Cloud Water Chemistry

Location: Coastal Chile (29° 26'S; 71° 15'W) and Robinson Crusoe Island, Chile (33° 37'S; 78° 52'W)

Scientists: Dr. Robert S. Schemenauer
Cloud Physics Research Division
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario, Canada M3H 5T4
Tel. (416) 739-4606 Fax (416) 739-4211

Professor Pilar Cereceda
Instituto de Geografía
Pontificia Universidad Católica de Chile
Casilla 114-D
Santiago, Chile
Tel. (56-2) 5522375 ext.4725 Fax (56-2) 5526028

Background

Extensive decks of marine stratocumulus clouds cover the Pacific Ocean to the west of the coasts of Chile, Peru and Ecuador. These clouds flow up against, and over, the coastal mountains resulting in high elevation areas with very frequent fog cover. A project began in 1987, with the support of IDRC Canada, to study the formation mechanisms of the fogs, their spatial distribution and microphysical properties, and means by which the fog could be used as a managed water supply (Schemenauer and Cereceda, 1991; Cereceda, Schemenauer and Suit, 1992). A coastal village is now receiving an average of more than 11,000 L a day of fog water, which meets the total domestic demand. Fog water is also now being used for reforestation projects in the arid coastal regions of

Chile and Peru, and evaluation projects have begun in Ecuador. An understanding of fog frequency and deposition rates to forests is also valuable in more southerly latitudes where this may be a major source of water for coastal forests. The highest low elevation fog frequencies in Chile are in fact between latitudes 35°S and 40°S (Cereceda and Schemenauer, 1991).

As part of this work, the fog water chemistry has been monitored at the arid coastal field site (780 m) since 1987. Samples were collected with Teflon string collectors that have been extensively used for this purpose in North America. The data (Schemenauer and Cereceda, 1992a) show frequent pH values below 4.0 and high concentrations of excess sulfate. In this remote area, with winds off the ocean, a possible source of the sulfur is emissions from the biologically rich Humboldt Current. In 1992 a small project was carried out on Robinson Crusoe Island (RCI), 670 km west of the Chilean coast, to study for the first time the precipitation distribution on the island and the relative importance of precipitation and fog to the cloud forests on the volcanic peaks in the center of the island. This resulted in a thesis by Hugo Zunino, supervised by Professor Pilar Cereceda, in the Geography Institute of the Pontifical Catholic University of Chile in Santiago. A description of the island's potential as a future remote atmospheric chemistry site was prepared for the World Meteorological Organization (WMO) (Schemenauer and Cereceda, 1992b). The island is of particular interest for the present

proposal since it lies on the west side (upwind) of the Humboldt Current.

Funding for the work on RCI in 1992 consisted of about \$2700 US from Environment Canada and \$750 US (SFR 1300) from WMO, for a total of \$3450 US.

1993 Field Program

The objective of this project was to perform a simple test of the role that emissions from the Humboldt Current may play in the sulfate concentrations in the marine stratocumulus deck.

The flow around the stable anticyclone in the eastern Pacific Ocean results in a southwest flow at low levels that passes over Robinson Crusoe Island, the Humboldt Current, and finally the coastal mountains of Chile. If emissions of DMS, or other sulfur compounds, from the bioplankton or zooplankton in the Humboldt Current are significant, one would expect to see a substantial difference in fog water $\text{SO}_4^{=}$ concentrations at the two sites and smaller differences in concentrations of other ionic species.

Funding for the work on RCI in 1993 consisted of about \$5000 US from Environment Canada and \$1000 US (SFR 1500) from WMO, for a total of \$6000 US.

Procedure

It was proposed to sample cloud/fog water, and precipitation, for a three week period, during July or August, 1993, on both RCI and the coast of Chile, at altitudes of 500 to 800 m. Existing instrumentation and protocols developed in the Canadian CHEF project were used. The samples obtained were analyzed for major ions at a laboratory in Montreal, Canada that has done thousands of fog water analyses.

Results

The results of the 1993 field sampling program are summarized in Table 1. For simplicity, only the SO_4^- concentrations and the pH values will be shown and discussed. One sample (#628) collected in the fog sampler was not kept in the data set since it was obtained during a period of very high winds and drizzle. Three precipitation samples (#638, 647, and 648) were removed from the data set because the collector was exposed for a two day period and there is a possibility of contamination by dry deposition. The data set collected on RCI then consists of: two samples from the fog collector, which are a mixture of fog and precipitation; and 16 samples from the precipitation collector. In addition, there are five precipitation samples collected from the city of Santiago on the mainland. No fog samples were collected during the corresponding period on the continental coastline despite

considerable effort. The period was unusually dry. Therefore, despite the desire to compare fog chemistry in the two locations, this initial comparison will be made with the precipitation data.

The sampling locations in Table 1 are: Selkirk, on a central ridgeline at 580 m; Villagra, to the southwest of Selkirk at 440 m; Punta, further to the southwest at 110 m; and Pangal, to the northeast of Selkirk, near the coastline at 25 m. Santiago is on the continent and about 60 km inland, at an elevation of 600 m, and separated from the coastline by a mountain range rising to 2000 m.

Precipitation samples were collected in high density polyethylene bags designed for precipitation sampling and used in the CHEF project (Schemenauer, 1986) in Canada. The mean SO_4^- concentration in field blanks taken from the bags was below the instrument detection limit of $1.0 \mu\text{eq L}^{-1}$ (0.05 ppm).

SO_4^- Concentrations

The mean SO_4^- concentration in precipitation ($n = 16$) on RCI was 1.11 ± 0.79 ppm ($23.1 \mu\text{eq L}^{-1}$). The two mixed fog and drizzle samples collected in the fog collector had a similar mean SO_4^- concentration, 1.26 ppm. Precipitation in Santiago ($n = 5$) had a mean SO_4^- concentration of 13.2 ± 11.9 ppm, with the concentration being inversely related to the amount of precipitation.

In comparison, the mean $\text{SO}_4^{=}$ concentration for coastal fog samples collected on the north-central coast of Chile (Schemenauer and Cereceda, 1992a) was 9.12 ± 9.96 ppm. The comparable value for fog on the coast of Oman (Schemenauer and Cereceda, 1992b), on the Arabian Peninsula, was 3.4 ppm. In North America, values (Schemenauer and Cereceda, 1992c) for mountain fog range from 52 ppm in North Carolina, to 12.5 ppm in New York, to 10.9 ppm in southern Quebec. On Amsterdam Island in the southern Indian Ocean ($37^{\circ}50'S$, $77^{\circ}30'E$), mean precipitation $\text{SO}_4^{=}$ values (Galloway and Gaudry, 1984) are 2.16 ± 1.62 ppm ($45.0 \mu\text{eq L}^{-1}$), and on Bermuda (Galloway et al., 1989) 1.35 ppm.

The mean $\text{SO}_4^{=}$ concentration in precipitation on RCI is an order of magnitude lower than for fog and precipitation samples collected on the Chilean mainland. The concentrations are also one to two orders of magnitude below values for high elevation fog in eastern North America. They are, however, similar or slightly lower than values for fog in Oman and for precipitation on Amsterdam Island.

Excess Sulfate

Excess sulfate is the portion of the measured value that cannot be attributed to a direct sea water source, i.e. that does not result from sea spray and the aerosol particles produced by the sea spray.

The percentage of excess sulfate in the RCI precipitation samples was $34.3 \pm 15.4\%$. By contrast, in the Santiago precipitation samples, it was $95.9 \pm 5.1\%$. It was similarly high, 89%, in the coastal fog samples (Schemenauer and Cereceda, 1992a). This argues for other sources for the sulfate on the mainland. The hypothesis is that it is oceanic production of sulfur in the Humboldt Current in the case of the fog samples at the remote coastal location. In Santiago both the Humboldt Current and antropogenic sources may play a role. On RCI, about one-third of the SO_4^- ($7.08 \mu\text{eq L}^{-1}$) may result from biological sulfur production and long range transport of pollutants. The comparable value on Amsterdam Island (Nguyen et al., 1992) was $2.07 \mu\text{eq L}^{-1}$, and on Bermuda (Galloway et al., 1989) $8.5 \mu\text{eq L}^{-1}$ when the source region was in the SE sector.

pH Values

The mean H^+ concentration in precipitation on RCI was $3.49 \mu\text{eq L}^{-1}$, which is a pH of 5.46. Galloway and Gaudry (1984) reported a value of 4.91 for Amsterdam Island and Nguyen et al. (1992) a value of 5.45, for the years 1984 and 1987-89, for the same location. The pH of precipitation on Bermuda (Galloway et al., 1989) is somewhat more acidic with a value of 4.86.

Correlation Coefficients and Enrichment Factors

Table 2 gives the mean correlation coefficients, for SO_4^- and the major ions, in precipitation on RCI and in Santiago. On the island, the presence of SO_4^- is strongly correlated with the presence of other ions found in significant quantities in sea water, Cl^- (0.99), Na^+ (0.99), and Mg^{++} (0.99), and to a lesser degree with Ca^{++} (0.87) and K^+ (0.66). The lowest correlations are found with the nitrogen species NH_4^+ (0.53) and NO_3^- (0.34), which are present in very low concentrations in sea water. On the continent, in Santiago, the situation is considerably modified. The correlations between SO_4^- and Cl^- (0.86), Na^+ (0.90) and Mg^{++} (0.97) are still strong, and Ca^{++} (0.79) is of similar importance, but the correlation with K^+ (0.92) is now much stronger as is the correlation with NO_3^- (0.86). In fact, in precipitation in Santiago, the presence of SO_4^- is well correlated with all the ions except for NH_4^+ (-0.37).

Table 3a presents the enrichment factor calculations for precipitation on RCI using Cl^- as the sea water tracer. The sea water values are from Kennish (1989). Na^+ (97%), Mg^{++} (97%) and K^+ (90%) are dominated by sea salt contributions. About 43% of the Ca^{++} and 37% of the SO_4^- , however, have a non sea salt (nss) origin. In Table 3b the possible contributions of soil (crustal) sources are calculated assuming Al is present in the precipitation in the amount seen in coastal fog in Chile (Schemenauer and Cereceda,

1992a) and using the crustal values from the CRC Handbook (1990). This calculation shows that the earth's crust is unlikely to be a significant source for the major ions and that about 40% of the Ca^{++} and SO_4^- are not derived from sea salt or crustal sources on RCI.

Table 4 presents an enrichment factor calculation for the precipitation in Santiago. All of the ions, for which calculations can be done, show a strong nss component. The sea salt contributions for Na^+ (59%), Mg^{++} (24%) and K^+ (23%) are much lower than for precipitation on RCI. Fully 99% of the Ca^{++} and 97% of the SO_4^- is of nss origin. As might have been hypothesized, this large city, 60 km inland, is receiving essentially all of its SO_4^- from sources other than sea salt.

Discussion

Concentrations of major ions have been measured in precipitation samples collected on Robinson Crusoe Island (RCI) and in Santiago, Chile. These are the first precipitation chemistry measurements from these locations that the authors are aware of. A brief comparison of sulfate and pH values on RCI, with those from Amsterdam Island in the southern Indian Ocean, and Bermuda in the north Atlantic Ocean, shows that, by these limited criteria, RCI would qualify as a remote location free of local sources of pollutants and relatively free of the effects of long range transport of pollutants. The RCI SO_4^- concentrations are lower than

the mean values in the literature for the other islands mentioned above. RCI is 670 km west of the coast of Chile and experiences predominant winds from the south to west quadrant, associated with the circulation around the subtropical anticyclone whose center lies to the north.

The mean H^+ concentration on the island was $3.49 \mu\text{eq L}^{-1}$ (pH = 5.46) for 16 samples collected in August (13) and October (3) 1993. The mean H^+ concentration for five precipitation samples collected in Santiago in August (2), October (2) and November (1) 1993 was $1.57 \mu\text{eq L}^{-1}$ (pH = 5.81). The RCI precipitation samples had a mean SO_4^- concentration of 1.11 ppm compared to a mean of 13.2 ppm in Santiago and a mean of 9.1 ppm for Chilean coastal, high elevation fog samples collected previously. These later values, of about 10 ppm, are similar to those reported in the literature for high elevation fog in southern Quebec and northern New York, both locations where anthropogenic sources of SO_4^- are dominant.

The hypothesis that the biologically rich Humboldt Current, which flows between RCI and the mainland, is a source of sulfur is supported by the preliminary study reported here. Background concentrations of SO_4^- are seen in precipitation samples from the island. The order of magnitude higher concentrations seen in the coastal high elevation fog samples are very unlikely to be due to anthropogenic sources in the remote sampling location with winds

off the ocean. The city of Santiago's high SO_4^- concentrations may be due to both anthropogenic and marine sources. The percentage of excess SO_4^- in the RCI precipitation samples was 34%, whereas in the Santiago precipitation samples it was 96% and in the coastal fog samples it was 89%. It is likely that the excess SO_4^- found in the RCI samples had an origin in emissions of sulfur compounds from the ocean rather than in long range transport of anthropogenic emissions but this cannot be confirmed with the present data set.

It was hoped at the initiation of the study that high elevation fog samples, obtained from marine cloud decks advecting over the mountains, could be obtained over a common period on both RCI and the Chilean coastline. This proved impossible with the resources available. The samples collected on RCI with the fog collector were a mixture of both fog and precipitation, with the chemical characteristics of precipitation. Samples were not collected on the mainland, despite considerable effort, due to the relative lack of fog during the August 1993 period and due to the inability to have observers in the field for extended periods of time. It is hoped that in 1994 the experiment can be repeated and that a more extensive set of winter precipitation samples can be obtained in Santiago for comparison purposes.

Acknowledgements

The authors would like to express their sincere thanks to Pablo Osses and Alvaro Monet for their efforts in the collection of the precipitation samples on Robinson Crusoe Island. Our thanks also go to Mauricio Calderone and the staff of CONAF, on the island, for logistical support and to the World Meteorological Organization (WMO) for financial support. We would like to thank Natty Urquizo for sample management and Richard Tanabe for the enrichment factor calculations. The laboratory analyses were carried out by Laboratoire Savoie-Dufresne in Montreal.

References

- Cereceda, P. and R.S. Schemenauer, 1991: The occurrence of fog in Chile. J. Appl. Meteor., 30, 1097-1105.
- Cereceda, P., R.S. Schemenauer and M. Suit, 1992: An alternative water supply for Chilean coastal desert villages. Intl. J. Water Resources Development, 8, 53-59.
- Galloway, J.N. and A. Gaudry, 1984: The composition of precipitation on Amsterdam Island, Indian Ocean. Atmos. Environ., 18, 2649-2656.

- , W.C. Keene, J.M. Miller, T.M. Church, and A.H. Knap, 1989: Processes controlling the concentrations of SO_4^{2-} , NO_3^- , NH_4^+ , H^+ , HCOO_T and CH_3COO_T in precipitation on Bermuda. Tellus, 41B, 427-443.

Schemenauer, 1986: Acidic deposition to forests: the 1985 Chemistry of High Elevation Fog (CHEF) project. Atmosphere-Ocean, 24, 303-328.

Schemenauer, R.S. and P. Cereceda, 1991: Fog water collection in arid coastal locations. Ambio, 20, 303-308.

Schemenauer, R.S. and P. Cereceda, 1992a: The quality of fog water collected for domestic and agricultural use in Chile. J. Appl. Meteor., 31, 275-290.

Schemenauer, R.S. and P. Cereceda, 1992b: Potential experimental site on Robinson Crusoe Island. Report to the World Meteorological Organization, SC92-01, 15 July, pp.16.

Schemenauer, R.S. and P. Cereceda, 1992c: Monsoon cloudwater chemistry on the Arabian Peninsula. Atmos. Environ., 26A, 1583-1587.

Table 1
Robinson Crusoe Island Sulfate Concentrations
August and October 1993

Fog

<u>Sample #</u>	<u>From</u>	<u>To</u>	<u>SO4 (ppm)</u>	<u>Comments (pH)</u>
631	19 Aug 1330	19 Aug 1640	2.18	drizzle (5.84)
641	26 Aug 1345	26 Aug 1500	0.33	drizzle (5.40)

Rain or Drizzle

630	17 Aug 1600	18 Aug 1300	2.67	drizzle, Selkirk (5.72)
632	22 Aug 2030	23 Aug 1230	1.02	drizzle, Selkirk (5.85)
633	22 Aug 2030	23 Aug 1300	2.53	drizzle, Villagra (6.25)
635	23 Aug 1700	24 Aug 1200	0.84	rain, Punta, 18 mm (5.61)
636	23 Aug 1300	24 Aug 1030	0.05	rain heavy, Villagra (5.15)
637	23 Aug 1230	24 Aug 1100	0.19	rain heavy, Selkirk (5.45)
639	24 Aug 1030	25 Aug 1200	1.28	drizzle, Villagra (5.28)
640	24 Aug 1100	25 Aug 1215	1.23	drizzle, Selkirk (5.22)
642	25 Aug 1200	26 Aug 1345	1.60	drizzle, Selkirk (5.20)
643	25 Aug 1200	26 Aug 1410	1.93	drizzle, Villagra (5.21)
644	26 Aug 1200	27 Aug 1600	1.57	drizzle, Punta (5.55)
645	26 Aug 1414	27 Aug 1330	0.36	drizzle, Villagra (5.62)
646	26 Aug 1345	27 Aug 1400	0.46	drizzle, Selkirk (5.58)
661	28 Oct 1840	28 Oct 1900	0.70	end of rain shower (5.42) Pangal
662	29 Oct 0000	29 Oct 0800	0.49	rain, Pangal (5.96)
664	29 Oct 2040	30 Oct 0800	0.82	rain, Pangal (5.63)

Rain Santiago

<u>Sample #</u>	<u>From</u>	<u>To</u>	<u>SO4 (ppm)</u>	<u>Comments (pH)</u>
653	29 Aug 1245	29 Aug 2130	0.42	rain, 25 mm in 9h 15min (5.14)
654	29 Aug 2130	30 Aug 1105	17.92	rain, 5 mm in 13h 35min (7.49)
672	30 Oct 1630	30 Oct 1930	5.08	rain, 12 mm (6.38)
673	30 Oct 1930	31 Oct 1000	11.63	rain, 6 mm (7.33)
684	04 Nov 0815	04 Nov 1455	30.85	drizzle, 1 mm (6.94)

Samples Not Used in the AnalysisFog

<u>Sample #</u>	<u>From</u>	<u>To</u>	<u>SO4 (ppm)</u>	<u>Comments (pH)</u>
628	17 Aug 1600	18 Aug 1230	46.1?	strong winds, drizzle (5.63)

Rain or Drizzle

638	24 Aug 1200	26 Aug 1200	4.93	drizzle, Punta (5.91) (2 day sample)
647	27 Aug 1400	29 Aug 1330	0.89	heavy rain, strong wind (6.72) (2 day sample)
648	27 Aug 1330	29 Aug 1415	0.73	heavy rain, strong wind (5.77) (2 day sample)

Table 2. Mean correlation coefficients, for SO_4^- with other major ions in precipitation, on Robinson Crusoe Island and in Santiago, Chile.

	Cl	NO_3	Na	NH_4	K	Mg	Ca
RCI	0.99	0.34	0.99	0.53	0.66	0.99	0.87
Santiago	0.86	0.86	0.90	-0.37	0.92	0.97	0.79

Table 3a. Mean enrichment factors for precipitation on Robinson Crusoe Island based on sea water Cl^- (EF_{Cl}) values. Sea Salt (SSF) and residual fractions (NSS) of the ions in the precipitation are also given.

Element	X/Cl^- ¹ Sea	X/Cl Rain	EF_{Cl}	SSF %	NSS %
Ca^{++}	0.021	0.037	1.743	57	43
Na^+	0.55	0.570	1.036	97	3
Mg^{++}	0.067	0.069	1.035	97	3
K^+	0.021	0.023	1.105	90	10
NH_4^+	n/a	0.005	-	-	-
Cl^-	1.00	1.000	1.000	100	-
Br^-	0.003	-	-	-	-
SO_4^-	0.14	0.222	1.586	63	37
NO_3^-	n/a	0.014	-	-	-
HCO_3^-	n/a	0.027	-	-	-

¹ Kennish (1989)

Table 3b. Mean enrichment factors for precipitation on Robinson Crusoe Island based on sea water Cl^- (EF_{Cl}) values. Sea Salt (SSF) and residual fractions (NSS) of the ions in the precipitation are also given.

Element	X/Cl^- ¹ Sea	X/Cl Rain	EF_{Cl}	X/Al^2 Crust	X/Al^* Fog	EF_{Al} Crust	SSF %	CRF %	NSS %
Ca^{++}	0.021	0.037	1.743	0.50	12	23	57	4	38
Na^+	0.55	0.570	1.036	0.28	243	869	97	0	3
Mg^{++}	0.067	0.069	1.035	0.28	31	110	97	1	2
K^+	0.021	0.023	1.105	0.25	16	62	90	2	8
NH_4^+	n/a	0.005	-	n/a	3	-	-	-	-
Cl^-	1.00	1.000	1.000	0.0016	430	268,498	100	0	0
Br^-	0.003	-	-	0.00003	-	-	-	-	-
SO_4^-	0.14	0.222	1.586	n/a	89	-	63	-	37
NO_3^-	n/a	0.014	-	n/a	4	-	-	-	-
HCO_3^-	n/a	0.027	-	n/a	5	-	-	-	-

¹ Kennish (1989)

² CRC Handbook (1990)

* Mean Al for coastal fog

Table 4. Mean enrichment factors for precipitation in Santiago, Chile based on sea water Cl^- (EF_{Cl}) values. Sea Salt (SSF) and residual fractions (NSS) of the ions in the precipitation are also given.

Element	X/Cl ¹ Sea	X/Cl Rain	EF_{Cl}	SSF %	NSS %
Ca^{++}	0.021	2.943	140.146	1	99
Na^+	0.55	0.926	1.683	59	41
Mg^{++}	0.067	0.275	4.104	24	76
K^+	0.021	0.092	4.401	23	77
NH_4^+	n/a	0.165	-	-	-
Cl^-	1.00	1.000	1.000	100	-
Br^-	0.003	-	-	-	-
SO_4^-	0.14	4.972	35.518	3	97
NO_3^-	n/a	0.139	-	-	-
HCO_3^-	n/a	1.212	-	-	-

¹ Kennish (1989)