Anonymous Referee #2:

Received and published: 18 January 2017

The submission deals with runoff generation and water sources in a high-mountain catchments dominated by a glacier and characteristic Andean grasslands (paramo). The work reports sampling of hydro chemicals and stable water isotopes along the stream and for one event at the catchment outlet. This data is supported by precipitation, ice, and spring sampling. The approach is not novel, yet the landscape and the crucial role of grasslands makes this study of interest for the scientific community, especially as high-mountain and glaciated catchments are under increased and constant stress. Yet, I wished that the senior authors would have invested more time in their student's submission rather than passing the work on to the reviewers. I feel that the paper needs quite substantial revisions before it can be accepted. I think that this work

We acknowledge and thank the contribution of the referee through his/her comments. Hereby we present a point-by-point reply to the referee´s questions and comments.

MAJOR CONCERNS

1) **i) What I am most critical about is the lack of a clear story line; especially the result section offers a bunch of data that were presented rather unstructured and it was hard to tease out the important bits of it. Why is what kind of data presented? I often felt lost, maybe also due to the lack of a proper description of the sampling.**

   The authors' intention in the manuscript was to make a synthesis of the work carried out in the studied catchment by: 1) giving an overview of the hydrochemical catchment characterization, and identifying the main runoff sources and 2) determining the contribution of glacier and páramo runoff to total runoff during dry and wet conditions using stable isotopes.

   We will improve the text in the data collection section 3.1, and we will add a table in the Annex section with the main characteristics, location and chemical composition of all the samples collected as also suggested by Reviewer 1 (please find the table in the Annex section of this response. The overall structure of the manuscript will be revised to make it more clear to the reader.

2) **ii) I felt confused throughout the read. There was plenty of sampling, along the stream, for events etc. What is clearly needed is a table and a more detailed description of the sampling.**

   We acknowledge that a more detail description of all the samples will help to better understand the sampling done in the catchment study. This table has been added in the Annex section at the end of the manuscript.

3) **iii) I felt that the use of the sampling along the stream was never really detailed used and the core of the works ends up as one hydrograph separation (which lacks the proper methodological description). What precipitation was used as end-member etc.?**

We agree with the reviewer's comment that the main focus of the research is the estimation of the contribution of the glacier and paramo runoff during dry and wet conditions. However, the sampling along the stream assisted in understanding the spatial hydrochemical distribution and the various runoff sources leading to the identification of glacier and páramo runoff. Sampling along the stream also assisted in determining the most suitable tracers to identify these runoff contributions. In addition, sampling along the stream contributed with additional information of what is happening in specific areas. For instance, the outliers of the springwater samples provided evidenced of meltwater infiltration of the glacier, which requires more attention in a future study.

The precipitation samples collected for the same rainfall event were used for the end-member analysis and hydrograph separation.

4) **iv) I am somewhat critical about the lack of precipitation samples, especially since they show quite some spread and plot below the LMWL. How does the station where the LMWL was recorded compare to the local conditions (such as elevation etc.). This could lead to a clear offset of the true local LMWL. There is no clear description where ice was sampled. Three samples is somewhat small, but at least the spread is small too.**

Thank you for the comment. This point was also raised by Reviewer 1. The amount of precipitation samples depended on the amount of rainfall collected during the event.

During the analysis, these precipitation samples were noted for deviating from the LMWL and GMWL slopes. We hypothesize that the distance of the precipitation samples to the LMWL and GMWL might indicate secondary evaporation processes that occur when raindrops fall in a warm atmosphere. This is suggested by the values of deuterium excess less than 10‰ in all precipitation samples. The event was not a heavy rain, and therefore the raindrops are slightly more enriched.

A statement has been included in the manuscript with the possible explanation. However, an in-depth and further analysis is not within the scope of this study. Pg 16 Line 16: *"The isotopic composition of rainfall and their relative distance to the GWML propose a possible evaporation effect. The first raindrops are usually more isotopically enriched (Gat & Carmi, 1970). For the specific case of precipitation, further research on rainfall events at this location should be done to check for possible re-evaporation processes and contributions of different water vapor sources that might occur taking into account inter and intra event variability in the hydrological process."*

In References:

Gat, J. R. and Carmi, I.: Evolution of the isotopic composition of atmospheric waters in the Mediterranean Sea area, Journal of Geophys. Res., 96, 13179-13188, 1970.

Izobamba station (0.37°S, 78.55°W) where the LMWL was recorded lies nearby the location where the samples were taken (0.5°S, 78.18°W). However, the conditions are slightly different. In terms of elevation the difference between Izobamba (3059 m a.s.l.) and

Humboldt (4010 m a.s.l.) is around 950m. The precipitation registered at Izobamba station is around 1400 mm/yr compared to 800 mm/yr at Humboldt station. The Andean Region is dominated by the altitude effect and could explain locally the significant deviations from the LWML.

We will include a statement to indicate where the ice samples were taken. We are aware that the amount of data is a limitation to make a complete analysis and determine the chemical signature of ice. We agree that the evidence is not conclusive of the chemical signature of ice based on the small dataset. In this regard, the results were only used to have an initial overview of the chemical components and stable isotopes present when comparing four different runoff sources including ice, precipitation, surface water and springwater.

5) **v) The landscape units are poorly described in the manuscript, e.g. Figure 1 does not even present the paramos.**

   Pg 2 lines 39-41 describe briefly the dominant growth forms of the paramo vegetation. We will improve the legend of the land cover map in Figure 1c to clarify that the 3 growth forms are the páramo vegetation.

6) **vi) The figures quality in general. Figures 1-3 are acceptable quality, figures 4-9 are not.**

   All figures will be improved in the revised version of this manuscript.

MINOR CONCERNS:

7) **The English could use a revision. The sentences are often nested and overly long. The title is not precise and too long. Please check the proper use of altitude, I think the differentiation between altitude and elevation needs some attention, cf. McVicar and Körner (2013), Oecologia. "On the use of elevation, altitude, and height in the ecological and climatological literature"**

   We are grateful for the suggestion, and we will check the English language throughout the manuscript in the next version. The title has been changed to: "*Quantification of runoff generation from a combined glacier and paramo catchment during dry and wet conditions using environmental isotopes within the Antisana Ecological Reserve in the Ecuadorian highlands*" as also suggested by the first reviewer.

   The paper from McVicar and Körmer (2013) gave a clear explanation of the different terms to explain vertical distance. We will consider changing altitude and altitudinal gradient for elevation and elevation gradient, respectively.

8) **The abstract needs some rework. Paramo is never explained. L14-16 lacks precision. The results need to be more detailed.**

   The abstract has been updated incorporating the suggestions from reviewer 1 and reviewer 2.

   Abstract:

   "In the Andean region, tropical grasslands more known as páramos are vitally important to serve the water needs of communities in the surrounding areas. Previous studies in combined glacier and páramo catchments have shown that the melting of glaciers contributes to runoff

generation and that the páramo ecosystem acts as a natural sponge, which plays an important role in regulating the runoff during the dry-season. However, not all runoff processes are well-understood in the Andean Region due to the high spatial variability of precipitation. Particularly in the northern Ecuador, young volcanic ash soil properties, soil moisture dynamics and other local factors such as vegetation interception and high radiation might influence the hydrological behavior. In addition, there is a lack of evidence of the origin and quantification of the contribution of runoff components in the páramo ecosystem. This study focuses on data collection and experimental investigations in a small catchment (15.2 km^2) that ranges between 4000 to 5700 m a.s.l. within the Antisana Ecological Reserve in the Ecuadorian Andean Region. It consists of 2.3 km^2 glaciers, 10.3 km^2 páramo grasslands and 2.6 km^2 moraines. The approach consists of the identification of suitable environmental tracers and hydrochemical features to identify the various runoff sources in order to determine their respective contribution during dry and wet conditions. Dry conditions defined as periods in which precipitation was absent for at least three consecutive days and wet conditions during rainfall events. The results show the great importance of the páramo on the contribution to total runoff during baseflow estimated around 70% and the capacity to dissipate the stream energy and buffer the peak flow during rainfall conditions. Electrical conductivity (EC) together with the stable isotopes ($\delta^{18}O$, and δ^2H) were identified as conservative tracers that characterize the end-member concentrations."

9) **P1L33-34: "... river's. . ..resurgence" this is unclear.**

   This sentence has been revised: *"... that feed directly the river's drainage system or may contribute further downstream due to glacial meltwater infiltrations and water resurgence through springs (Cauvy-Fraunié et al., 2013; Favier et al., 2008; Villacis, 2008)"*

10) **P1L39. The concern. . .. Check the grammar.**

    Thank you for the observation. We will correct the grammar in the new version.

11) **P2L10ff: Please make the research gap clearer, really try to make an effort why exactly this study is needed.**

    Pg2 lines 12-14 were revised to address this comment: *"However, appropriate tracers for a suitable spatial hydrochemical characterization have not been yet identified. In addition, a quantification of the different contributions from glacier and páramo components in these catchments of complex geology and topography remains a challenge."*

12) **P2L15ff: Restructure and specify the research question (or use hypotheses).**

    This paragraph has been revised: *"This study aims to i) identify effective environmental tracers (stable isotopes and major ions) to quantify the contribution of the main runoff components, and ii) provide a fair understanding of the hydrological interactions of a glacierized-páramo system during dry and wet conditions."*

13) **P2L33: "Location". For me this seems not right, as there is much more described here, such as catchment properties.**

Thank you for the observation. We have included subtitles for the paragraphs. Before line 38: Land cover and before line 44: Soil properties.

14) **P2L34ff. It was not always clear to me if the individual information was for the catchment, or the region. Furthermore, I found it difficult to follow since the authors jumped around in there references to distinct elevation ranges. What is low, what is high, etc. Please consider restructuring the section 2.**

Our intention was to differentiate the catchment properties between different elevations as described in previous studies that were linked to this one. However, section 2 will be updated.

The following changes have been made:

"Location

The catchment study Los Crespos-Humboldt (15.2 km2) lies within the Antisana Ecological Reserve (628.1 km2) in the Andean region of Ecuador (Figure 1a). It is located at the south-western slope of the Antisana volcano (0°30'S, 78°11'W) and its elevation ranges from 4000 to 5700 m a.s.l. This catchment is one of several water sources for La Mica reservoir that supplies water for the southern part of Quito, the capital city of Ecuador, located 50 km north of this catchment.

Land cover

It consists of 15% glaciers, 68% páramo grasslands and 17% moraines (Figure 1b). The latter one is an ecosystem in transition between the glacier and the páramo. The páramo vegetation is dominated by tussock grasses (TU) (Calamagrostis intermedia), acaulescent rosettes (AR) (Werneria nubigena, Hypochaeris sessiliflora) and cushions (CU) (Azorella Pedunculata) (Minaya et al., 2015) (Figure 1c). The páramo vegetation has adapted to specific climatic conditions of low atmospheric pressure, high radiation and wind drying effects (Luteyn, 1999). The glacier is an icecap that has retreated around 200 meters in the last 20 years (Cáceres et al., 2005; Hall et al., 2012).

Soil properties

Soils are mainly andosols, based on the FAO classification (Gardi et al., 2014), derived from volcanic material characterized by their high soil moisture (Buytaert et al., 2005a) and water retention capacity (Janeau et al., 2015; Roa-García et al., 2011). The soil texture varies from silty loam at elevations between 4000 to 4400 m a.s.l. to sandy clay loam soil at higher elevations where vegetation is sparse (Minaya et al., 2015). The soil texture influences the ecological and hydrological processes. Sandy soils drain well and reduce the capability of holding moisture; silty soils offer a high water-holding capacity. The slopes are moderate (up to 15°) at lower elevations and increases up to 30° close to the moraines at higher elevations."

15) **P2L45-47: Not sure if some information that is clearly not linked to the catchment is needed.**

We agree that some information might not be needed. Careful revision will be made of this section to make it more concise.

16) **P4L10-11. Make it easier. Subcatchment#2 flows through. . .. and subcatchment#9. . .**
   Thank you for the suggestion. The sentence has been updated to: *"Subcatchment # 2 flows through large boulders and rocks of different size; whilst subcatchment 9 flows through páramo vegetation."*

17) **P5L4: Please introduce a table where details are described.**
   A table with the main characteristics and location of the samples has been added in the Annex section in the revised manuscript. It is also added at the end of this response.

18) **P5L5: Every 200m, you leave it for the reader to guess. You should clearly state that this was sampling along the flowing stream channel.**
   Thank you for the comment. The sentence has been updated to: *"Every 200m along the flowing stream channel, electrical conductivity (EC) and...."*

19) **P5L10: reference for the method P5L14: You mean catchment outlet? How many events?**
   The reference for the method has been included:
   HACH: Silica, Silicomolybdate HR Method 8185, Powder Pillows. DOC316.53.01133. Edition 9. Hach Company/Hach Lange GmbH, 2014.
   Sentence on Pg5 line 14 has been updated to: *"During rainfall events, the sampling of the surface water and precipitation was undertaken only at the outlet of the catchment at Humboldt Station for rainfall-runoff analyses. Samples were collected with a resolution of 15-20 min during the rainfall event."*

20) **P5L16: When were the precip samples taken?**
   This information has been added in Section 3.1 to clarify that the period is different for dry and wet conditions, pg4 line 8: *"Isotopic and hydrochemical samples were collected in a sampling campaign carried out in July 2014. For dry conditions July 4-7 and for wet conditions July 14-15."*

21) **P5L29ff: The text would profit when transformed to active style. The PCA was not mentioned in the methods.**
   We have deleted the sentence of PCA on Pg 10 lines 3-4 to address this comment.

22) **P6L1: The header is unclear, I am also not sure what exactly was done with this mixing analysis. I stay confused.**
   We have changed the header to Flow routing to reflect the description in section 3.4.2.
   Regarding the mixing analysis, the intention was to identify interrelationships between major ions using the chemical components and find their suitability as tracers for the hydrograph separation.

23) **P6L29: Maybe "end member" would be a better term?**

We agree that subtitle 4.1.1 Runoff sources does not reflect the content of this subsection. Therefore we will delete this subtitle, and this section will fall under the Hydrochemical catchment characterization description.

24) **P6L30ff.: See major concerns. Please avoid methods in the results, describe everything in section 3.**

We agree that it is repetitive. In this regard, the first sentence has been deleted.

25) **P7: Figure 4: Box plots with 3 and 4 data points are sketchy. The quality of the figure needs to be improved, line width, font size, a, b etc is not mentioned in the captions**

This comment was also raised by reviewer 1. We are aware of the limited number of ice and precipitation samples. We have updated Figure 4 and replaced the box-plots for other type of plot showing only the distribution of samples and their mean.

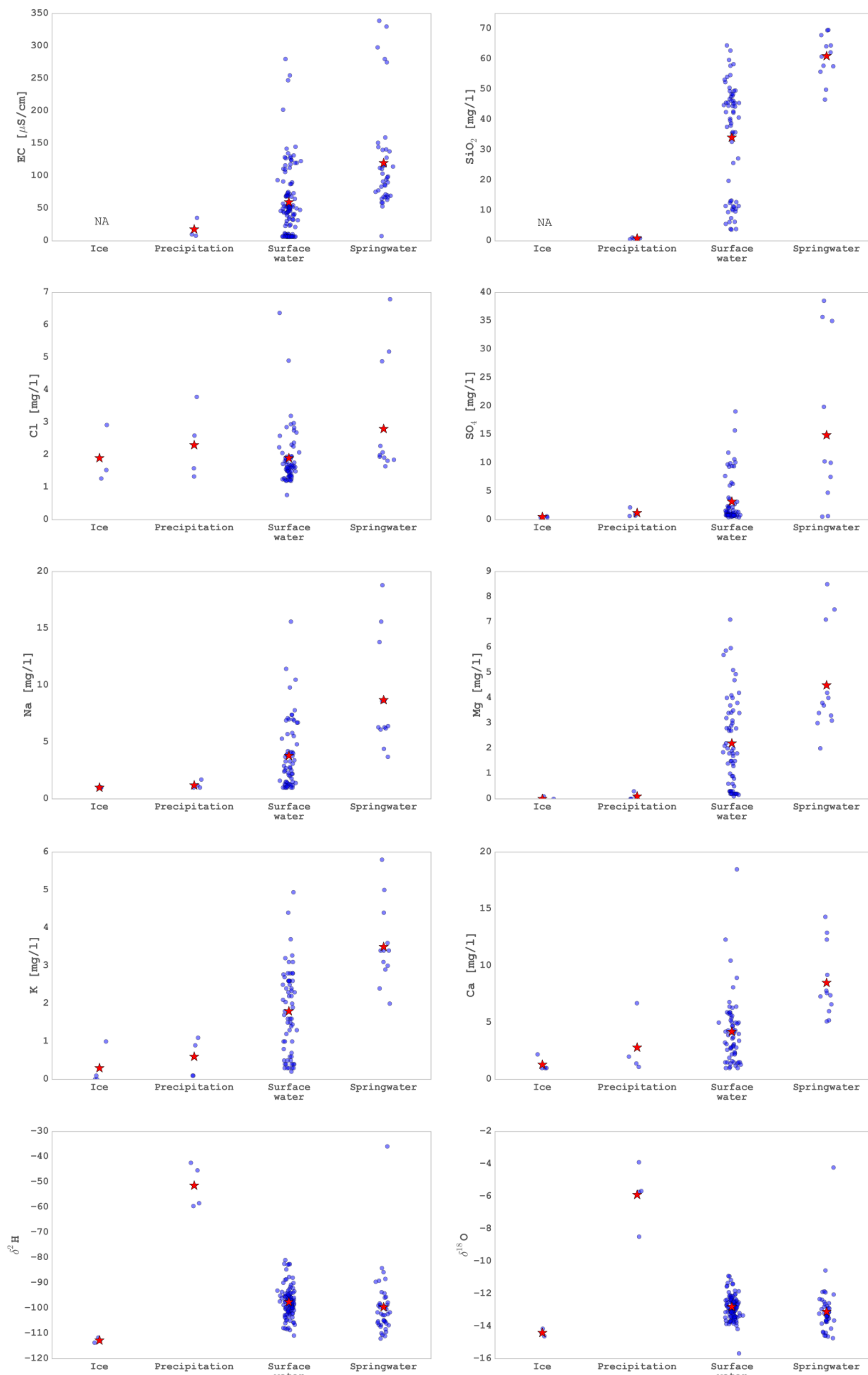

Figure 4. Chemical components and stable isotopes of water samples within the Los Crespos-Humboldt basin of different runoff sources (Ice, Precipitation, Surface and Spring water). The blue dots represent the samples and the red star the mean values. NA= samples are not available.

26) **P8L2: Avoid introductory sentences in the results paragraph. Straight to the point. What is important?**

Thanks for the comment. It will be taken into account throughout the manuscript in the revised version.

27) **P8L7-8, this should be mentioned in the study site.**

Indeed, this sentence is more descriptive and should be moved to section 3.1 where a small description of the subcatchments is done.

28) **P9: Please reconsider the presentation in this figure. You leave it to the reader what might be of importance. Furthermore, the figure is not understandable just based on the captions. Font size, line width etc. should be improved.**

Thank you for the comment. All figures will be improved in the revised version and careful revision will be made to this specific figure to pinpoint only the important results.

29) **P11: completely revise**

The intention with this figure was to display how the chemical signature of surface water within each subcatchment changes when they confluence with other tributaries. However, we will revise this figure to display clearer results.

30) **P12L2-3: You refer to event and events. How many?**

We have revised the sentence to clarify that the analysis is done with one rainfall event: *"The sampling during the rainfall event corresponds to low-medium intensity rain and it was considered as representative for rainfall-runoff evaluation. The duration of the event was 12 hours with a maximum intensity of 0.3 mm/h and an average intensity of 0.18 mm/h."*

31) **P12L2: 2mm rain is not an intensity. Was it just one event that had 2mm? These lines are confusing, I cannot figure out what was done and sampled (see suggestion about tables earlier).**

We agree with the comment. We will consider rewriting this paragraph for clarification. Tables will be added in the Annex section.

32) **P12L2ff. You do not mention the LMWL here. How does the LMWL relate to the local conditions? How many km away? On what elevation? Etc.**

We will include a small description of the Izobamba station where the LMWL was calculated. The information of the local conditions and the difference with the Izobamba station was given above, please refer to comment #4.

33) **P13: The mixing plot and hydrograph separation section should be merged.**

We will consider how to merge these two analyses in the same section for the revised version of the manuscript.

34) **P14: It is not clear here what end-members are used, but a merger with the mixing diagram section will help. Also consider presenting this information in the methods (which may not work, in case the mixing diagram was used to determine the end members, so just results in that case).**

As mentioned in the previous comment, we will merge these analyses to clarify how from the end member analysis, we identified the suitable tracers and end members for the hydrograph separation.

35) **P16L9ff. The discussion here needs some more work. You need to really make the point how your results improved both, the understanding of runoff generation in the catchment beyond previous understanding, and how this makes the work relevant for the same landscape at other places, and how the results compare to other researcher's work. The latter is needed to show the importance of the results for the community, you can close the story that you opened at the end of the introduction, where you should state (earlier comment) why this work is needed.**

We recognized the need to improve the discussion in the revised version of the manuscript and to find more comparable studies to highlight the contribution of our research for the scientific community. We believe that although no final conclusions can be withdrawn from the limited amount of data, it is important to publish the results obtained that contribute to an overall understanding of the runoff generation in this combined glacier and páramo catchment.

Annex

Table A-1. Location of the water samples taken from four different runoff source (Ice, Prec = precipitation, SW = springwater and Surf = surface water) and main characteristics and chemical concentrations (EC = electrical conductivity [µS/cm], SiO_2 [mg/l], Cl^- [mg/l], SO_4^{2-} [mg/l], Na^+ [m/l], Mg^{2+} [mg/l], K^+ [mg/l], Ca^{2+} [mg/l], δ^2H [‰],$\delta^{18}O$ [‰]) taken during July 2014. The UTM coordinates (WGS84) of the area are Zone 17M North and East, Dist = distance to the outlet, Subcat = subcatchment, Cat = catchment and Geol = geological background (Ch = Chacana volcanic rocks, Hi = Hialina lava, LaRo = Lahar Rojo, Lapl = Lavas Pleistocene, Ti = Tillite late ice age). NA = samples are not available.

ID	Source	N (m)	E (m)	Elev.	Dist.	EC	SiO_2	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	K^+	Ca^{2+}	δ^2H	$\delta^{18}O$	Subcat.	Cat.	Geol.
10	Ice	9945370	816341	4736	7300	NA	NA	2.9	0.6	1.0	0.1	1.0	2.2	-112.8	-14.4	23	2	-
20	Ice	9945370	816341	4736	7300	NA	NA	1.3	0.4	1.0	0.0	0.1	1.0	-111.6	-14.2	23	2	-
30	Ice	9945370	816341	4736	7300	NA	NA	1.5	0.4	1.0	0.0	0.0	1.0	-113.6	-14.6	23	2	-
P_01	Prec	9943248	810185	4060	1	NA	0.7	3.8	2.2	1.7	0.3	1.1	6.7	-59.5	-8.5	1	1	-
P_02	Prec	9943248	810185	4060	1	7.9	0.9	1.3	0.7	1.0	0.0	0.1	1.4	-45.4	-5.7	1	1	-
P_03	Prec	9943248	810185	4060	1	10.0	1.1	1.6	0.7	1.0	0.0	0.1	1.1	-42.4	-3.9	1	1	-
P_04	Prec	9943248	810185	4060	1	35.4	0.5	2.6	1.1	1.2	0.1	0.9	2.0	-58.4	-5.7	1	1	-
T_S1_01	SW	9943424	810258	4047	320	144.5	57.8	1.9	10.3	8.7	4.0	3.0	7.3	-111.0	-13.4	1	1	Hi
T_S1_20	SW	9943451	812460	4166	2850	70.0	NA	NA	NA	NA	NA	NA	NA	-89.1	-11.9	7	5	Ch
T_S1_26	SW	9943471	813147	4206	3600	116.2	NA	NA	NA	NA	NA	NA	NA	-85.7	-11.9	9	5	Ti
T_S1_22	SW	9943489	812029	4135	2500	NA	NA	NA	NA	NA	NA	NA	NA	-98.9	-12.4	7	5	LaPl
T_S1_25	SW	9943502	812928	4191	3370	NA	NA	NA	NA	NA	NA	NA	NA	-90.4	-12.7	9	5	LaPl
T_S1_21	SW	9943521	812319	4146	2800	116.3	NA	NA	NA	NA	NA	NA	NA	-99.6	-13.6	7	5	Ti
T_S1_16	SW	9943524	811802	4127	3670	NA	NA	NA	NA	NA	NA	NA	NA	-89.5	-11.9	5	5	LaPl
T_S1_15	SW	9943526	811662	4122	3675	140.9	NA	NA	NA	NA	NA	NA	NA	-105.2	-14.4	5	5	LaPl
T_S1_14	SW	9943543	811655	4121	2100	137.7	NA	NA	NA	NA	NA	NA	NA	-106.7	-14.6	5	5	LaPl
T_S1_17	SW	9943547	812001	4134	2540	94.5	55.8	NA	NA	6.3	4.2	3.1	6.0	-105.3	-13.5	6	5	Ch
T_S1_09	SW	9943576	811372	4109	2020	114.4	NA	NA	NA	NA	NA	NA	NA	-88.4	-12.5	5	5	LaPl
T_S1_06	SW	9943599	811130	4114	1550	275.0	69.5	6.8	19.9	13.8	7.5	5.8	14.3	-99.6	-13.6	31	3	LaRo
T_S1_02	SW	9943639	810532	4077	817	159.2	NA	NA	NA	NA	NA	NA	NA	-109.4	-14.6	1	1	Hi
T_S1_03	SW	9943708	810640	4079	1005	140.0	NA	NA	NA	NA	NA	NA	NA	-109.9	-14.7	1	1	Hi
T_S1_13	SW	9943739	810657	4083	1050	151.0	57.6	2.3	14.8	8.6	3.8	2.9	6.6	-110.5	-13.7	1	1	Hi

ID	Source	N (m)	E (m)	Elev.	Dist.	EC	SiO_2	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	K^+	Ca^{2+}	δ^2H	$\delta^{18}O$	Subcat.	Cat.	Geol.
T_S1_04	SW	9943741	810709	4080	1113	330.0	NA	NA	NA	NA	NA	NA	NA	-106.0	-14.1	1	1	LaRo
T_S1_29	SW	9943790	814275	4325	4850	86.6	49.9	NA	NA	NA	NA	NA	NA	-98.6	-13.1	9	5	Ti
T_S1_12	SW	9943797	810758	4083	1100	339.0	NA	NA	NA	NA	NA	NA	NA	-112.0	-13.0	1	1	LaRo
T_S1_27	SW	9943812	814257	4316	4780	99.1	NA	1.8	0.7	3.7	3.0	2.4	5.1	-101.6	-12.6	9	5	Ti
T_S1_28	SW	9943825	814281	4319	4800	110.8	46.6	NA	NA	NA	NA	NA	NA	-93.6	-12.6	9	5	Ti
T_S1_05	SW	9943878	811156	4100	1455	280.0	64.5	4.9	35.7	15.6	7.1	4.4	12.3	-106.6	-14.6	22	2	LaRo
T_S1_31	SW	9943930	814545	4341	5015	NA	NA	1.5	1.4	NA	NA	NA	NA	-94.9	-11.6	9	5	Ti
T_S1_32	SW	9943934	814574	4345	5060	59.0	NA	NA	NA	NA	NA	NA	NA	-95.8	-12.3	9	5	Ch
T_S1_30	SW	9943935	814517	4334	4975	77.7	NA	NA	NA	NA	NA	NA	NA	-101.6	-13.1	9	5	Ch
T_S1_33	SW	9943973	814685	4354	5170	58.8	NA	NA	NA	NA	NA	NA	NA	-94.1	-12.8	9	5	Ch
T_S1_11	SW	9943975	811328	4103	1790	298.0	60.8	5.2	38.5	18.8	8.5	5.0	12.9	-108.3	-14.3	22	2	LaRo
T_S1_34	SW	9943985	814740	4356	5200	67.0	NA	NA	NA	NA	NA	NA	NA	-98.6	-12.9	9	5	Ch
T_S1_35	SW	9944017	814842	4369	5400	64.7	NA	NA	NA	NA	NA	NA	NA	-97.7	-13.2	9	5	Ch
S1_49	SW	9944045	813496	4246	4150	75.5	NA	1.6	0.5	4.4	2.0	2.0	5.2	-84.1	-10.6	8	5	Ti
T_S1_36	SW	9944054	814937	4382	5450	53.1	NA	NA	NA	NA	NA	NA	NA	-100.4	-12.8	9	5	Ch
T_S3_14	SW	9944054	811454	4110	1950	NA	66.1	NA	NA	NA	NA	NA	NA	-105.5	-14.6	22	2	Ch
T_S1_37	SW	9944066	814948	4386	5475	67.8	NA	NA	NA	NA	NA	NA	NA	-105.2	-13.7	9	5	Ch
T_S3_13	SW	9944099	811526	4113	2100	NA	NA	NA	NA	NA	NA	NA	NA	-107.2	-14.8	22	2	Ch
T_S1_38	SW	9944100	815040	4389	5530	69.5	NA	NA	NA	NA	NA	NA	NA	-98.1	-14.4	9	5	Ch
T_S3_12	SW	9944108	811526	4113	2170	112.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	22	2	Ch
T_S3_11	SW	9944111	811570	4117	5980	103.5	NA	NA	NA	NA	NA	NA	NA	-102.2	-13.4	22	2	Ch
T_S3_10	SW	9944237	811748	4129	2370	91.5	64.2	2.1	10.0	6.4	3.3	3.4	7.4	-106.5	-13.4	22	2	Ch
T_S3_09	SW	9944239	811757	4129	4920	83.6	NA	NA	NA	NA	NA	NA	NA	-107.3	-13.2	22	2	Ch
T_S3_02	SW	9944265	812357	4179	7100	63.2	NA	NA	NA	NA	NA	NA	NA	-105.7	-13.4	41	4	Ch
T_S3_01	SW	9944332	812494	4190	6750	71.5	NA	NA	NA	NA	NA	NA	NA	-104.7	-13.6	41	4	Ch
T_S3_08	SW	9944362	811920	4149	2590	97.6	NA	NA	NA	NA	NA	NA	NA	-102.3	-13.8	22	2	Ch
T_S3_04	SW	9944462	812125	4171	3800	85.2	67.9	1.9	4.8	6.2	3.4	3.6	7.8	-104.9	-13.7	22	2	Ch
T_S3_03	SW	9944477	812033	4159	2550	90.1	69.6	2.0	7.5	6.3	3.1	3.4	7.6	-102.7	-13.4	22	2	Ch
T_S3_05	SW	9944521	812189	4176	3900	128.1	62.2	1.8	35.0	6.1	3.7	3.4	9.2	-102.7	-12.9	22	2	LaPl
T_S3_06	SW	9944576	812602	4209	2550	67.1	NA	NA	NA	NA	NA	NA	NA	-95.5	-12.0	22	2	Ch
T_S3_07	SW	9944602	813584	4274	2900	7.4	NA	NA	NA	NA	NA	NA	NA	-35.9	-4.2	22	2	Ti

ID	Source	N (m)	E (m)	Elev.	Dist.	EC	SiO_2	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	K^+	Ca^{2+}	δ^2H	$\delta^{18}O$	Subcat.	Cat.	Geol.
S1_01	Surf	9943252	810178	4044	100	127.2	44.8	2.6	9.4	7.0	4.0	2.4	5.9	-98.3	-13.1	1	1	-
S1_02	Surf	9943306	810262	4046	200	122.8	NA	NA	NA	NA	NA	NA	NA	-101.3	-12.1	1	1	-
S1_03	Surf	9943396	810158	4047	300	124.4	45.5	2.3	7.7	7.4	4.1	2.6	6.4	-101.7	-12.0	1	1	-
S1_04	Surf	9943443	810304	4053	400	112.5	NA	NA	NA	NA	NA	NA	NA	-98.7	-12.1	1	1	-
S1_25	Surf	9943452	812467	4166	2950	36.3	NA	NA	NA	NA	NA	NA	NA	-95.6	-13.2	7	5	-
S1_05	Surf	9943467	810390	4066	500	116.3	44.5	2.7	9.7	7.1	3.8	2.5	5.9	-98.6	-11.9	1	1	-
T_S1_10	Surf	9943470	811664	4122	2240	72.0	38.0	2.2	2.1	2.5	2.2	1.5	3.6	-98.6	-12.6	7	5	-
S1_27	Surf	9943471	812000	4133	2480	45.4	NA	NA	NA	NA	NA	NA	NA	-97.5	-12.5	7	5	-
S1_24	Surf	9943477	812678	4179	3200	59.7	42.5	1.6	0.5	3.4	2.8	2.4	4.7	-82.5	-10.9	8	5	-
S1_28	Surf	9943478	812864	4187	3300	57.2	37.6	1.7	0.9	2.4	1.5	1.6	3.0	-96.6	-13.4	9	5	-
S1_29	Surf	9943481	813062	4200	3500	54.7	NA	NA	NA	NA	NA	NA	NA	-95.3	-13.4	9	5	-
S1_06	Surf	9943505	810474	4076	600	110.9	NA	NA	NA	NA	NA	NA	NA	-98.3	-12.2	1	1	-
S1_26	Surf	9943507	812253	4143	2750	43.7	40.3	1.6	0.8	2.0	1.5	1.3	3.1	-98.2	-12.5	7	5	-
T_S1_19	Surf	9943514	812666	4179	2700	68.2	NA	NA	NA	NA	NA	NA	NA	-82.5	-10.9	8	5	-
S1_18	Surf	9943529	811891	4129	2500	48.9	NA	NA	NA	NA	NA	NA	NA	-104.5	-13.9	6	5	-
S1_07	Surf	9943548	810515	4078	700	124.5	46.2	2.7	9.9	7.8	4.2	2.8	6.3	-100.0	-12.5	1	1	-
S1_16	Surf	9943548	811455	4112	2190	127.7	NA	NA	NA	NA	NA	NA	NA	-102.4	-14.2	5	5	-
B_1	Surf	9943548	811455	4116	1850	128.7	38.8	2.4	6.3	5.5	2.8	2.0	5.1	NA	NA	31	3	-
S1_19	Surf	9943557	812079	4139	2700	47.7	48.5	1.8	1.2	3.9	1.7	2.2	4.1	-108.6	-13.8	6	5	-
S1_17	Surf	9943558	811675	4122	2300	52.9	45.6	1.9	1.4	4.1	2.1	2.1	3.9	-102.3	-13.5	6	5	-
A_1	Surf	9943562	811460	4116	2000	254.8	57.8	6.4	15.7	10.5	6.0	4.9	18.5	NA	NA	32	3	-
S1_23	Surf	9943566	812862	4189	3400	50.1	NA	NA	NA	NA	NA	NA	NA	-82.8	-11.5	8	5	-
S1_30	Surf	9943569	813246	4214	3700	54.2	35.5	1.3	1.1	2.7	1.9	1.8	4.2	-96.8	-13.5	9	5	-
S1_08	Surf	9943621	810526	4078	800	117.9	NA	NA	NA	NA	NA	NA	NA	-99.1	-12.5	1	1	-
T_S1_23	Surf	9943624	812177	4149	2670	44.1	NA	NA	NA	NA	NA	NA	NA	-107.8	-13.7	6	5	-
S1_15	Surf	9943630	811327	4107	1900	106.1	45.6	2.3	6.0	5.7	3.4	2.3	5.0	-99.8	-13.3	5	5	-
T_S1_24	Surf	9943638	812201	4155	2680	43.5	47.5	1.9	1.3	2.8	1.3	1.6	2.8	-108.3	-13.6	6	5	-
S1_22	Surf	9943661	813059	4204	3600	47.3	44.3	1.5	0.4	4.2	2.9	2.8	5.8	-84.6	-11.2	8	5	-
S1_31	Surf	9943669	813421	4230	3900	52.3	NA	NA	NA	NA	NA	NA	NA	-95.3	-13.1	9	5	-
3_2C	Surf	9943673	811237	4103	1620	142.0	42.3	1.8	3.9	6.7	3.4	2.3	5.4	NA	NA	31	3	-
S3_17	Surf	9943675	811337	4108	2020	75.2	NA	NA	NA	NA	NA	NA	NA	-103.1	-12.4	41	4	-

ID	Source	N (m)	E (m)	Elev.	Dist.	EC	SiO_2	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	K^+	Ca^{2+}	δ^2H	$\delta^{18}O$	Subcat.	Cat.	Geol.
S1_32	Surf	9943689	813619	4244	4100	52.8	35.8	1.5	1.0	2.9	1.8	1.9	4.1	-99.2	-13.0	9	5	-
S1_09	Surf	9943690	810581	4078	900	120.0	45.5	2.8	10.1	7.0	3.5	2.6	5.6	-100.4	-12.4	1	1	-
T_S1_08	Surf	9943703	811488	4116	1120	93.5	49.4	1.5	2.4	4.8	3.0	2.5	4.7	-98.9	-13.4	41	4	-
S1_10	Surf	9943706	810637	4079	1000	130.0	NA	NA	NA	NA	NA	NA	NA	-99.5	-13.3	1	1	-
S3_16	Surf	9943711	811540	4119	950	69.1	50.5	1.7	2.4	5.3	2.8	2.8	5.0	-103.2	-12.7	41	4	-
C_1	Surf	9943717	811140	4114	1840	131.6	39.7	2.9	9.3	3.8	1.9	1.5	3.2	NA	NA	31	3	-
S1_14	Surf	9943724	811178	4100	1500	144.9	42.7	3.2	6.5	6.7	3.4	2.3	8.1	-101.9	-13.5	31	3	-
S3_15	Surf	9943733	811602	4123	1220	90.1	49.6	1.6	0.6	6.9	5.7	3.7	6.8	-92.0	-11.4	41	4	-
S1_11	Surf	9943735	810706	4082	1100	110.0	45.3	2.9	9.5	6.9	3.7	2.6	5.9	-101.0	-12.2	1	1	-
S1_12	Surf	9943746	810801	4088	1200	120.0	NA	NA	NA	NA	NA	NA	NA	-99.6	-13.1	1	1	-
S1_33	Surf	9943756	813817	4259	4300	52.0	NA	NA	NA	NA	NA	NA	NA	-98.7	-12.8	9	5	-
S1_13	Surf	9943767	810978	4092	1300	134.9	46.8	3.0	10.7	7.4	4.0	2.7	6.4	-102.6	-13.4	1	1	-
21_1_2C	Surf	9943783	811014	4094	1345	247.2	59.7	1.5	19.1	11.4	5.9	3.3	10.5	NA	NA	21	2	-
S1_34	Surf	9943790	914018	4281	4500	49.1	34.5	1.9	2.2	2.2	1.4	1.5	2.9	-105.9	-13.7	9	5	-
S1_35	Surf	9943814	814221	4314	4700	50.6	NA	NA	NA	NA	NA	NA	NA	-101.4	-12.8	9	5	-
S1_21	Surf	9943817	813187	4225	3800	46.3	NA	NA	NA	NA	NA	NA	NA	-82.4	-11.4	8	5	-
S3_14	Surf	9943854	811772	4133	1545	91.5	NA	NA	NA	NA	NA	NA	NA	-95.4	-11.8	41	4	-
S1_36	Surf	9943871	814412	4324	4900	53.3	35.9	1.4	0.7	2.5	1.5	1.6	3.4	-103.6	-13.1	9	5	-
22_1_2C	Surf	9943878	811156	4050	1445	280.0	64.5	4.9	NA	15.6	7.1	4.4	12.3	NA	NA	22	2	-
21_2_2C	Surf	9943894	811126	4100	1420	202.0	47.9	0.8	11.8	9.8	4.9	2.8	8.9	NA	NA	21	2	-
S2_28	Surf	9943926	811107	4101	1500	11.8	10.6	1.3	0.8	1.0	0.3	0.4	1.2	-89.9	-12.5	23	2	-
S1_20	Surf	9943934	813378	4236	4000	42.5	40.7	1.6	0.5	3.3	2.0	2.2	4.4	-80.9	-11.3	8	5	-
S1_37	Surf	9943957	814637	4347	5100	49.9	NA	NA	NA	NA	NA	NA	NA	-99.5	-13.4	9	5	-
S1_38	Surf	9944019	814821	4365	5300	49.0	32.7	1.6	1.3	1.5	0.9	1.0	3.7	-96.7	-13.7	9	5	-
S3_13	Surf	9944046	811889	4146	1990	87.7	52.4	1.6	0.9	5.8	4.7	3.2	5.7	-95.0	-11.8	41	4	-
S1_39	Surf	9944090	815015	4386	5500	46.1	NA	NA	NA	NA	NA	NA	NA	-96.0	-13.5	9	5	-
S2_29	Surf	9944102	811177	4127	1700	9.4	10.5	1.6	1.0	1.3	0.3	0.5	1.5	-90.0	-12.4	23	2	-
S3_12	Surf	9944139	812070	4161	2190	71.3	NA	NA	NA	NA	NA	NA	NA	-104.9	-13.2	41	4	-
S1_40	Surf	9944153	815208	4410	5700	41.1	27.2	1.4	1.6	1.5	1.0	1.0	2.6	-96.5	-13.7	9	5	-
S3_11	Surf	9944207	812233	4172	2370	73.4	49.5	1.9	0.6	3.9	2.7	3.1	5.0	-98.4	-12.3	41	4	-
S2_27	Surf	9944207	811300	4138	1900	10.2	NA	NA	NA	NA	NA	NA	NA	-91.5	-12.3	23	2	-

ID	Source	N (m)	E (m)	Elev.	Dist.	EC	SiO_2	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	K^+	Ca^{2+}	δ^2H	$\delta^{18}O$	Subcat.	Cat.	Geol.
S1_41	Surf	9944209	815393	4431	5900	33.9	NA	NA	NA	NA	NA	NA	NA	-99.8	-13.1	9	5	-
S1_46	Surf	9944216	816351	4596	7000	23.5	11.4	2.1	3.2	1.2	0.5	0.7	2.3	-100.8	-13.7	9	5	-
S1_45	Surf	9944223	816189	4567	6800	24.8	NA	NA	NA	NA	NA	NA	NA	-99.8	-12.5	9	5	-
S1_44	Surf	9944233	816003	4538	6600	26.5	12.5	2.1	2.7	1.3	0.6	0.8	2.4	-96.8	-13.0	9	5	-
S1_47	Surf	9944273	816511	4634	7200	22.9	NA	NA	NA	NA	NA	NA	NA	-98.9	-13.4	9	5	-
S1_42	Surf	9944323	815567	4462	6100	32.5	19.8	1.3	2.0	1.4	0.8	1.0	2.7	-97.7	-13.9	9	5	-
S3_08	Surf	9944327	812892	4221	7000	41.0	NA	NA	NA	NA	NA	NA	NA	-95.5	-11.6	41	4	-
T_S1_39	Surf	9944328	815945	4522	6550	39.2	25.7	NA	NA	2.2	0.9	1.3	2.8	-108.0	-13.7	9	5	-
S3_09	Surf	9944331	812703	4207	6600	39.2	48.4	1.7	1.1	2.7	1.4	1.7	2.2	-100.3	-12.3	41	4	-
S3_10	Surf	9944331	812495	4190	7300	70.5	NA	NA	NA	NA	NA	NA	NA	-102.5	-13.2	41	4	-
S1_43	Surf	9944356	815746	4492	6300	31.8	NA	NA	NA	NA	NA	NA	NA	-97.3	-13.7	9	5	-
S1_48	Surf	9944382	816692	4673	7400	21.3	7.5	1.4	3.6	1.0	0.6	0.6	3.1	-100.9	-12.8	9	5	-
S2_26	Surf	9944402	811469	4148	2100	10.3	6.2	1.3	1.0	1.8	0.3	0.6	1.9	-90.7	-12.4	23	2	-
S3_07	Surf	9944403	813078	4236	3700	55.4	46.2	1.9	1.3	2.1	1.8	1.2	2.2	-100.6	-12.2	41	4	-
S3_06	Surf	9944505	813280	4257	3900	64.7	NA	NA	NA	NA	NA	NA	NA	-101.4	-12.9	43	4	-
S3_18	Surf	9944534	813410	4268	4030	55.1	44.6	1.6	0.6	3.3	3.2	2.0	4.3	-92.4	-12.1	42	4	-
S3_19	Surf	9944594	813565	4286	4230	32.9	NA	NA	NA	NA	NA	NA	NA	-99.7	-13.1	42	4	-
S2_25	Surf	9944600	811518	4157	2300	10.8	NA	NA	NA	NA	NA	NA	NA	-88.7	-12.3	23	2	-
S3_20	Surf	9944666	813704	4297	4430	51.2	62.8	2.0	1.2	4.1	1.8	2.8	4.3	-97.0	-15.7	42	4	-
S3_01	Surf	9944677	813367	4281	4100	68.7	54.1	1.6	1.7	2.3	2.7	1.4	2.8	-105.6	-12.9	43	4	-
S3_21	Surf	9944713	813880	4314	4630	30.7	NA	NA	NA	NA	NA	NA	NA	-103.7	-12.7	42	4	-
S3_02	Surf	9944766	813536	4303	4300	73.8	NA	NA	NA	NA	NA	NA	NA	-104.8	-12.9	43	4	-
S2_24	Surf	9944809	811679	4170	2500	9.8	11.5	1.5	0.9	1.4	0.2	0.4	1.1	-87.9	-12.7	23	2	-
S3_22	Surf	9944829	814097	4343	4830	45.8	53.2	1.8	1.6	4.0	2.0	2.6	4.9	-110.8	-14.0	42	4	-
S3_03	Surf	9944918	813657	4317	4500	69.5	58.3	1.7	1.4	3.7	3.1	2.6	4.0	-105.7	-13.3	43	4	-
S2_23	Surf	9944947	811791	4179	2700	9.5	NA	NA	NA	NA	NA	NA	NA	-88.5	-12.9	23	2	-
S2_01	Surf	9945081	811901	4188	2900	7.6	12.8	1.2	0.8	1.0	0.3	0.3	1.5	-93.0	-13.0	23	2	-
S3_04	Surf	9945090	813820	4341	4700	68.2	NA	NA	NA	NA	NA	NA	NA	-107.8	-13.8	43	4	-
S2_02	Surf	9945155	812102	4208	3100	6.6	NA	NA	NA	NA	NA	NA	NA	-93.5	-13.0	23	2	-
S3_05	Surf	9945164	813983	4370	4900	87.4	54.7	1.7	0.9	3.1	5.1	3.1	5.2	-106.5	-13.5	43	4	-
S2_03	Surf	9945262	812266	4232	3300	6.7	11.2	1.3	0.9	1.2	0.2	0.4	1.4	-95.2	-12.9	23	2	-

ID	Source	N (m)	E (m)	Elev.	Dist.	EC	SiO_2	Cl^-	SO_4^{2-}	Na^+	Mg^{2+}	K^+	Ca^{2+}	δ^2H	$\delta^{18}O$	Subcat.	Cat.	Geol.
Lake	Surf	9945276	815577	4664	7050	6.6	3.9	1.2	0.7	1.6	0.2	0.5	1.0	-87.6	-12.6	23	2	-
S2_22	Surf	9945276	815578	4664	7050	6.6	3.9	1.4	0.8	1.0	0.2	0.3	1.0	NA	NA	23	2	-
S2_21	Surf	9945331	815528	4650	6900	6.3	3.7	1.7	0.8	NA	NA	NA	NA	-94.9	-13.4	23	2	-
S2_04	Surf	9945351	812415	4237	3500	6.7	NA	NA	NA	NA	NA	NA	NA	-94.1	-12.9	23	2	-
S2_05	Surf	9945411	812613	4260	3700	6.5	13.3	1.2	0.8	1.2	0.2	0.3	1.5	-94.2	-12.8	23	2	-
S2_20	Surf	9945449	815378	4597	6700	6.4	NA	NA	NA	NA	NA	NA	NA	-95.5	-13.4	23	2	-
S2_15	Surf	9945503	814384	4431	5700	6.9	5.6	1.2	0.8	1.3	0.3	0.4	1.5	-97.4	-13.1	23	2	-
S2_19	Surf	9945504	815186	4552	6500	6.4	9.7	1.6	0.8	1.0	0.2	0.2	1.0	-93.0	-13.4	23	2	-
S2_17	Surf	9945509	814813	4489	6100	6.6	6.3	1.2	0.8	1.0	0.2	0.3	1.5	-97.2	-12.9	23	2	-
S2_14	Surf	9945510	814192	4413	5500	6.9	NA	NA	NA	NA	NA	NA	NA	-96.9	-13.2	23	2	-
S2_18	Surf	9945524	814995	4521	6300	7.5	NA	NA	NA	NA	NA	NA	NA	-95.8	-12.8	23	2	-
S2_06	Surf	9945534	812806	4275	3900	6.5	NA	NA	NA	NA	NA	NA	NA	-95.0	-12.7	23	2	-
S2_16	Surf	9945534	814618	4460	5900	6.7	NA	NA	NA	NA	NA	NA	NA	-96.6	-12.9	23	2	-
S2_07	Surf	9945599	813004	4294	4100	6.5	10.1	1.5	0.8	1.5	0.2	0.5	1.6	-96.0	-12.6	23	2	-
S2_13	Surf	9945612	813989	4397	5300	6.9	9.5	1.2	0.8	1.2	0.2	0.4	1.4	-97.2	-13.1	23	2	-
S2_12	Surf	9945716	813831	4370	5100	7.0	NA	NA	NA	NA	NA	NA	NA	-94.0	-12.4	23	2	-
S2_08	Surf	9945758	813117	4303	4300	6.4	NA	NA	NA	NA	NA	NA	NA	-94.0	-12.6	23	2	-
S2_11	Surf	9945769	813624	4353	4900	6.9	13.1	1.2	0.8	NA	NA	NA	NA	-94.6	-12.5	23	2	-
S2_10	Surf	9945858	813448	4338	4700	6.7	NA	NA	NA	NA	NA	NA	NA	-93.3	-12.4	23	2	-
S2_09	Surf	9945899	813229	4320	4500	6.5	11.5	1.3	0.8	1.1	0.1	0.3	1.3	-93.8	-12.5	23	2	-

Table A2. Statistical summary of the chemical components and stable istopes of water samples within the Los Crespos-Humboldt basin.

	EC	**SiO_2**	**Cl^-**	**SO_4^{2-}**	**Na^+**	**Mg^{2+}**	**K^+**	**Ca^{2+}**	**δ^2H**	**$\delta^{18}O$**
Ice (n=3)										
mean	-	-	1.9	0.5	1.0	0.0	0.3	1.3	-112.7	-14.4
std	-	-	0.9	0.1	0.0	0.1	0.5	0.6	1.0	0.2
min	-	-	1.3	0.4	1.0	0.0	0.0	1.0	-113.6	-14.6
max	-	-	2.9	0.6	1.0	0.1	1.0	2.2	-111.6	-14.2
Precipitation (n=4)										
mean	17.8	0.8	2.3	1.2	1.2	0.1	0.6	2.8	-51.4	-5.9
std	15.3	0.3	1.1	0.7	0.3	0.1	0.5	2.6	8.8	1.9
min	7.9	0.5	1.3	0.7	1.0	0.0	0.1	1.1	-59.5	-8.5
max	35.4	1.1	3.8	2.2	1.7	0.3	1.1	6.7	-42.4	-3.9
Springwater (n=46)										
mean	119.9	61.0	2.8	14.9	8.7	4.5	3.5	8.5	-99.5	-13.1
std	77.7	7.2	1.7	14.2	4.8	2.1	1.1	3.1	12.0	1.6
min	7.4	46.6	1.5	0.5	3.7	2.0	2.0	5.1	-112.0	-14.8
max	339.0	69.6	6.8	38.5	18.8	8.5	5.8	14.3	-35.9	-4.2
Surface water (n=113)										
mean	59.6	34.1	1.9	3.2	3.8	2.2	1.8	4.2	-97.5	-12.8
std	53.9	18.2	0.9	4.1	3.0	1.8	1.1	2.9	6.0	0.7
min	6.3	3.7	0.8	0.4	1.0	0.1	0.2	1.0	-110.8	-15.7
max	280.0	64.5	6.4	19.1	15.6	7.1	4.9	18.5	-80.9	-10.9