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Discussions

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Interactive comment on "Mountain water cellars: a chemical characterization and quantification of the hydrological processes and contributions from snow, glaciers and groundwater to the Upper Mendoza River basin (~32° S), Argentina" *by* Sebastián A. Crespo et al.

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Responses to Referee 2, identiffied as follows: (1) comments from Referee, (2) author's response, (3) author's changes in manuscript.

Answer to Referee comment 1.

(1) The significant lack of clarity of presentation, particularly the English. There are

many parts which are not clearly formulated so a proof-reading by native speaker is strongly recommended.

(2) The manuscript was streamlined, discarding any non essential parts. We clarify the presentation, objectives and after-coming analysis. The entire manuscript is being reviewed and corrected by an ad-hoc specialist and native English speaker.

Answer to Referee comment 2.

(1) The context for the analysis is not clear. Is the aim to analyse and compare the runoff generation processes during the extra drought event (2010-2015) only? If so, then I missed some more information on how this period differs/compares with a normal situation. Is this drought defined in terms of precipitation deficit only? Or also in terms of streamflow? What are the differences to other studies on such topic? Why it is interesting/important to look at it in the Andes?

(2) We believed it is important to look at glacier-snow-river dynamics in the Andes, because many people live from water originated in these mountains. In the Central Andes more than 12 million people depend on this resource for domestic consumption, irrigation, industries, hydroelectric generation and aquifer recharge. Studies in other areas may not be extrapolated to the Andes. In addition, global change is affecting glaciers all over the world, and an understanding of glacier and river dynamics in a region with the highest peak from America contributes to the global understanding of global change. The aim of the study was clarified, and we hope it is easier to understand. Basically, the aim of the study is to estimate the contribution of different water sources to a river basin of major importance for the development of western Argentina. In particular, estimating the contributions of glaciers and groundwater justify conservation efforts being done in our and other countries, to protect glaciers and other strategic water resources for future generations. Currently, glacial and periglacial environments are protected by law, but it is not clear for policy makers and society the hydrological contribution from these environments. This study shows the importance of groundwater and rock glaciers (the

most representative periglacial environment crioform) on the water provision during dry years, when agriculture, industry and society in general suffer from water scarcity. For more clarity about the analysis period description, a figure (Fig. S1) and two tables (S8 and S9), describing the precipitation and streamflow context of the analyzed year, were added in the Supplementary data file. The context for the analysis is a melting period (December 2013 to March 2014), which in turn felt in an arid period framed by the Mega-drought. This arid condition was useful to separate more clearly the different water sources signals, without a prolonged snowmelt noise. The mega-drought is fully documented (and cited in this work) and it is not the aim of this study to describe it in the main manuscript. Because the aim of this work was to separate and quantify all the different water sources draining the basin, it should be carried out during a melting season. This works continues the work of Crespo et al. (2016), were a 2-year isotopic characterization was done. In that work a seasonal sampling time resolution was used. During that study, we started to identify some different water sources contributions. Therefore, a deeper in time resolution and focus in the main streamflow period (the melting season, which accounts for half of the year streamflow) was needed. For that purpose, we carried out this work, with a weekly resolution (instead of seasonal) along a melting period.

(3) See Figure S1 and Tables S8 and S9 in Supplementary Data file.

Context: Part of the Introduction section:

Globally, glaciers are melting at unprecedented rates and in the Andes of South America they display a widespread retreat (Masiokas et al., 2016). The water supply for the oasis irrigated by the Mendoza River depends on the recharge of snow and ice, which has been under extraordinary pressure following the mega–drought that affected the Central Andes during the 2010–2015 period (CR2, 2015; Cornwell et al., 2016). This basin is supplied mainly from snow contributions in years of normal to abundant loads (Masiokas et al., 2006). In very dry years, hydrographs show a displacement of the maximum monthly flows from January to February (Boninsegna, 2013; Lascano and

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Villalba, 2007), which indicate higher contributions of glaciers to the Mendoza River flow than during average or wet years (Bruniard, 1994). According to the monthly distribution of the hydrograph, the regime of the Mendoza River could be classified in normal years as "mitigated glacial" (Bruniard, 1994, Lascano and Villalba, 2007). However, for years of extreme drought (p.e. 1968, 2010), that maximum would be transferred to the month of February (Fig. S1, Tables S8 and S9), becoming an "ultra-glacial" regime. Some authors (Leiva, 1999; Boninsegna and Villalba, 2006; Masiokas et al, 2010; Boninsegna, 2014; Lauro et al., 2016), mention that in dry years, the decreasing stream flows do not follow the marked decrease of snowfall, which would be explained by a proportionally greater contribution of ice bodies. The importance of the glacial contribution to the flows in dry years has been recognized in the region, so a national law (Law 26639) was sanctioned to map, monitor and protect glaciers as strategic water reserves. The objetives of the Argentinean National Glaciers Inventory (IANIGLA-ING, 2010), as part of the mentioned law, include the quantification of glaciers contributions to river flows, but they have not been quantified for the Mendoza River basin to date. The more widely used techniques for ice melt quantification in a glaciated basin (outflow measurements, mass balance or/and satellite images) do not allow for the quantification of temporal changes of the contributions from different sources (i.e. from snow, glaciers, rock glaciers or groundwater). Naturally occurring tracers, such as ions and isotope composition, may facilitate such differentiation. Contact time of water with air and sediments is different for water sources such as groundwater, snow, rock glaciers and glaciers, and results in distinct ions and stable isotope composition for each water source (Crespo et al., 2016). These chemical properties provide natural tracers of flow inputs along the melting season by different water sources and sub–basins to a river. In other similar glaciated basins from different geographical regions like the Bhagirathi River in Indian Himalayas (Lambs, 2000), the use of electrical conductivity and δ18O composition served as tracers to identify water from ice, snow, and rain water. Comparable findings were published by Lambs et al. (2010) for the Garonne Valley (France), where runoff water from high altitudes was identified using stable oxygen isotopes and conductivity data from river water samples. Similarly, Pu et al. (2013), using only δ18O composition from different water sources in the Baishui River catchment (China), made a hydrograph temporal separation between rain and melt water contributions to the river, but did not differentiate between snow and ice melting (neither groundwater) contributions separately. Moreover, quantitative estimation of the diverse water sources has been achieved for the Tarim River, Central Asia, by Fan et al. (2016), where a marked seasonal variability was identified by the use of water stable isotopes and electrical conductivity. The aim of this work was to quantify the different water sources inputs from groundwater, glacial and periglacial environments along the melting season, which represents the major water contribution period in the year using two approaches: gauging glacier flows, and using naturally occurring chemical tracers.

Answer to Referee comment 3.

(1) The objectives needs to be reformulated in order to more clearly show the scientific novelty and significance compared to existing studies. The research hypotheses are in its current form rather obvious. E.g. Which environmental variables control the initial thawing. Is it not the physics and energy balance which is controlling that? I would suggest to bring forward more the context of comparative hydrology to justify the significance and contribution of the paper.

(2) The objectives were reformulated as recommended. The research novelty was more clearly expressed. The comparative hydrology analysis was incorporated (see point 3 in comment 6).

(3) Part of the new introduction section:

The importance of the glacial contribution to the flows in dry years has been recognized in the region, so a national law (Law 26639) was sanctioned to map, monitor and protect glaciers as strategic water reserves. The objectives of the Argentinean National Glaciers Inventory (IANIGLA-ING, 2010), as part of the mentioned law, include the quantification of glaciers contributions to river flows, but they have not been quantified to date. The more widely used techniques for ice melt quantification in a glaciated basin (outflow measurements, mass balance or/and satellite images) do not allow for the quantification of temporal changes of the contributions from different sources (i.e. from snow, glaciers, rock glaciers or groundwater). Naturally occurring tracers, such as ions and isotope composition, may facilitate such differentiation. Contact time of water with air and sediments is different for water sources such as groundwater, snow, rock glaciers and glaciers, and results in distinct ions and stable isotope composition for each water source (Crespo et al., 2016). These chemical properties provide natural tracers of flow inputs along the melting season by different water sources and sub–basins to a river. In other similar glaciated basins from different geographical regions like the Bhagirathi River in Indian Himalayas (Lambs, 2000), the use of electrical conductivity and δ18O composition served as tracers to identify water from ice, snow, and rain water. Comparable findings were published by Lambs et al. (2010) for the Garonne Valley (France), where runoff water from high altitudes was identified using stable oxygen isotopes and conductivity data from river water samples. Similarly, Pu et al. (2013), using only δ18O composition from different water sources in the Baishui River catchment (China), made a hydrograph temporal separation between rain and melt water contributions to the river, but did not differentiate between snow and ice melting (neither groundwater) contributions separately. Moreover, quantitative estimation of the diverse water sources has been achieved for the Tarim River, Central Asia, by Fan et al. (2016), where a marked seasonal variability was identified by the use of water stable isotopes and electrical conductivity. The aim of this work was to quantify the different water sources inputs from groundwater, glacial and periglacial environments along the melting season, which represents the major water contribution period in the year, using two approaches: gauging glacier flows, and using naturally occurring chemical tracers.

Answer to Referee comment 4.

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(1) The data description is not rigorous. I missed more information about the temporal resolution of the data and time period. Is only one season available? Is it enough to draw some more general interpretations? Are there some other/longer data sets available?

(2) The data description was better explained. This work follows the work published in Crespo et al. (2016). The 2016 paper reflects the inter-seasonal and regional analysis in a more extensive time and space resolution. The aim of this work was to characterize and quantify in a more precise time resolution (intra-seasonal, among the melting period-season) what we couldn′t define at the seasonal scale. This melting period was characterized because hydrologically it is the most relevant period for this basin, accounting for ∼50% of the year streamflow (Table S9). There are no other data sets available, no previous works quantifying the water sources (snow, glacial, periglacial or groundwater) contributions to the Mendoza River basin has been presently carried out. Long term streamflow data (1957-2017) and winter snow water equivalent (1987-2015) was added in the Supplementary document (Fig. S1 and Tables S8 and S9).

(3) See point 2 in Referee comment 2, Figure S1 and Tables S8 and S9 in Supplementary Data file.

Answer to Referee comment 5.

(1) I missed some more process based interpretation of the results. The linear regression between streamflow and some climatic data seems to me not enough to justify the interpretations about the contributions of individual variables. Why not to use a hydrological model for the analysis?

(2) The aim of the work was better explained in the actual version. Basically it is to quantify the different water sources contributions with chemical tracers and compare with streamflow data (in the ice bodies case). The environmental variables influences are a complement for the main analysis. It would be ideal to carry out a more complex hydrological modeling, but it would make the manuscript very extense and out of the

main scope of the present work. In fact, it has been suggested (by other referee and co-authors), to shorten this description. In the new version this section is significantly reduced. In any case, the influence of environmental variables on the streamflow was modeled with the generalized linear effects model, with proven and significant probabilities. The generalized linear effect model was carried out for all the environmental variables measured in stations 1 and 2 (Table S2). We also expected solar radiation statistical significance. Solar radiation may influence the ice melting but, during the period studied in the austral summer, the effect was not significant. The temperature (which probably includes the solar radiation effect), was significant. The results for the Horcones Inferior Glacier were expressed in section 3.1.1. The results for the Tolosa rock glaciers conglomerate are expressed in 3.1.2. (see 3).

(3) Section 2.1 reference: The Irrigation General Department of Mendoza weather station (labelled as 1 in Fig. 1), located at 3043 m a.s.l. in “Laguna de Horcones” (32.80°S – 69.95°W), measured: air temperature, soil temperature, wind speed and direction, relative humidity, incident radiation and snow water equivalent, hereinafter “station 1”. Air and soil temperature HOBO sensors were also installed in the Horcones Inferior Glacier (labelled as 2 in Fig. 1), at 4016 m a.s.l. (32.69°S – 69.97°W), hereinafter “station 2” (Table S2). Both stations covered an altitude gradient of 973 m. Generalized linear models (nlme package, Pinheiro et al., 2013) in the R program (R Core Team, 2013) were conducted. The streamflow was considered the response variable, as a function of environmental data (predictor variables).

Section 3.1.1. Horcones Inferior Glacier

Streamflow of the Horcones Inferior Glacier showed a similar variability as that of temperatures (Fig. 2a). The best overall linear model obtained for the total measured variables in both, stations 2 and 1 (Table S2), includes as significant variable only mean daily air temperature ($p < 0.01$). The response variable Horcones Inferior Glacier average daily streamflow, fits linearly with mean daily air temperature for both stations, following equations 8 (R2 = 0.7) and 9 (R2 = 0.6), respectively:

MDS HI= 0.2221 * MDAT2 + 0.9243 (Eq. 8) MDS HI= 0.2318 * MDAT1 - 0.6489 (Eq. 9)

For: MDS: Horcones Inferior Glacier mean daily streamflow (m3 s-1) MDAT2: mean daily air temperature (°C) in station 2 MDAT1: mean daily air temperature (°C) in station 1

The relationship between the average daily air temperatures measured at both stations 1 (3043 m a.s.l.) and 2 (4016 m a.s.l.) was also significant. The difference in temperature between the station 2 (973 m uppermost than station 1) is negative by about 7 ° C and the temperature decreases by 0.73 ° C every 100 m a.s.l., according to Eq. 10 (R2 = 0.89):

MDAT2 = -1.03833 * MDAT1 - 7.08138 (Eq. 10)

Section 3.1.2 Mt. Tolosa rock glaciers conglomerate

From all the environmental variables measured in stations 1 and 2 (Table S2), the most influential variables in the emergent flow of the analyzed rock glacier cluster, were mean daily air temperature ($p < 0.01$) and mean daily maximum air temperature ($p = 0.027$), both corresponding to station 2 (R2 = 0.56). A generalized linear modeling was performed based on this result, considering the response variable (average daily flow) regarding just those significant variables (R2 = 0.49). Subsequently, an inference of models with elimination of variables according to their significance was followed to determine the relative importance of each predictor variable, in order to simplify the model to the minimum number of variables explaining the streamflow. The most significant predictor variable was the mean daily air temperature measured in station 2 ($R^2 = 0.62$), adjusted through a third–order polynomial equation (Eq 11):

MDS T= 4E-5x 3 - 9E-5x 2 - 0x + 0.007 (Eq. 11)

For: MDS T: Tolosa rock glacier conglomerate mean daily streamflow (m3 s-1) x: mean daily air temperature (°C) in station 2

Certain threshold, around 6 °C (Fig. 2b), is needed for a higher flow delivery rate, as the air temperature increases. The isolation created by the debris layer, which in turn makes a more delayed thermal inertia for the glacier ice thawing (Østrem, 1965; Buk, 2002; Trombotto and Ahumada, 2005), could explain this behavior.

Answer to Referee comment 6.

(1) The discussion of the results can be improved. What has been learned compared to other existing studies (i.e. related to the assessment of drought controls in other regions/climates, or related to normal situation in similar regions?) In its current form it reads more as a summary.

(2) We agree. The discussion was changed to “Results and discussion” as suggested by another referee. It was streamlined and deeply changed. The focus of the discussion is the chemical quantification of each water source and its comparison with the measured streamflow for the glaciated basins, in order to show the importance of groundwater and ice bodies on streamflow. A new hydrological conceptual model was developed; pointing to the importance of doing more studies about the glacier-groundwater-river (stream-aquifer) exchanges (new Fig. 7). Conclusion was changed to “Summary and Conclusions”. In that section we recommend a catchment protection were the glacial, periglacial and groundwater inputs are originated, according with the results and the new conceptual model. Also, further work recommendation (concerning residence time analysis) is advised.

(3) New segment of discussion

Based on the results of the PCA, water isotopic composition ($\delta18O$) and electrical conductivity, the variables that mostly explained the two dimensions were used as tracers in an End Member Mixing Analysis. A mixing model with two tracers, allow the identification of three sources. Three water source types contributing to Cuevas River in December were assumed for the EMMA analysis: snow, groundwater and glaciers. The first component to melt will be the snow, which is even observed in Mt. Tolosa rock glacier conglomerate samples (Fig. 5). According to field observations, MODIS imagery analysis (Fig. 4 and 5) and station 1 data, the snow had already melted for this period before January 2014. Thus, in January and February, it was assumed that the water sources contribution to the Cuevas River changed, being rock glaciers, groundwater and glaciers (Fig. 6). Although glaciers represent 6% of the Cuevas River basin area (IANIGLA–ING, 2018a), during the analyzed melting period, the EMMA analysis shows a contribution between 8 to 9% in the months of January–February, respectively, to the total Cuevas River streamflow, and up to almost 20% in December (Table 5). This high percentage calculated for December may be due to a snowmelt from the upper elevation bands which is not detected with the markers and characterized sources. However, it is more clear that in January and February (when the signal can be purely attributed to ice melt), ice bodies contribute 8.5% (averaging both months). Rock glaciers occupy 17.6 km2 (2.6% of the Cuevas River basin area), but contributes between 47 to 34% of Cuevas River flow in January and February, respectively, according to the EMMA analysis (Table 5). Snowmelt, considered as a contributor only in December under this analysis assumption, contributes 48% to the total flow of the Cuevas River. Groundwater contributes 32, 45 and 56% for the Cuevas River flow rates corresponding to December, January and February, respectively (Table 5). This emphasizes the importance of this source, which may represent either groundwater or the continuous and discontinuous permafrost melting. When analyzing the relative contribution from each glaciated basin to the Cuevas River for each month, the streamflow (Table 4) and the EMMA results (Table 5) both methods yield different information. The streamflow measured at the Tolosa rock glaciers conglomerate represents 0.21 and 0.11% of the Cuevas streamflow for January and February, respectively (Table 4), while the EMMA shows 47 and 34% input from rock glacier source for the same months (Table 5). The small area of this conglomerate may explain the low contributions estimated with direct streamflow measurements. The larger estimates of rock glaciers input estimated with EMMA may be attributed to other rock glaciers draining the Cuevas River. For glacier contributions estimates, considering only the Horcones Inferior Glacier, just one of the 190 crioforms in the basin (IANIGLA-ING, 2018a), the measured streamflow represents 42.43 and 34.10% (for January and February, respectively) of the Cuevas River streamflow measured in Punta de Vacas (Table 5). For the same months, the EMMA estimates 8 and 9% input from the glacier source (Table 5). In this case, contributions estimated with direct streamflow measurements of one glacier are much larger than the estimated with EMMA, pointing to other processes, not considered with any of the approaches. The water delivered by glaciers might infiltrate through deep fractured aquifers and to the soil, generating a large groundwater matrix draining in the lower basin area, where the Cuevas River flows (Fig. 7). This process may change ion chemistry during water transport to the Cuevas River sampling site, increasing salinity and emerging in EMMA as groundwater source. In addition, between the glacier and the Punta de Vacas Cuevas River sampling site (in Puente del Inca), deep thermal groundwater flow to the river, probably changing its ion concentration. These results imply that the 32, 45 and 56% of groundwater contributions obtained with EMMA for December, January and February, respectively (Table 5), are composed of old glacier water infiltrated to aquifers. In EMMA with two tracers and three components, the three components form the vertices of a triangle and all the river samples must be framed by the triangle. If samples are located outside the triangle, as the Cuevas River in March, it means either that the tracers are not conservative, or there may be contributions from additional sources (Fig. 6). Puente del Inca geothermal waters may represent this additional source (Fig. 1 and 6). The Puente del Inca geothermal waters were confined in a very narrow region of the scatter plot (Fig. 3). This stable isotopes low dispersion may indicate the isolation of water, compared to the surface waters, without being affected by the fluctuations in precipitation or water melting from snow or ice bodies. The deviation to the right of the global meteoric line indicates an enrichment in 18O, probably due to prolonged isotopic exchange with the rocks at temperatures between 25 and 100 °C (Craig, 1963; Aggarwal et al., 2007). Puente del Inca geothermal water presented stable temperatures of 33°C in all samples. According to this hypothesis, the EMMA results for March, where the Cuevas River waters are outside of the triangle, can be explained by the oxygen enrichment caused by the Puente del Inca geothermal waters input (Fig. 4, 6 and 7). In the Aconcagua River of Chile, situated at the same latitude as the Mendoza River basin, an hydrograph separation, resulting from an EMMA analysis for the 2011-2012 melting period, was done by Rodriguez et al. (2014). They show a December snow contribution of 19-25% to the Juncal River, different from the 48% obtained in this work. In the Chilean work they do not discriminate between the glaciers from the periglacial (rock glaciers) and from the glacial environments. For that large group of glaciarized sources considered in that work, they calculate a contribution of 51-55% in the spring, while for our study it was 19.7% (December month, Table 5). A closer result was observed for subsurface sources, where the Juncal River basin contribution was around 20-30% to the spring flow, and 32% in the Cuevas River. Glacial contributions during the summer increased to 58-66% of the seasonal flow in the Rodriguez et al. study, and in our results were 43-55% (considering glaciers and rock glaciers). The underground sources for the summer were calculated for the Rio Juncal 2011-2012 study at 34-42%, while in our study it was between 45-56%. Although the estimates for both basins differ because of different time period and geographic location of the studies, both point to glaciers as important contributor to river flow.

Summary and conclusions section

Distinct water sources differ in composition along a melting season for both, stable water isotopes and ion chemistry. This reinforces what had been observed at a seasonal scale by Crespo et al. (2016) and allows us to estimate the relative contribution of snow, groundwater, and ice bodies to rivers. The convective summer precipitation events were detected in glaciated basin stream water stable isotope, allowing to pair singular flow increases to particular summer storm events. The snow to ice contribution transition could also be detected in a sub weekly resolution. Air temperature significantly modulates the glaciated basins streamflow along the melting period, presenting a delayed thermal inertia for rock glaciers. Periglacial (rock glaciers) and glacial environments contributions were relevant during this analyzed dry year, with ice bodies and groundwater contributing most to the Cordillera Principal rivers streamflow

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in this relatively dry period analyzed. Natural tracers indicated at least, 8-9% of the water was from glacial sources, 34-47% from rock glacier melting and between 32 to 56% from groundwater system. Direct streamflow measurements indicated large discharges for a particular glacier, Horcones Inferior, which was not detected as a proportional glacier contribution downstream at the Cuevas River, with natural tracers. This discrepancy suggests that an important proportion of water derived from glacier melting is infiltrated to groundwater, where it increases ionic composition, and then discharges downstream with the chemical signal of groundwater. Thus, the major contributor to the Cuevas River obtained with natural tracers is groundwater, which may reflect delayed water inputs incoming from glacial and periglacial environments, with some contributions of geothermal groundwater. To estimate groundwater residence times, and validate the conceptual model developed here, other tracers could be used, such as radioactive isotopes (tritium, 14C). This is the first work estimating glacial, periglacial and groundwater contributions to the Mendoza River basin, reinforcing previous assumptions about the importance of ice bodies to maintain river flows. Furthermore, this study points to the importance of glacier-groundwater-river relations, and the need of additional groundwater studies to better map strategic water source areas to be protected, in addition to those included in the National Glacier Inventory.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-212/hess-2018-212-AC1-supplement.pdf

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-212, 2018.

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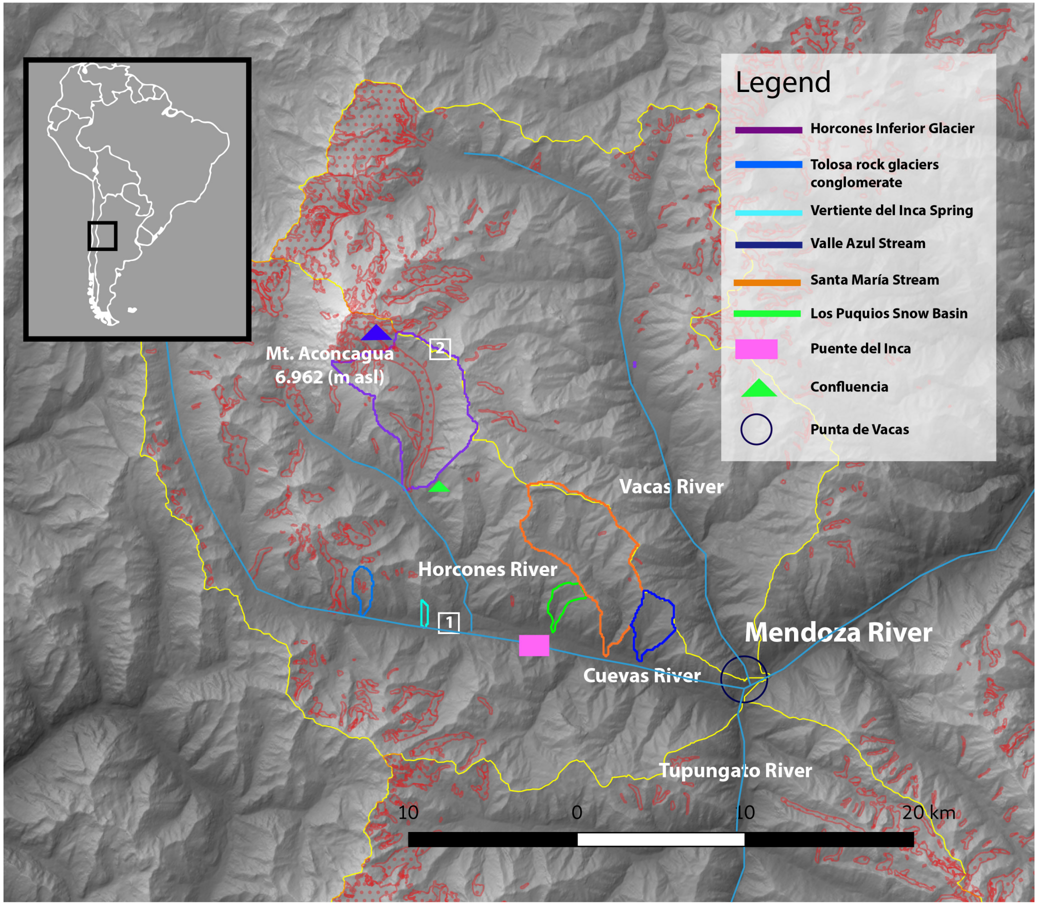

Fig. 1. Map with the digital elevation model, sampling sites and ice bodies. Glacier shapes (marked with red contour) were taken from the glacier official inventory (IANIGLA–ING, 2018a and 2018b).

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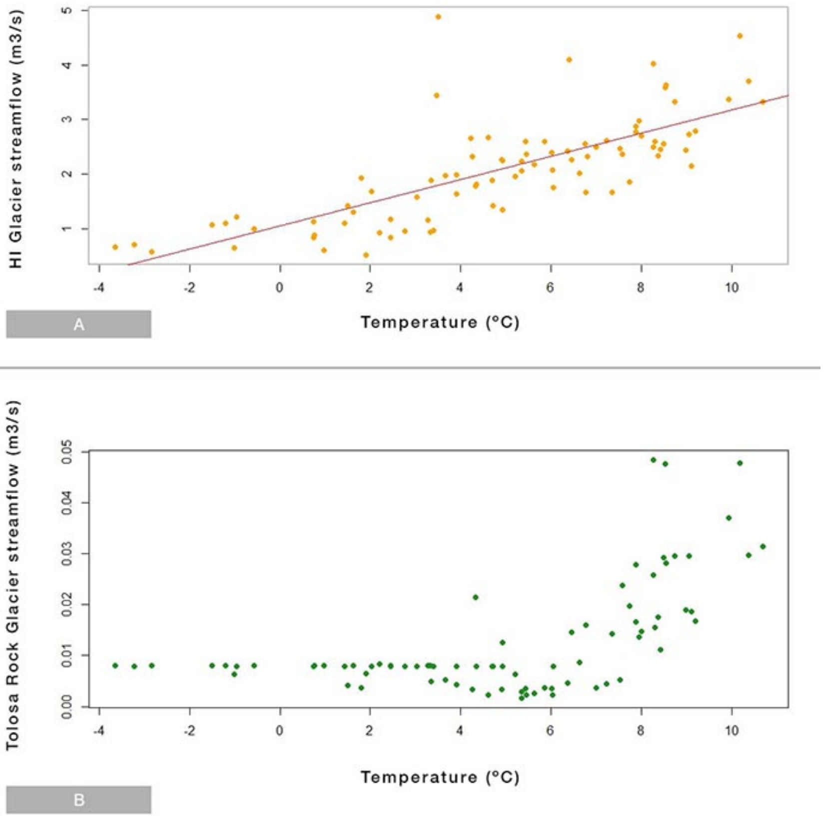

Fig. 2. Scatter plot of streamflow and mean daily air temperature for Horcones Inferior Glacier (A) and for Mt. Tolosa rock glaciers conglomerate (B).

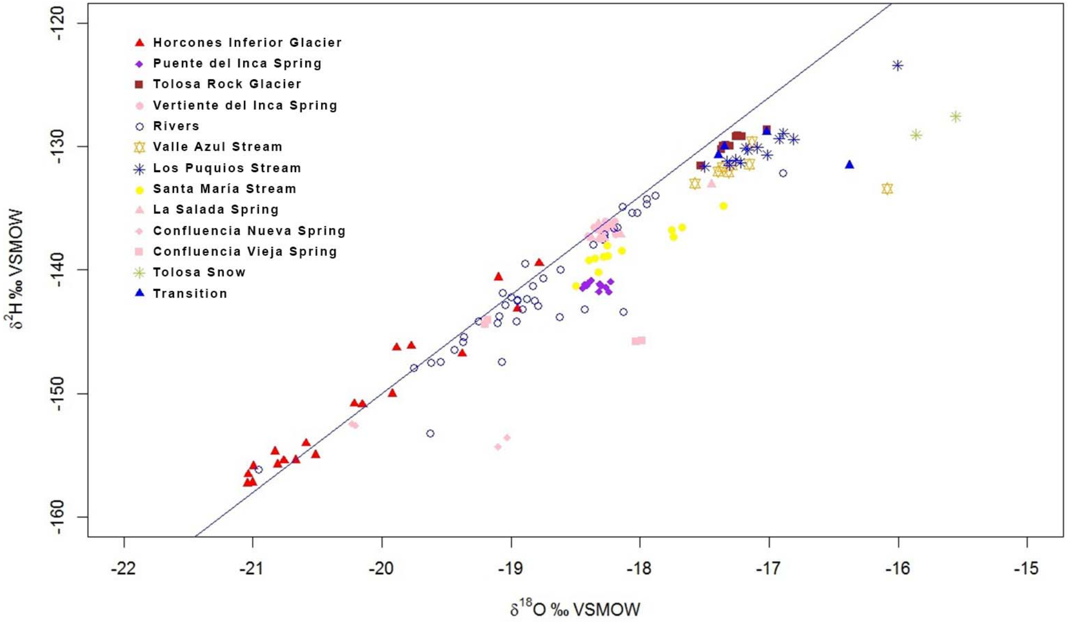

Fig. 3. δ18O and δ2H values scatter plot of the analyzed samples. The adjusted line is the global meteoric water line (Craig, 1961).

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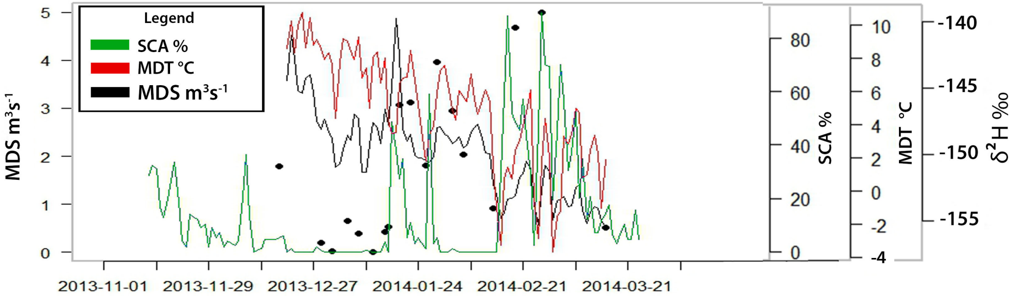

Fig. 4. Snow covered area (SCA), mean daily streamflow (MDS), mean daily air temperature (MDT) and deuterium composition of the Horcones Inferior Glacier. The black points are the δ2H water composition.

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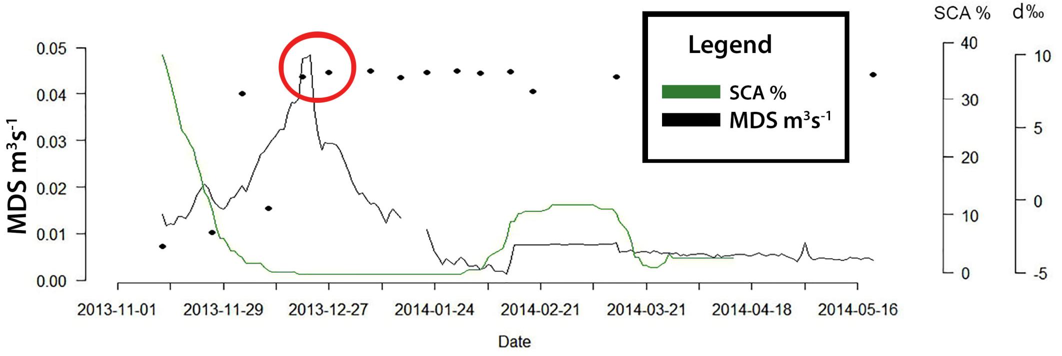

Fig. 5. Mean daily streamflow (MDS) of Mt. Tolosa rock glaciers conglomerate and snow covered area percentage (SCA). The dots are the deuterium excess values (d‰.

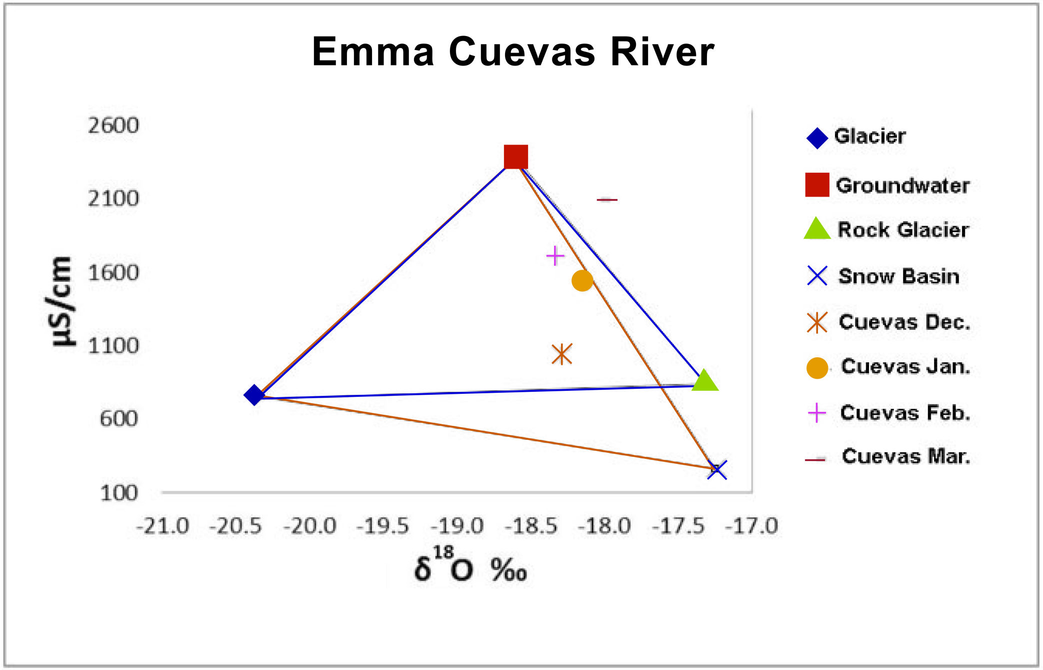

Fig. 6. Dispersion plot of mean stable water isotope composition and electrical conductivity of different water sources draining to the Cuevas River.

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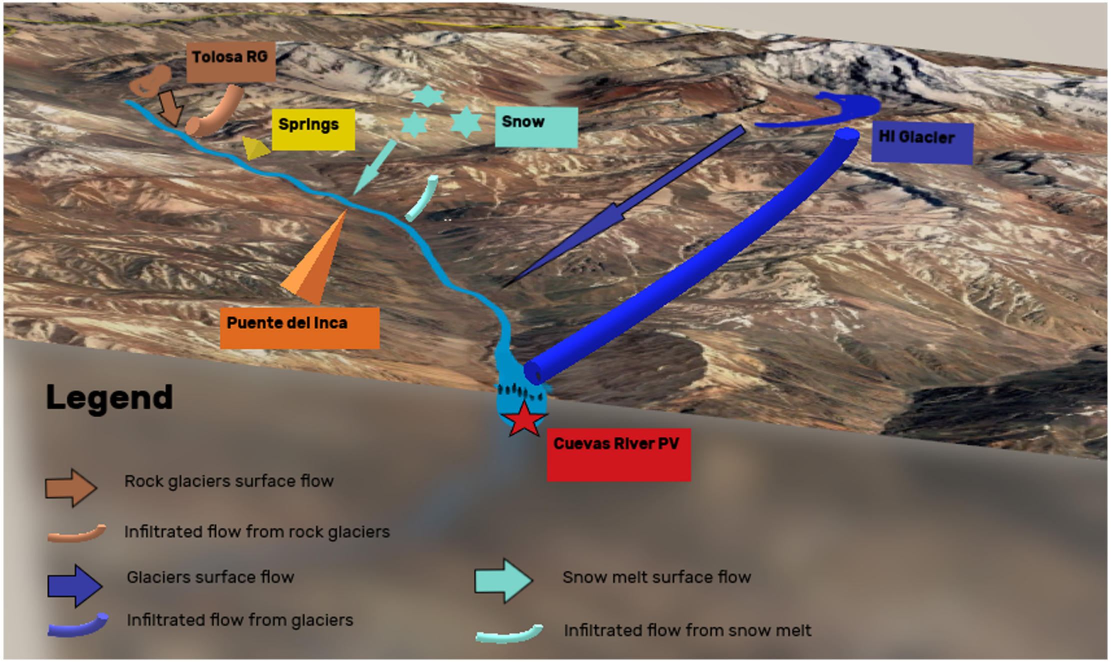

Fig. 7. Hydrological conceptual model.

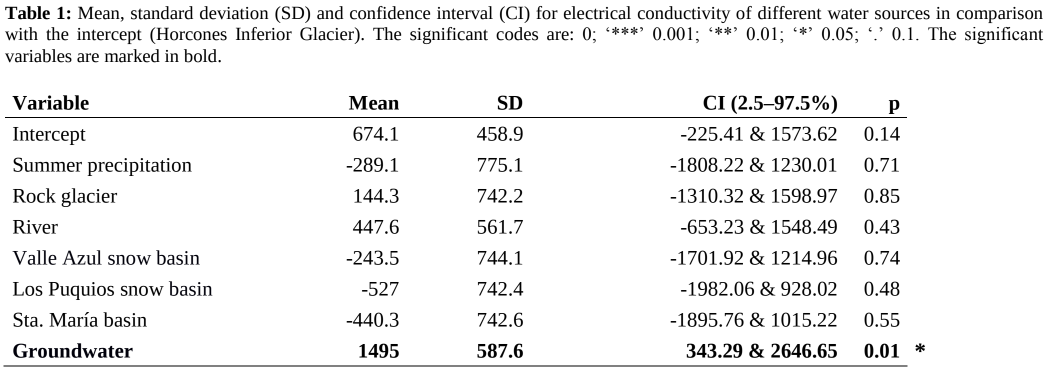

Table 1: Mean, standard deviation (SD) and confidence interval (CI) for electrical conductivity of different water sources in comparison with the intercept (Horcones Inferior Glacier). The significant codes are: 0; '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1. The significant variables are marked in bold.

Variable	Mean	SD	CI (2.5–97.5%)	p	
Intercept	674.1	458.9	-225.41 & 1573.62	0.14	
Summer precipitation	-289.1	775.1	-1808.22 & 1230.01	0.71	
Rock glacier	144.3	742.2	-1310.32 & 1598.97	0.85	
River	447.6	561.7	-653.23 & 1548.49	0.43	
Valle Azul snow basin	-243.5	744.1	-1701.92 & 1214.96	0.74	
Los Puquios snow basin	-527	742.4	-1982.06 & 928.02	0.48	
Sta. María basin	-440.3	742.6	-1895.76 & 1015.22	0.55	
Groundwater	**1495**	**587.6**	**343.29 & 2646.65**	**0.01**	*

Fig. 8. Table 1

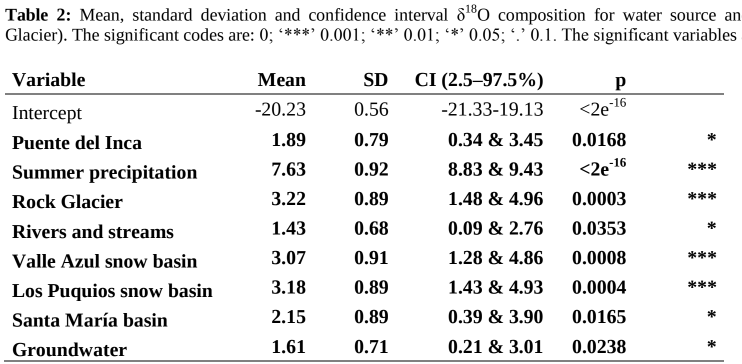

Table 2: Mean, standard deviation and confidence interval δ^{18}O composition for water source and the intercept (Horcones Inferior Glacier). The significant codes are: 0; '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.1. The significant variables are marked in bold.

Variable	Mean	SD	CI (2.5–97.5%)	p	
Intercept	-20.23	0.56	-21.33-19.13	$<2e^{-16}$	
Puente del Inca	**1.89**	**0.79**	**0.34 & 3.45**	**0.0168**	*
Summer precipitation	**7.63**	**0.92**	**8.83 & 9.43**	$<2e^{-16}$	***
Rock Glacier	**3.22**	**0.89**	**1.48 & 4.96**	**0.0003**	***
Rivers and streams	**1.43**	**0.68**	**0.09 & 2.76**	**0.0353**	*
Valle Azul snow basin	**3.07**	**0.91**	**1.28 & 4.86**	**0.0008**	***
Los Puquios snow basin	**3.18**	**0.89**	**1.43 & 4.93**	**0.0004**	***
Santa María basin	**2.15**	**0.89**	**0.39 & 3.90**	**0.0165**	*
Groundwater	**1.61**	**0.71**	**0.21 & 3.01**	**0.0238**	*

Fig. 9. Table 2

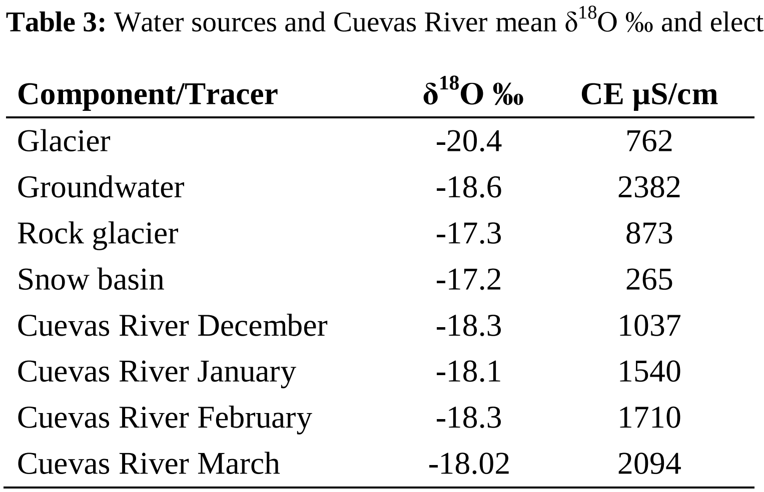

Table 3: Water sources and Cuevas River mean $\delta^{18}O$ ‰ and electrical conductivity.

Component/Tracer	**$\delta^{18}O$ ‰**	**CE µS/cm**
Glacier	-20.4	762
Groundwater	-18.6	2382
Rock glacier	-17.3	873
Snow basin	-17.2	265
Cuevas River December	-18.3	1037
Cuevas River January	-18.1	1540
Cuevas River February	-18.3	1710
Cuevas River March	-18.02	2094

Fig. 10. Table 3

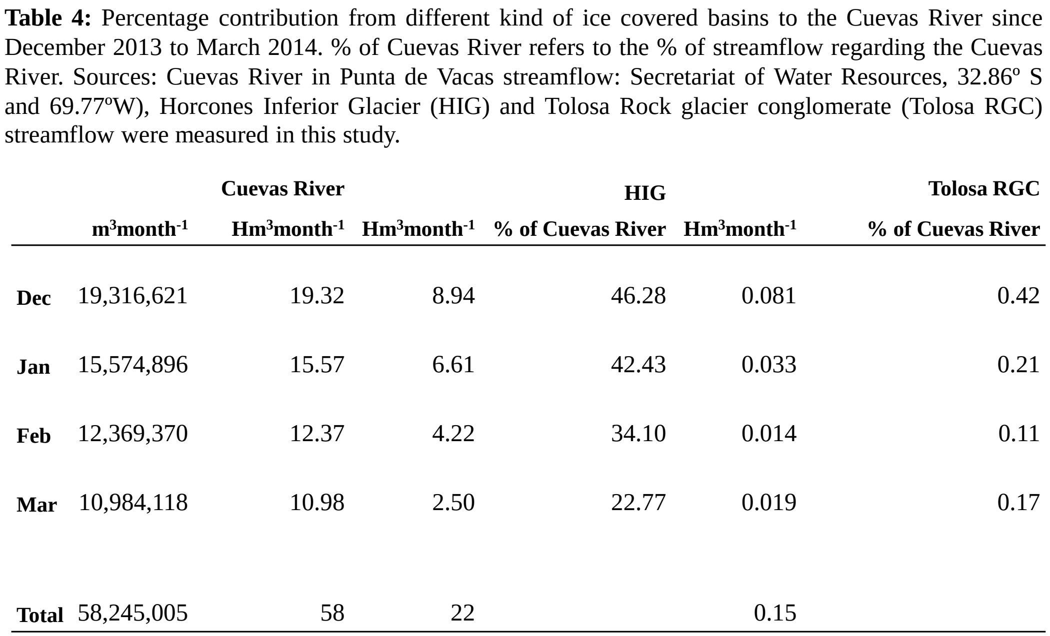

Table 4: Percentage contribution from different kind of ice covered basins to the Cuevas River since December 2013 to March 2014. % of Cuevas River refers to the % of streamflow regarding the Cuevas River. Sources: Cuevas River in Punta de Vacas streamflow: Secretariat of Water Resources, 32.86º S and 69.77ºW), Horcones Inferior Glacier (HIG) and Tolosa Rock glacier conglomerate (Tolosa RGC) streamflow were measured in this study.

	Cuevas River		HIG		Tolosa RGC	
	m^3month^{-1}	**Hm^3month^{-1}**	**Hm^3month^{-1}**	**% of Cuevas River**	**Hm^3month^{-1}**	**% of Cuevas River**
Dec	19,316,621	19.32	8.94	46.28	0.081	0.42
Jan	15,574,896	15.57	6.61	42.43	0.033	0.21
Feb	12,369,370	12.37	4.22	34.10	0.014	0.11
Mar	10,984,118	10.98	2.50	22.77	0.019	0.17
Total	58,245,005	58	22		0.15	

Fig. 11. Table 4

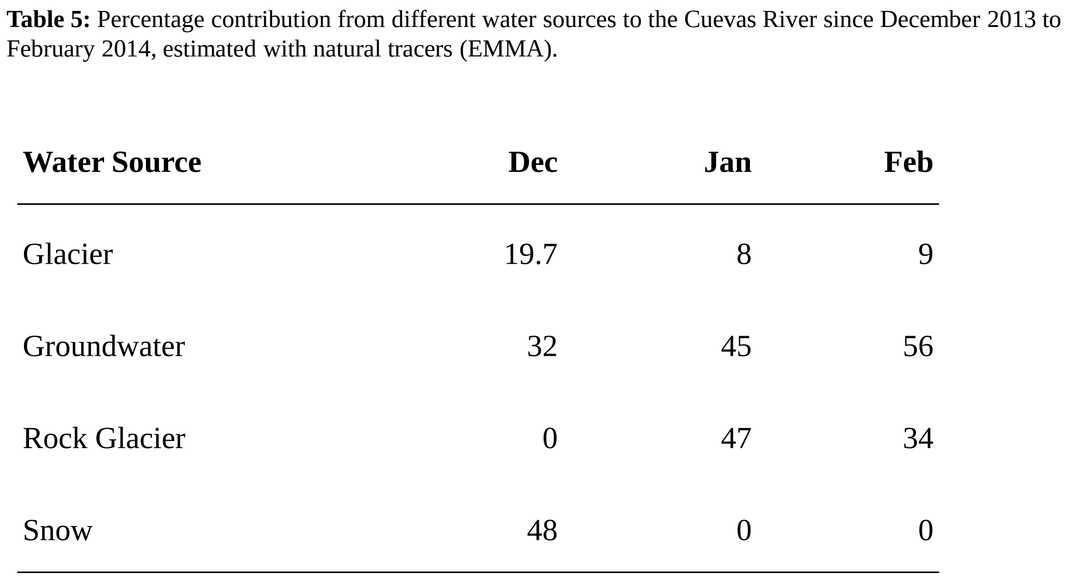

Table 5: Percentage contribution from different water sources to the Cuevas River since December 2013 to February 2014, estimated with natural tracers (EMMA).

Water Source	**Dec**	**Jan**	**Feb**
Glacier	19.7	8	9
Groundwater	32	45	56
Rock Glacier	0	47	34
Snow	48	0	0

Fig. 12. Table 5