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QUANTITATIVE GEOMORPHOLOGY APPLIED TO FLUVIAL DYNAMIC IN AVILES AND MONETA BASINS, TIERRA DEL FUEGO, SOUTHERN ARGENTINA

--Manuscript Draft--

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Abstract:	The morphometric characteristics of the Moneta river basin are compared to those of the Avilés river basin. Both are located in the north of the province of Tierra del Fuego in Argentina, and they also have their catchment area in the same range: the Sierras del Bosque; runoff on the NE oriented slopes form the Avilés river basin, while runoff on the SE slopes form the Moneta river basin. The analysis was made in two different scales: the first as a general scale of the basin, and the second as the catchment sector (upper, middle and lower). The quantitative analysis was applied in order to know the behavior of these two fluvial systems. For the analysis, a cartographic basis scale to 1: 20,000 was used, made on a mosaic of images from Google Earth ®; the altimetric information was obtained throughout a digital elevation model of 45 m spatial resolution SRTM45 (Shuttle Radar Topographic Mission). The indices used were Rr, Rb, Ish and Dd to characterize the geological and geomorphological context, and Rl, Re, If, Ct and Ca to infer the behavior of the runoff in the catchment. It was established that the Moneta river basin reaches 6 in order of hierarchy; its main channel is 65.52 km long. The Re determines an elongated basin. The Ct obtained in the basin is 0.96, whereas the sub-basin level was identified to a maximum value of the O3-SM-10 (1.46). The Dd is low (1.94 km/km2), which is directly proportional to the intensity of rainfall and the slopes of the area considered. The comparison, made at the same scale, between basins determines specific fluvial characteristics of each sector (upper, middle, lower).
Response to Reviewers:	

Ushuaia, Febraury 17, 2016

Editors by Journal: Environmental Earth Sciences

Dear Editor

We have the pleasure of submitting the following manuscript to your consideration: QUANTITATIVE GEOMORPHOLOGY APPLIED TO FLUVIAL DYNAMIC IN AVILES AND MONETA BASINS, TIERRA DEL FUEGO, SOUTHERN ARGENTINA. whose authors make a team composed of: Quiroga Diego R.A, Gil Verónica, Coronato Andrea

King Regards

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Ushuaia, February, 2017

Dear James W. LaMoreaux

I am sending the third revised version of the Manuscript Number: QUANTITATIVE GEOMORPHOLOGY APPLIED TO FLUVIAL DYNAMIC IN AVILES AND MONETA BASINS, TIERRA DEL FUEGO, SOUTHERN ARGENTINA, by Quiroga et al.

We wish to thank you and the reviewer for the time spent in improving our contribution. In order to facilitate your evaluation, this time the changes in our paper are in color green.

Please do not hesitate to contact me if you have any additional comments or concerns. Thank you again.

Sincerely yours,

Lic. Diego Quiroga

CADIC-CONICET

Justifications to the and reviewer' comments:

Reviewer #1:

1. It is observed that authors have made corrections but still some of them remained.

Quiroga et al.: *The new corrections are in color green.*

2. Abstract last line, Page 2 line 3, Page 10 line 4, page 17 line 10 and page 20 caption of Table 3 the conversion of 'low' to "lower" remained.

Quiroga et al.: *We think it was done. But the pages and lines where we made the changes do not match those the reviewer. (Page 2 line 3; page 5, line 7; Page 12, line 11)*

3. Page 11 line 2 Tab. 1 can be replaced by Table 1, similarly Page 11 line 21, page 13 line 17 etc Tab.2 can be replaced by Table 2. In spite of pointed and suggested by Editor-in-Chief in his comment No. 3 the mistake of spelling Tab. in place of Table is continued e.g. pages 27, 28, 29, etc also.

Quiroga et al.: *We think it was done. But the pages and lines where we made the changes do not match those the reviewer. (Page 7 line 1; Page 8 line 6 and 22; Page 15, Line 15, 16, 17)*

4. Page 11 line 21 "..... between 1.02 y 1.47 ....." other corrections are made in sentence but between 1.02 and 1.47 "y" still remained what is y, is it '&' you wanted to write, if then convert it as "and".

Quiroga et al.: *It was done. The letter "y" means "and" in Spanish. Sorry, we forgot to write it in English. (Page 7, line 1)*

5. Page 13 line 16 ".....highest number of sub-basins is located in the north side......" The word 'is' can be replaced by 'are'.

Quiroga et al.: *It was done. (page 8, line 19)*

6. The reference 'Gregory and Wallings 1973' is given in text but in the list of references it is mentioned as "Gregory and Walling 1973" which one is correct.

Quiroga et al.: *It was done. The second is correct. (page 11, line 8)*

QUANTITATIVE GEOMORPHOLOGY APPLIED TO FLUVIAL DYNAMIC IN AVILES AND MONETA BASINS, TIERRA DEL FUEGO, SOUTHERN ARGENTINA

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Abstract

The morphometric characteristics of the Moneta river basin are compared to those of the Avilés river basin. Both are located in the north of the province of Tierra del Fuego in Argentina, and they also have their catchment area in the same range: the Sierras del Bosque; runoff on the NE oriented slopes form the Avilés river basin, while runoff on the SE slopes form the Moneta river basin. The analysis was made in two different scales: the first as a general scale of the basin, and the second as the catchment sector (upper, middle and lower). The quantitative analysis was applied in order to know the behavior of these two fluvial systems. For the analysis, a cartographic basis scale to 1: 20,000 was used, made on a mosaic of images from Google Earth ®; the altimetric information was obtained throughout a digital elevation model of 45 m spatial resolution SRTM45 (Shuttle Radar Topographic Mission). The indices used were R_r, R_b, I_{sh} and D_d to characterize the geological and geomorphological context, and R_l, R_e, I_f, C_t and C_a to infer the behavior of the runoff in the catchment. It was established that the Moneta river basin reaches 6 in order of hierarchy; its main channel is 65.52 km long. The R_e determines an elongated basin. The C_t obtained in the basin is 0.96, whereas the sub-basin level was identified to a maximum value of the O3-SM-10 (1.46). The

D_d is low (1.94 km/km^2), which is directly proportional to the intensity of rainfall and the slopes of the area considered. The comparison, made at the same scale, between basins determines specific fluvial characteristics of each sector (upper, middle, lower).

Keywords: Morphometry, basin, water availability, Avilés and Moneta River, Argentina

1. Introduction

To define the hydrological behavior of basins is necessary to have good data set and measurements of the hydrological parameters (Tazioli 2011). Nevertheless, when they lack, morphometric analysis can give a good estimation of hydrological properties of a basin. This analysis results in a quantitative knowledge of the basins' dynamics. Horton (1945), Strahler (1952, 1964), Schumm (1956), Morisawa (1962) first proposed a variety of indices to quantify topographic/altimetric conditions related to fluvial processes in a basin. Since then, morphometric indices were used to describe and compare hydrological processes in different types of basins (Romero Díaz 1989; Leopold et al. 1992; Guido and Busnelli 1993; Senciales González 1999; Moussa 2003; Sreedevi et al. 2005; Doffo and González Bonorino 2005; Mesa 2006; Viramontes-Olivas et al. 2008; Al Saud 2009; Gil et al. 2009; Eze and Efiong 2010; Thomas et al. 2012; Jobin et al. 2012). Also, morphometric indexes have been used as quantitative tools for flood dynamics and as input for runoff modeling simulation (Esper Angillieri 2008; Diez-Herrero et al. 2008; Lastra et al. 2008; Atrayee et al. 2014; Ibrahim et al. 2015; Tazioli et al. 2015). Also, according to Soni et al. (2013), various hydrological problems of ungauged watershed are solved by different regional hydrological models, which are developed using geomorphological characteristics of the watershed.

The development of Geographic Information Systems (GIS) allows the application of algorithms resulting in better morphometric details than those obtained with former cartographic techniques (Ozdemir and Bird 2009; Paretta and Pareta 2011; Magesh et al. 2013). By using direct and indirect mapping techniques, and applying several algorithms, a first understanding of fluvial dynamics is possible in those basins without hydrometric data records (Tripathi et al. 2013; Sreedevi et al. 2013; Singh et al. 2013; Banerjee et al. 2015). This is the situation of the Avilés and Moneta river basins in the Fuegian steppe located in southern Sudamerica, Argentina. A quantitative analysis was applied in order to know the behavior of these two fluvial systems. The results determine the surface water availability and the dynamics of surficial runoff in different parts of the basins. Such results are necessary for a wiser use of water in order to satisfy water demand in the region and improve the river basin management.

2. Study Area

The Avilés and Moneta river basins are located between 53°30´ - 53°40´S and 68°01´ - 68°48´ W in Isla Grande de Tierra del Fuego, southern of the Magellan Straits. The Avilés river basin has an area of 157.28 km^2 with 21.15% of the total surface located in Chilean territory; whereas the Moneta river basin has an area of 583.61 km^2 with 32.66% of the surface in Chile (Fig. 1).

The general runoff direction is W-E. Both basins have the same catchment area: the Sierras del Bosque range (345 m a.s.l). Runoff on the NE oriented slopes form the Avilés river basin, while runoff on the SE slopes form the Moneta river basin.

The basins are developed over marine deltaic rocks from the Middle Miocene (Carmen Sylva Formation, sensu Codignotto and Malumián, 1981), marine continental and proximal rocks from the Upper Miocene (Castillo Formation, sensu Codignotto and Malumián 1981), and till and glaciofluvial deposits from the Middle Pleistocene (Codignotto and Malumian 1981; Bujalesky et al. 2001; Olivero et al. 2007). The western part of the basin consists of hills, with a SW-NE orientation, formed by sedimentary rocks with low altitude ranges (345-100 m a.s.l) and flat summits. Eroded till plains and glaciofluvial fans, with a lower gradient to the east, form the central and eastern parts of the basins.

The climate is Oceanic Cold and Subhumid, with a mean temperature ranging between 5-10 °C and aridity index value of 0.75 (Coronato et al. 2008). In the warmest months (January-February), the mean temperatures reach 9 to 10°C, while in the coldest months (July-August) the mean temperature varies between 0 to -4°C. There is a thermal gradient accentuated to the west, far from the Atlantic Ocean. Annual precipitation varies between 300 to 400 mm/yr. The driest period is November to February, during the windy summer, with values ranging between 100-200 mm/yr. Cloud cover is 70% during summer and 60% during winter (Tuhkanen 1992). The vegetation cover is *Festuca Gracillima* (Coirón dulce o fueguino), *Chiliotrichum diffusum* (Mata verde) and *Empetrum rubrum* (Brecillo o Murtilla de Magallanes).

3. Material and Methods

High resolution Google Earth® images were used as a visual reference for the morphometric analyses. Altimetry values were obtained using a 45 m spatial resolution digital elevation model (DEM) from the SRTM 45 (Shuttle Radar Topographic Mission) free downloaded from the web site www.ign.gob.ar. Altimetry control points scattered all around the study area were obtained using Differential GPS survey in order to improve the DEM spatial resolution.

A data base was conformed in ArcGis 10® platform with 10 m contour levels and 1:20.000 scale. Universal Transverse Mercator (UTM), zone 19 south and WGS84 datum were used for mapping. Fluvial morphometric analyses were developed following Strahler (1964) methodology. The main channel of the basins was defined according to the longest distance criterion (from the headwaters to the mouth). Sub-basins in both sides of the main channel were delimited. Changes along the longitudinal profile of the Moneta river basin were used to define the three parts of the basin: upper, middle and lower.

At first, a low-detail basin analysis was performed to obtain a general view. A change in scale, to a more detailed one, allowed completing the channel network and classifying sub-basins by stream order. Morphometric parameters (area, basin length, main channel length) of sub-basins order 3, 4 and 5 were combined, and several indices were obtained following Strahler (1964), Horton (1945), Schumm (1956) and Mueller (1968). Indices such as Relief ratio (R_r), Bifurcation Ratio (R_b), Stream length ratio (R_l), main channel Hydraulic Sinuosity (I_{Sh}), Elongation Ratio (Re), Drainage Density (D_d), Frequency Index (I_f), Torrential coefficient (C_t), Channel-storage capacity (C_a), Constant of maintenance channel (C_m) were obtained in the Moneta river basin.

The obtained indices were compared with those taken from the Avilés river basin (Quiroga et al. 2014). The Fluvial Intesity (D_d, I_f, C_t, C_m) and R_e index were used to compare the sub-basin of both basins. These are considered as the best tools to represent the surface runoff without other hydrological data (Senciales Gonzales 1999).

4. Moneta river basin morphometry

The Moneta river basin reaches 6 in order of hierarchy, its main channel is 65.52 km long, and it is conformed by 74 sub-basins with order 1 draining directly to the main channel (Fig.

2). Order 2 sub-basins are 57, from which 34 are developed on the north side of the main channel. Order 3 sub-basins are 17, 11 of them are on the left side of the main channel. Order 4 sub-basins are 8, and 5 of them, located on the left side and in the upper basin, are the most extensive. Two Order 5 sub-basins are developed on the left side along the upper and middle basin (Table 1).

The maximum elevation of the basin 380 m a.s.l. is in the west, while the minimum elevation is 10 m a.s.l., where the basin joins Grande river. In the east, 47% of the basin extent is over the mean elevation value (120.9 m). Most of the slope values range between 1.99 - 5.60 %, while those with values higher than 9.97% are the less represented along the basin (Fig. 3). The higher slope values are located in the middle basin reaching a maximum value of 24.68 %. The morphometric index of each sub-basin in the Moneta fluvial system is shown in Table 2.

Considering the R_r index is related to the annual loss of sediments and reflects the erosive capacity of the basin (Sala and Gay 1981), the obtained value (R_r=0.006) points to low erosive capacity for the total basin. For each sub-basin there are differences; for example, the O3-SM-16 (R_r= 0.032), which could be identified as having the highest erosive capacity, is localized in the upper basin; whereas the O3-SM-3 sub-basin has the minimum erosive capacity (R_r= 0.005) and is localized in the lower basin.

The R_b index is the ratio between the number of channel in a given order and the number of channels in the order immediately higher. The R_b for the Moneta river basin is 4.07. For the sub-basins, the maximum value obtained is 5.81 for O4-SM-6, located in the middle basin. The minimum is 2.25 for the sub-basins O3-SM-11; 03-SM-9; O3-SM-6 and O3-SM-1, located in the middle and lower basins.

The I_{sh} of the entire basin is 1.6, but in the sub-basins it varies between 1.02 and 2.17 (Table 2). The lower Ish (1.02) corresponds to SB-04-1, indicating straight channels. The higher Ish (2.17) corresponds to O3-SM-5, reflecting meandering channels. The R_l value for the entire basin is 2.65 which is generally high for this index. This ratio varies between 0.78 km (O3-SM-11) and 4.86 km (O3-SM-4) located in the middle and lower basins.

The area (A) of the basins is related to the capacity for water collection and drainage into a channel (Schumm 1956). The Moneta river basin has an area of 583.61 km^2, which corresponds to a medium-size basin, after Chow et al (1994). Order 5 sub-basins area values vary between 45.45 km^2 – 73.22 km^2 (O5-SM-2), while order 4 sub-basins have values between 14.71 (O4-SM-4) and 79.05 (O4-SM-6), and order 3 sub-basins´ values are between 1.39 km^2 (O3-SM-11) and 21.25 km^2 (03-SM-17), which correspond to small basins (Chow et al. 1994)

The Re index refers to the basins´ elongation, and it is the index which best correlates with its hydrology. It is assumed that low values represent elongate shapes in which there is a delay in runoff concentration and a reduction in flood impact (Senciales Gonzáles 1999). The Moneta river basin (06-BM) has a R_e=0.28, but order 4 and 5 sub-basins have values from 0.42 (O4-SM-8) to 0.71 (O4-SM-3), and order 3 from 0.47 (O3-SM-3) to 1.08 (O3-SM- 11).

The Frequency index (I_f), the ratio between the number of first order channels and the basin area, for Moneta river basin is 1.87, which indicates a low intensity of runoff concentration in the smaller channels. The values obtained for the sub-basins are in Table 2. The maximum value obtained is 3.6 in O3-SM-11, located on the North side, in the middle basin. The minimum value obtained is 0.65 in O3-SM-14, located on the South side, in the upper basin, close to the heads of the main channel.

The channel- storage coefficient (C_a) for Moneta river basin is 0.65. The obtained values for this index in the sub-basins vary between 0.35 (O3-SM-11) and 1.59 (O4-SM-2), both on the left side of the main channel, middle basin. The D_d value of the Moneta river basin is 1.94 km/km^2; the highest value (3.08 km/km^2) was obtained for two sub-basins (O3-SM-6 y 9) of order 3, both located on the right side of the main channel, middle basin. The minimum value of 1.14 km/km^2 was obtained for O3-SM-14 (Table 2). All these values represent low drainage density (Horton 1945; Gregory and Walling 1973; Morisawa 1985; Senciales González 1999). The C_t in the Moneta river basin is 0.96, while in the sub-basins the values vary between 1.46 (O3-SM-10) and 0.58 (O3-SM-12). The highest C_t coefficient values are in the middle basin.

5. A comparison of Moneta (Mb) and Avilés (Ab) river basins morphometric characteristics.

The Avilés river basin is located between 53°30´ - 53°40´S and 68°01´ - 68°48´ W in Isla Grande de Tierra del Fuego, southern of the Magellan Straits. Although the major basin development is in Argentina, part of the catchment area is located in Chile. The Avilés river basin has an area of 157.28 km^2, and 21.15% of the total surface is located in Chilean territory (Fig. 4). The Ab area is only 27 % of the area of the Mb. First order channels are 25 % related to the same in Mb (Ab: 276 Channel Order 1 / Mb: 1091 CO1). The highest number of sub-basins are located in the north side of the main channel.

The R_r index values indicate low relief energy and low erosive capacity for both basins (Table 2). The bifurcation index (R_b) is similar for both basins. But when the R_b between orders is analyzed, the drainage anomalies are shown between order 3, 4 and 5 in Avilés river basin. Meanwhile, Mb shows a geometric progression, which starts with the unique channel of order 6 and grows in a constant relationship between orders and number of channels (Fig. 5).

The R_l of Avilés river basin has a higher value (6.55) in relation to Moneta river basin (2.65). Figure 6 shows the stream length ratio of both basins. The trend line remains a positive exponential regression in both basins. However, the Avilés river basin presents a deviate from the trend line in orders 3 and 4. This is due to differences in the geomorphological conditions presented by its lower part in comparison to the rest of the basin. Quiroga et al. (2014) explains that in the lower Ab there is a small number of sub-basins of order 3, and they present long channels parallel to the mainstream. This is a result of the actual runoff occurring on a glaciofluvial fan and paleobays (Bujalesky et al. 2001).

The Mb I_{sh} value is higher than the Ab value (1.60 vs 1.47), but both represent the development of sinuous channels. The D_d value is lower than 2 km/km^2, which indicates low erosion capacity and low water availability for surficial runoff. The C_t value (1) indicates and reinforces the low torrential dynamics for both basins. Although both basins have a similar I_f value, it is higher in the Mb due to the higher number of order 1 channels. As a consequence, the intensity of concentrated runoff should be more intensive in this basin. The main difference between basins´ morphometrics is the C_a values (1.38 (Ab) vs 0.65 (Mb)), which indicates that the flood peak is less modulated in Mb. The R_e values indicate that both basins are elongated. The C_m value is similar in both basins, indicating that 0.5 km^2 is the minimum area required to originate and maintain a 1 km-length channel.

5.1 Basin sectors comparison

The Area, Elongation ratio and Fluvial Intensity values (C_a, D_d and C_t) for each basin sector are shown in Table 3, Figure 2 and 4, but some considerations are made in the following paragraphs.

5.1.1 Upper basins

The D_d value is higher in the Mb than in the Ab (2.16 vs 2.02 km/km^2), where soft sediments occupy a huge area, but relative relief is lower than in the Mb. The C_t values are similar in both basins (Ab: 0.92, Mb: 0.96). The C_a is higher in the Ab than in the Mb (0.71 vs. 0.61), so the upper basin of the Ab has more capacity for flood mitigation. The R_e index shows more elongation in Ab (0.84). These morphometric characteristics in the Mb, coupled with the area and the amount of order 1 channels, indicate higher torrentially conditions in response to precipitation or snow-melting events.

5.1.2 Middle basin

The Ab values of D_d, C_a and C_t are less than in the Mb. The Re index values show elongated shapes in both middle basins. This means that the middle Ab has more capacity for flood mitigation and, consequently, erosion processes are less frequent.

5.1.4 Lower Basin

The D_d is higher in the Mb than in the Ab (2.01 vs. 1.35 km/km^2), but the C_t (0.94 vs. 0.97) and the C_a (0.69 vs. 1) are lower. The lower basin of Moneta system has the best capacity for flood mitigation.

Results and discussion

In the Ab and Mb basins, which are ungauged, the results of the indices allow a better description of the river dynamics. The bifurcation ratio (R_b) is similar in each basin, but the stream length ratio is different. If analyzed in terms of orders, these differences can be explained by the change in geomorphological conditions between them.

The R_e is low in both basins indicating a delay in the concentration time of water and an attenuated peak discharge in the stream channel (Strahler 1964; Diez Herrero et al. 2008).

However, Senciales Gonzales (1999) explains that low values of this index may indicate a sudden flood once the water is concentrated in the main channel. This can be further understood by taking into account the slopes of the basin and the main channel. In the Moneta river basin and Avilés river basin comparison, the former has higher slopes than the latter. This is probably the cause of flash flood events in the Moneta river basin. Then, the R_e value must be accompanied by the analysis of slope to make it more representative of actual conditions.

Drainage Density (D_d) is similar in both basins (Ab: 1.90; Mb: 1.94), and these values are considered low drainage density and thick texture by Gregory and Walling (1973), Morisawa (1985), Senciales Gonzalez (1999). According to Marchetti (2000), this index is directly proportional to the intensity of the rainfall and the slope of basin. The relief characteristics in a basin have a direct relationship with the erodibility and an inverse relationship with permeability. In the study area, relative variations occur at sub-basins and are due to lithological and geomorphological differences previously stated. These have influence in infiltration and erodibility of the sub-basins.

According to Gil et al. (2009) the C_a decreases as the drainage density increases. The authors suggest that the larger amount of water available to generate runoff, due to the low infiltration (low C_a), the higher is the drainage density. In the case of Ab sub-basins, the D_d decreases from the upper reaches to the lower ones as the C_a increases its value. In Mb, the D_d is maintained while C_a varies. This could be due to differences in the characteristics of relief, which is steeper in the middle basin.

The Constant of Channel Maintenance (C_m) shows, in these cases, that in areas with a surface of high permeability rainfall infiltrates the soil. These values are similar to those suggested by Morisawa (1962) and Ghosh (2011).

Conclusions

The morphometric analysis of the Moneta river basin established that the Mb reaches 6 in order of hierarchy, and it is formed by 158 sub-basins. Its main channel is 65.52 km long, the mean elevation of the basin is 120.9 m a.s.l., and the maximum is 380 m a.s.l. These characteristics determine a relative low relief basin, mainly moderate slope values mostly soft in the middle and upper basin. The value of I_{sh} indicates the development of sinuous channels, as a response to the values of moderate slope. According to the shape and size indexes, the Moneta river basin is defined as an elongated (R_e 0.28) medium size basin (583.61 km^2). Finally, the fluvial intensity corresponding to river indexes define it as a basin with torrential behavior. The morphometric analysis of the river basin by sectors (upper, middle and lower) indicates that the middle and upper basins are more torrential than the lower ones.

The Ab area represents the 27% of the Mb area. The channel of the order 1 represents 25% of the Mb. The spatial dimensions are one of the main differences between the basins. With respect to R_b, in both basins it is similar. The R_l differs establishing the Mb has higher values. The R_e of both basins is low, indicating that they are elongated. This indicates a delay in runoff concentration and a reduction in flood impact. This index together with the geomorphological condition (slope), explains the presence of flash floods in Mb contrary to Ab. Finally, the indices representing the fluvial intensity of both river basins are define with low D_d. In the Ab, the value of D_d decreases from the upper reaches to the lower, while the value of C_a increases; however, in Mb the D_d is constant, and the C_a varies. This variation is related to the geomorphological conditions.

The importance of morphometric analysis of a basin at different scales (basin, basin sectors and sub-basins) allows inferring some of its fluvial dynamics and hydrological characteristics. The change of scale for the basin study enables to acquire a detailed behavior approach in each basin sector, and how it may relate to the rest. This is a first stage in further investigations which are being carried out in order to improve the hydrology and hydro-geomorphology knowledge of ungauged basins. Until a gauging system works in the future, the results herein presented are taken as tools which will improve the management strategies of water resources and catchment planning.

Acknowledgements

We deeply thanks to María Behety, Los Flamencos, San Julio and El Salvador ranches staffs for allowing working into their fields. The Estación Astronómica Río Grande – *EARG*- helps in logistics. Geologist Laura Smith (laura.ko.smith@gmail.com; Princeton University) reviewed the language style. PICT FONCYT 2012-0628, supported this work.

Figures and tables list

Figures

- **Fig. 1:** Location of the studied basins.
- **Fig. 2: A)** Sub-basins with hierarchy order higher than 3; **B)** Moneta sub-basins and main channel. Since the streams do not have a local designation, the corresponding sub-basins were identified using a code which refers to: O=hierarchy order number; S=sub-basin, M= Moneta; number which individualize the basin from others with same order (i.e.: O3-SM-4= Moneta Sub-basin, order 3, number 4).
- **Fig. 3:** Slope map (values in % of the Moneta river basin)
- **Fig. 4:** Avilés river valley in different sectors of the basin. Modified from Quiroga et al. 2014
- **Fig. 5:** Bifurcation ratio for Moneta and Avilés river basins.
- **Fig. 6:** Rl values for Moneta and Avilés river basins.

Tables:

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- **Table 2:** Morphometric indixes for Avilés and Moneta fluvial system subbasins.
- **Table 3:** Basin morphometry by sectors (upper, middle and lower).

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Tables

Side	Order			
	2	**3**	**4**	**5**
North	23	11	5	2
South	34	6	3	0
Total	57	17	8	2

Table 1: distribution of sub basin of the main stream side

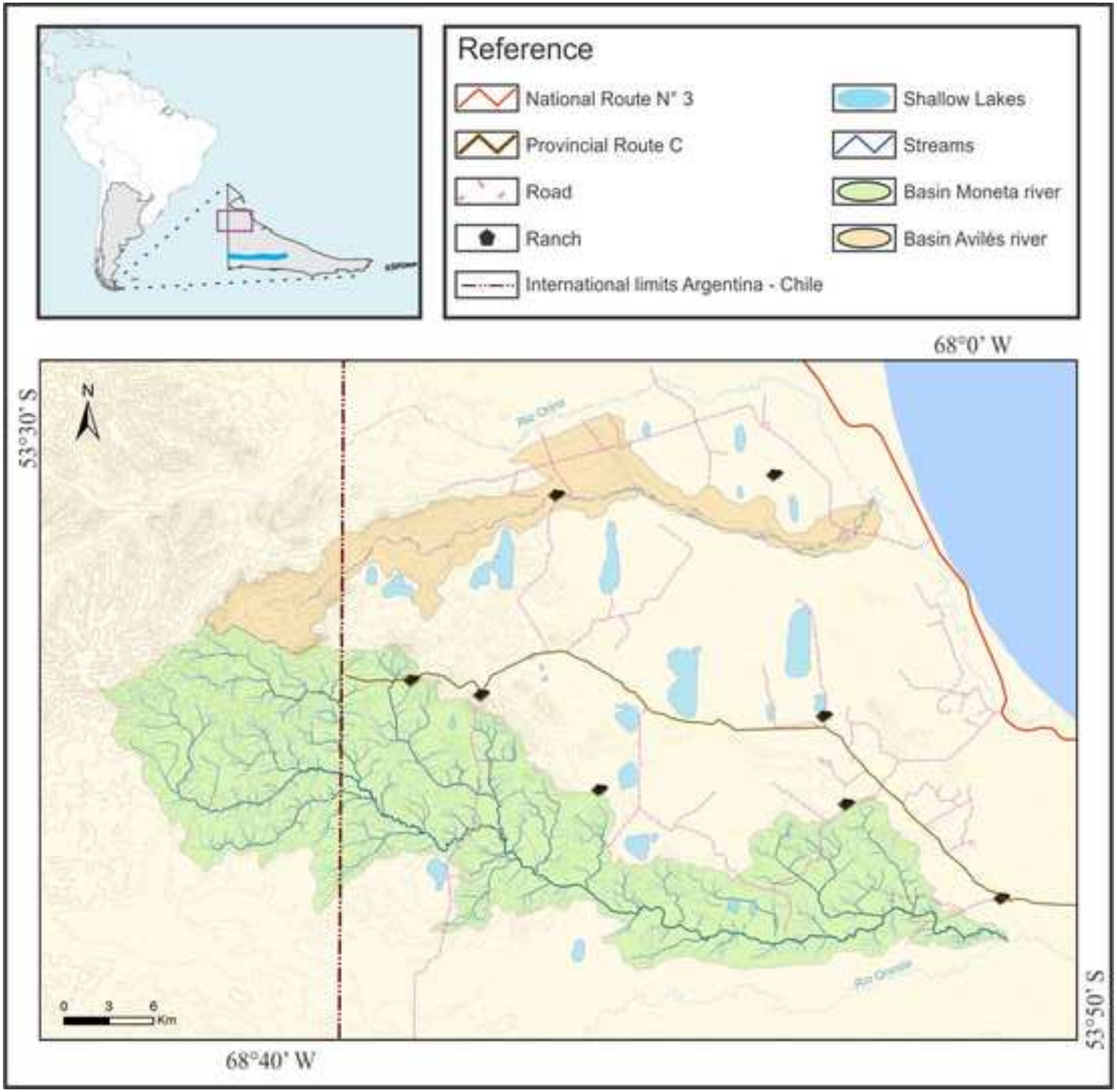
Variables	Topology and length				Shape and size				Fluvial intensity			
Sub basin	Rr	Rb	Ish	Rl	A^2 (km^2)	P (Km	L-Cca (m)	Re	If	Ca	Dd	Ct
Ab-O5	0.007	4.40	1.47	6.55	156.75	132.7	47866.8	0.22	1.76	1.38	1.90	0.92
Mb-O6	0.006	4.07	1.60	2.65	583.61	192.56	62759.0	0.27	1.87	0.65	1.94	0.96
O3-SM-1	0.014	2.25	1.13	0.98	1.55	5.19	2067.2	0.80	3.22	0.43	2.79	1.15
O3-SM -2	0.020	3.00	1.17	1.53	4.26	9.40	3449.7	0.70	2.11	0.51	2.16	0.96
O3-SM -3	0.005	3.75	1.08	2.66	6.84	14.57	5923.0	0.47	1.61	0.71	2.11	0.76
O3-SM -4	0.019	4.13	1.47	4.86	8.50	14.90	4744.5	0.55	2.00	1.18	2.16	0.92
O3-SM -5	0.017	3.63	2.17	3.18	4.69	10.39	3688.4	0.57	2.77	0.88	2.19	1.27
O3-SM -6	0.023	2.23	1.17	1.79	1.50	7.02	2347.6	0.53	1.59	0.79	3.08	1.08
O3-SM -7	0.020	2.83	1.19	2.63	4.67	3.95	3675.7	0.78	1.71	0.93	1.81	0.95
O3-SM -8	0.018	3.00	1.30	2.47	2.33	7.70	2676.6	0.58	3.43	0.82	2.38	1.44
O3-SM -9	0.023	2.25	1.14	1.78	1.50	7.02	2347.6	0.53	3.34	0.79	3.08	1.08
O3-SM -10	0.021	2.75	1.08	1.88	2.27	6.81	2448.5	0.73	3.09	0.68	2.11	1.46
O3-SM -11	0.026	2.25	1.06	0.78	1.39	4.92	1691.1	1.08	3.60	0.35	2.60	1.39
O3-SM -12	0.016	2.67	1.18	1.32	7.36	11.94	3860.2	0.71	0.95	0.49	1.65	0.58
O3-SM -13	0.017	2.75	1.25	2.42	3.54	9.25	3376.5	0.54	1.98	0.88	2.16	0.91
O3-SM -14	0.022	3.00	1.08	3.03	12.31	17.25	6315.1	0.67	0.65	1.01	1.14	0.57
O3-SM -15	0.023	3.00	1.11	1.42	8.49	13.37	3553.2	0.88	1.06	0.47	1.69	0.63
O3-SM -16	0.032	5.00	1.26	1.80	17.34	19.37	5608.1	0.66	1.21	0.36	1.92	0.63
O3-SM -17	0.012	4.20	1.19	3.26	21.25	23.44	9335.2	0.54	0.80	0.78	1.16	0.69
O4-SM -1	0.018	3.53	1.02	2.25	19.98	23.96	8016.1	0.63	1.80	0.64	1.86	0.97
O4-SM -2	0.016	3.03	1.09	4.83	16.48	19.19	6417.2	0.68	1.40	1.59	1.65	0.85
O4-SM -3	0.019	3.33	1.28	2.13	18.08	20.33	7017.6	0.71	1.77	0.64	1.90	0.93
O4-SM -4	0.011	2.96	1.23	2.06	14.71	21.54	7666.7	0.48	1.56	0.70	2.15	0.73
O4-SM -5	0.007	3.67	1.15	1.77	20.06	24.05	8899.4	0.53	1.99	0.48	2.16	0.92
O4-SM -6	0.016	5.81	1.35	4.18	79.05	53.91	15552.7	0.49	2.02	0.72	2.08	0.97
O4-SM -7	0.006	4.15	1.39	4.56	37.36	39.41	12833.7	0.42	1.79	0.86	1.90	0.94
O4-SM -8	0.015	3.96	1.43	1.90	24.46	22.71	6158.1	0.66	2.48	0.48	2.07	1.16
O5-SM -1	0.014	3.16	1.45	1.89	45.45	32.16	9745.2	0.66	1.87	0.50	1.80	0.99
O5-SM -2	0.015	3.63	1.28	2.50	73.22	46.61	15662.2	0.49	1.98	0.69	1.80	1.10

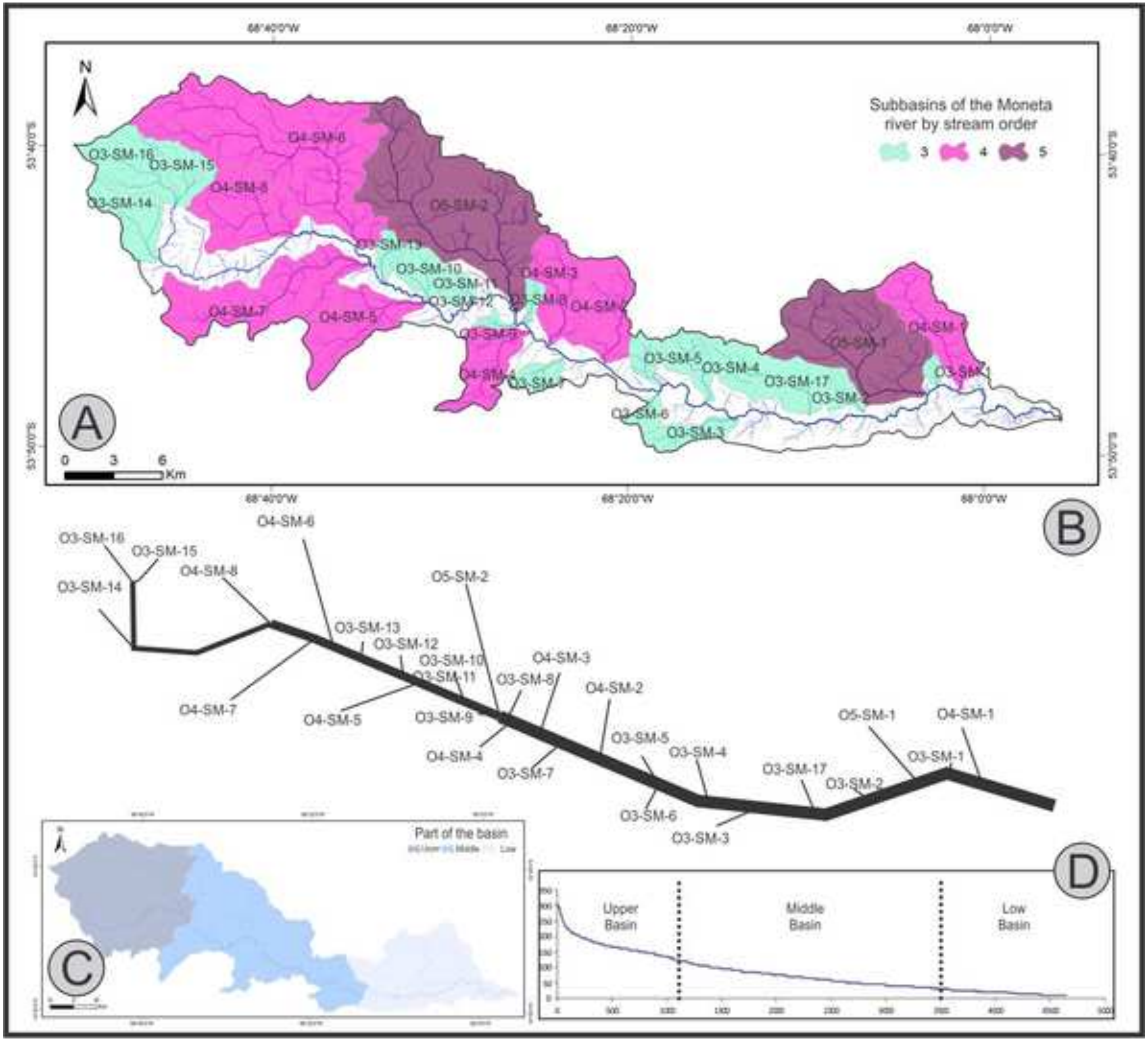
Table 2: morphometric indices for Avilés and Moneta fluvial system sub-basins

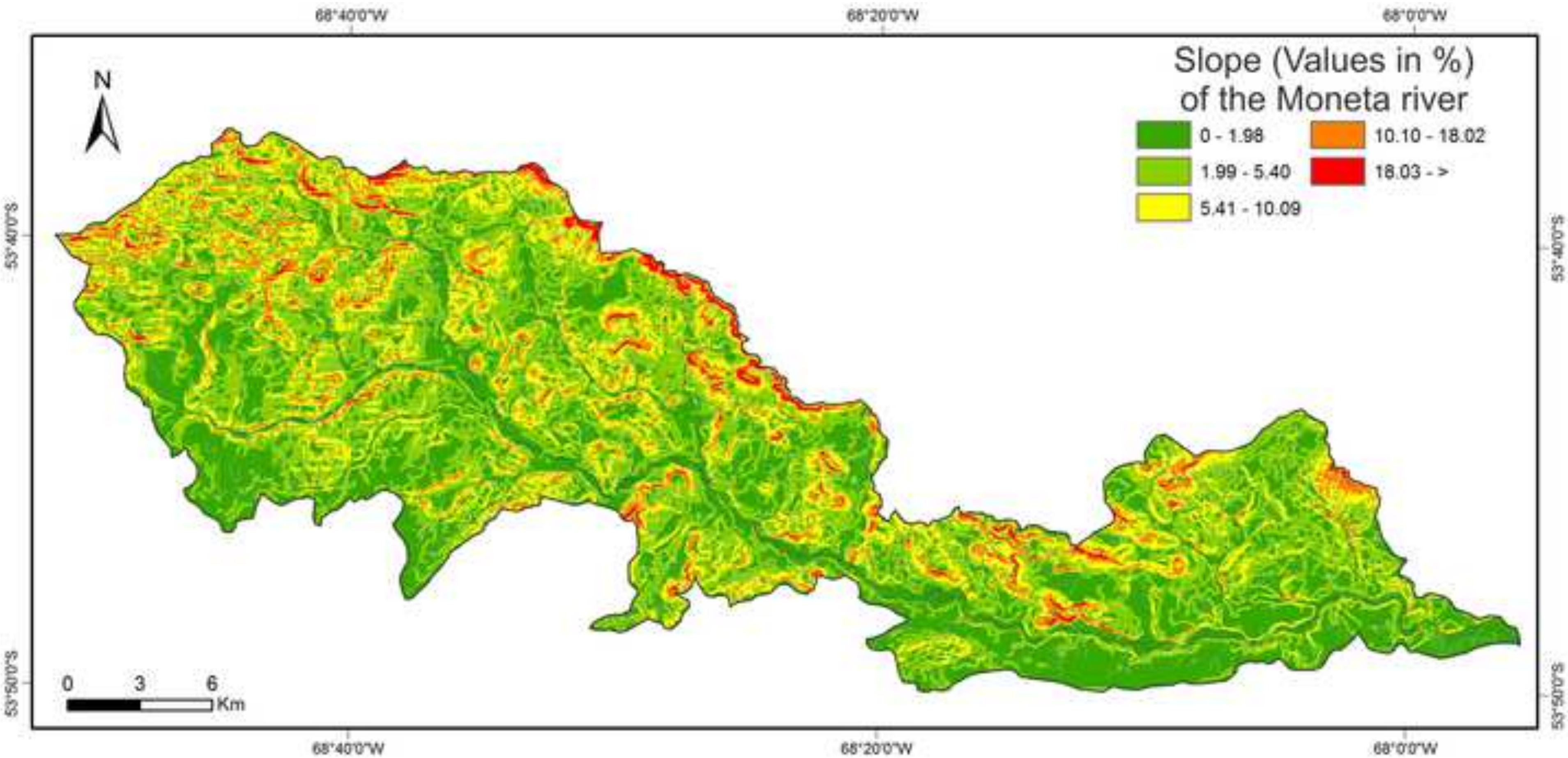
Basins		**N° O1**	**Surface km^2**	**Ca**	**Ct**	**Dd**	**Re**
Upper (BU)	Avilés (Ab)	75	39.63	0.71	0.84	2.16	0.84
	Moneta (Mb)	403	211.59	0.61	0.89	2.02	0.61
Middle	Avilés (Ab)	150	32.25	0.88	1.48	1.99	0.65

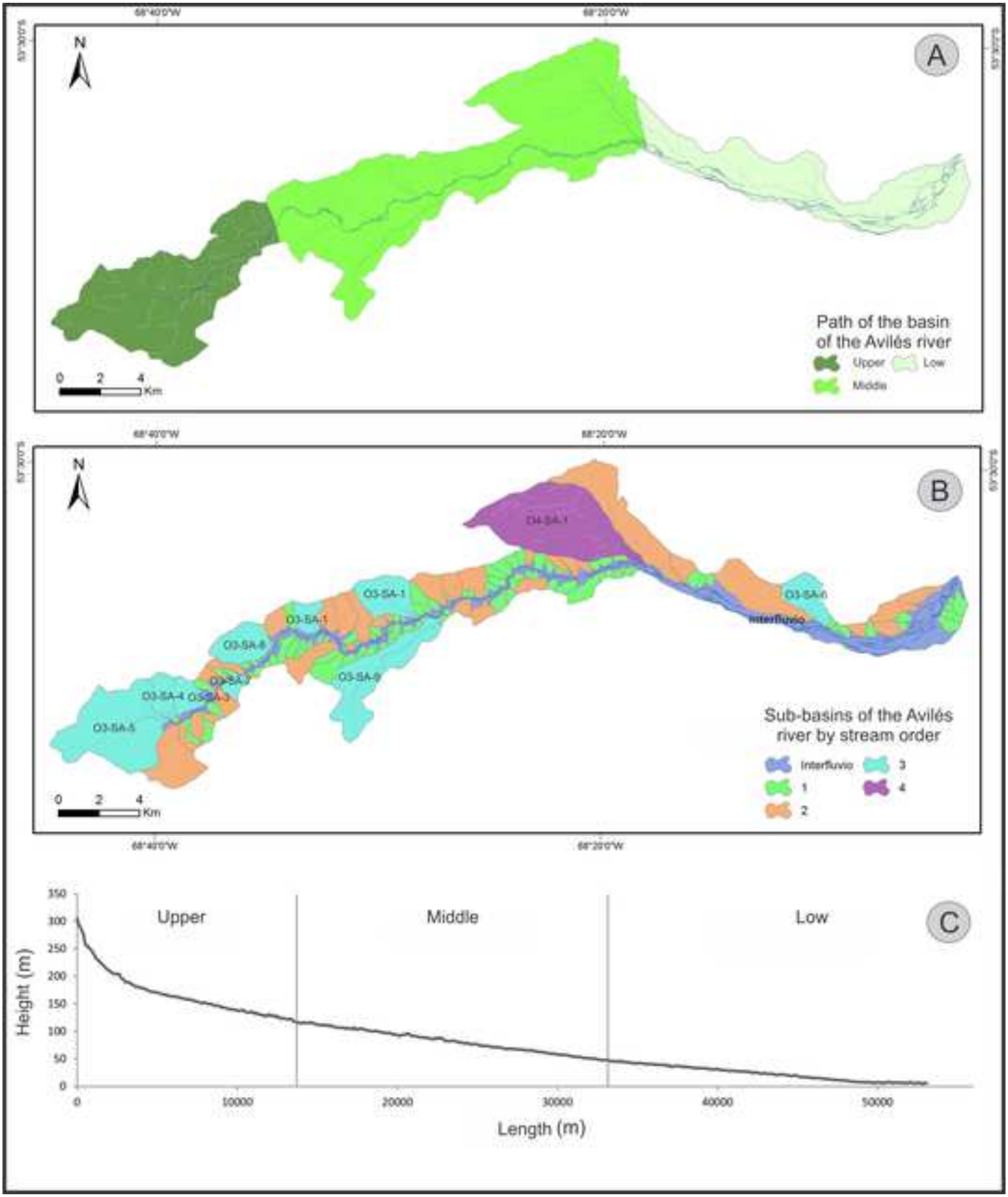
(BM)	Moneta (Mb)	427	235.54	0.72	1	2.08	0.63
Lower (BL)	Avilés (Ab)	37	32.25	1	0.97	1.35	0.63
	Moneta (Mb)	254	139.08	0.69	0.93	2.01	0.65

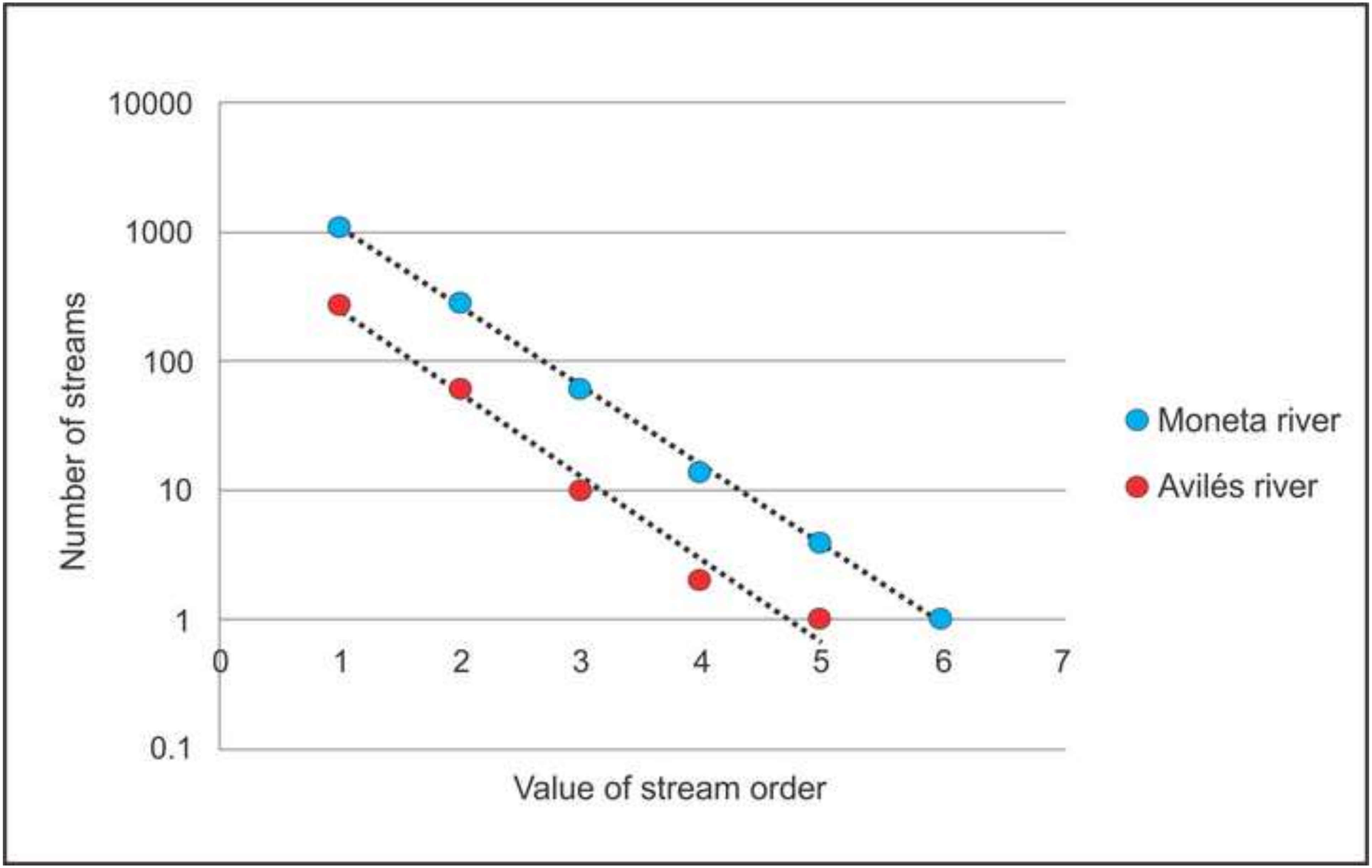
Table 3: basin morphometric by sectors (upper, middle and lower)


Reference
National Route N° 3
Provincial Route C
Road
Ranch
International limits Argentina - Chile
Shallow Lakes
Streams
Basin Moneta river
Basin Avilés river
68°0' W
53°30' S
N
Río Chico
Río Grande
0 3 6
Km
68°40' W
53°50' S

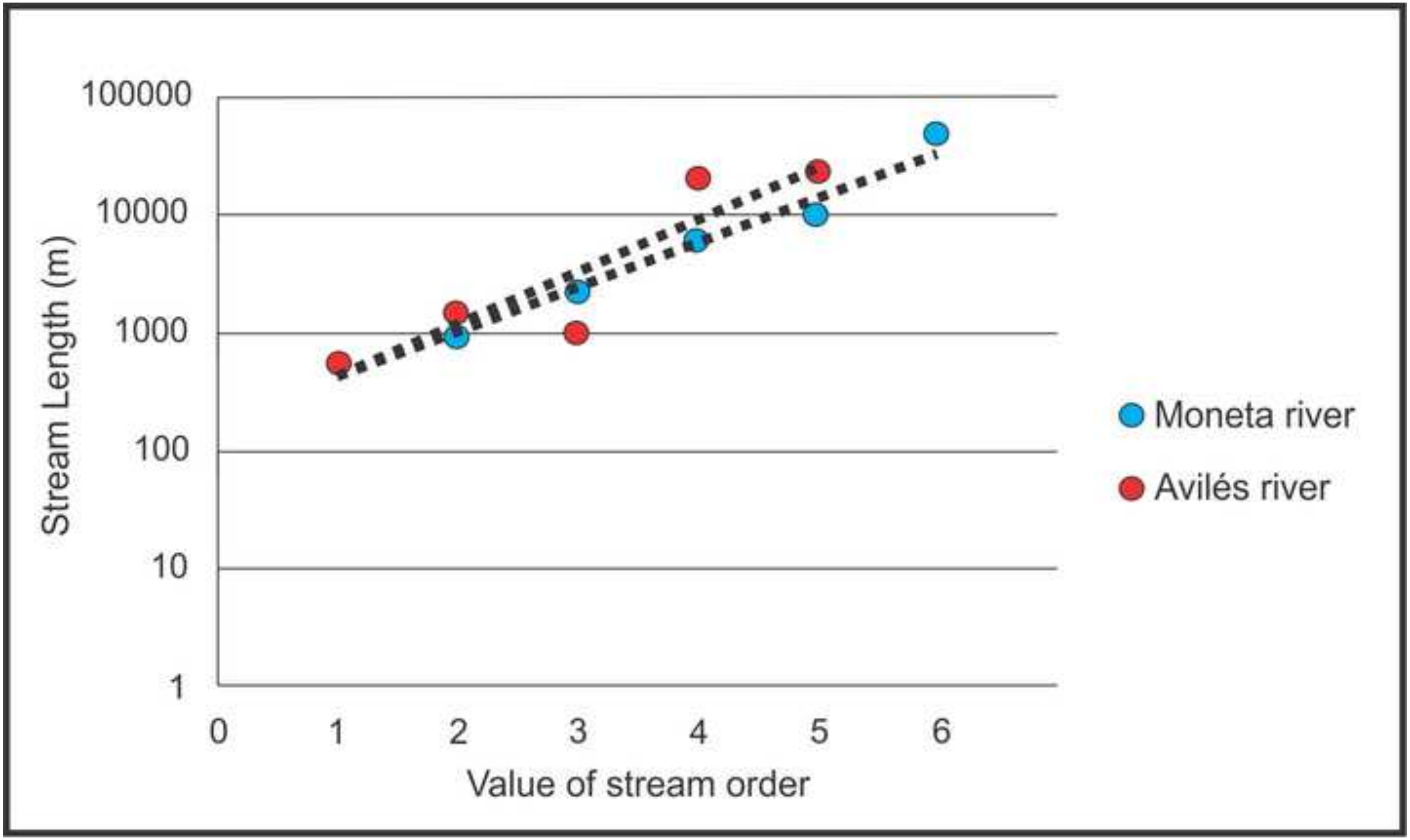

68°40'0"W
68°20'0"W
68°0'0"W
53°40'0"S
53°50'0"S
N
Subbasins of the Moneta river by stream order
3
4
5
O3-SM-16
O3-SM-15
O4-SM-6
O4-SM-8
O3-SM-14
O5-SM-2
O3-SM-13
O3-SM-10
O3-SM-11
O3-SM-12
O4-SM-3
O3-SM-8
O4-SM-2
O4-SM-7
O4-SM-5
O3-SM-9
O4-SM-4
O3-SM-7
O3-SM-5
O3-SM-4
O3-SM-17
O3-SM-2
O5-SM-1
O4-SM-1
O3-SM-1
O3-SM-6
O3-SM-3
A
0 3 6
Km
B
C
Part of the basin
D
Upper Basin
Middle Basin
Low Basin


Slope (Values in %)
of the Moneta river
0 - 1.98
1.99 - 5.40
5.41 - 10.09
10.10 - 18.02
18.03 - >
N
0 3 6
Km
68°40'0"W
68°20'0"W
68°0'0"W
53°40'0"S
53°50'0"S


A
N
Path of the basin
of the Avilés river
Upper
Low
Middle
0 2 4
Km
B
Sub-basins of the Avilés
river by stream order
Interfluvio
1
2
3
4
O4-SA-1
O3-SA-1
O3-SA-6
O3-SA-5
O3-SA-4
Interfluvio
C
Upper
Middle
Low
Height (m)
Length (m)
0
10000
20000
30000
40000
50000
50
100
150
200
250
300
350



10000
1000
100
10
1
0.1
Number of streams
0
1
2
3
4
5
6
7
Value of stream order
Moneta river
Avilés river


100000
10000
1000
100
10
1
Stream Length (m)
0
1
2
3
4
5
6
Value of stream order
Moneta river
Avilés river