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Channel Pattern and Flow Rate Analyses of the Juruá River, Northwest of Brasil

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Abstract: *This paper aim to describe the flow rate and fluvial morphology of the Juruá River, Amazonas, Brazil. Using Agência Nacional de Águas (ANA) and Instituto Nacional de Meteorologia (INMET) hydrology and climatology datas. Associated with Landsat and SRTM images interpretations. Thus, according the analyzes, this river in Brazil start with a 559 m^3/s mean flow rate in the Porto Walter, gradually increasing until the connection with Taraucá River. Where increase the mean flow rate from 1,832 to 4,227 m^3/s in this place. Returning to stabilize from this point to 4,882 m^3/s in the last station. According to fluvial morphology, it is classified like a high sinuosity meandering river with high-suspended load and relative stability. Showing sinuosity degree varying from 1.65 from Porto Walter to 3.26 next to Eirunepé.*

Keywords*: discharge, meandering channel, sinuosity, fluvial*

1. INTRODUCTION

The Juruá River come from Peruvian Amazonia, intensifying in Brazil by the southwest of Acre state, reworking cenozoic sedimentary rocks composed by Solimões, Cruzeiro do Sul and Içá Formation (CAVALCANTE 2006; MAIA & MARMO 2010; CAPUTO 2014). It is one of the most important Amazon River tributary by the right sideways before the Purus and Madeira rivers. Along your course, raised some communities that converted in cities as Marechal Thaumaturgo, Porto Walter, Rodrigues Alves, Cruzeiro do Sul and Guajará in the Acre State and Ipixuna, Eirunepé, Itamarati, Carauari and Juruá City inside the Amazonas state. Around the Juruá physiographic aspects, the main tributaries are in right boundary where Taraucá is the most important in the discharge volume, parallel with streams named Gregório and Eiru.

COSTA *et al*. (1996) and CAPUTO (2014) carried out previous works about Juruá River's physical aspects related with the tectonic and Andean uplift influence in the Amazon River and your tributaries patterns. SOUTO *et al*. (2015) about changing of physic-chemistry characteristic of the Amazon River who use a sample from Juruá River in your research. SILVA *et al*. (2014) that carried out a study by the physical characterization of the Canela Fina and Preto streams of Juruá River in the Acre State and SILVA (2017) about the water quality.

However, although that scientific works whom discusses about some tributaries and specific portions of the Juruá River there is a great information gap about your physical and chemistry characteristic. Specially connecting this

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parameters with the river dynamic, water quality, aquatic life and human activities around the river area influence.

Therefore, to increasing the knowledge of this important Amazon River tributary, this study aim to understand the Tarauacá River's influence with annual discharge and channel pattern of Juruá River, between Porto Walter (Acre) and Itamarati City (Amazonas).

2. MATERIALS AND METHODS

2.1. Study Area

The regional geology in the area are Cenozoic sedimentary rocks Solimões, Cruzeiro do Sul and Içá Formations, laying over magmatic and metamorphic Amazon Craton basement. Solimões Formation are sedimentary rocks with fossiliferous sandstones, siltstone, limestone, claystone and lignite coal deposited in fluvial and lacustrine environment. The Cruzeiro do Sul Formation are sandstones and claystones. While the Içá Formation are sandstones, claystones, siltstones and peat, both deposited in siliciclastic continental system (MAIA and MARMO, 2010; CAPUTO, 2014).

2.2. Data analyses

Discharge data used to this paper it was extracted from Agência Nacional de Águas (ANA) and the Instituto Nacional de Meteorologia (INMET) recorded from years 2000 to 2015. Which these data represent some stations along the Juruá River from Porto Walter to Gavião and two tributaries Gregório and Tarauacá (figure 1, table 1).

The sinuosity degree (Sd) is the product of the channel length (L) divided by the valley length (Lv) as the following equation according BRICE *et al*. (1978) and SCHUM (1981):

$$Sd = \frac{\mathrm{L}}{\mathrm{Lv}}$$

While the channel slope is the product from highest elevation divided by the channel length, according SCHUM (1985). The radar images was extracted from Del'Arco *et al.* (1977) in RADAMBRASIL project, which represent the geological and geomorphological studies in the SB.19 Juruá chart. The Channel Slope versus Discharge diagram is from LEOPOLD & WOLMAN (1957) model used to channel pattern classification. Percentage calculation of the mean Juruá River discharge in each station it was did by the total river discharge 5,692 m^3/s according ANA (2016). The increase in every station it was a differentiation between the local and the next station. Slope analysis was builded by using Global Mapper software.

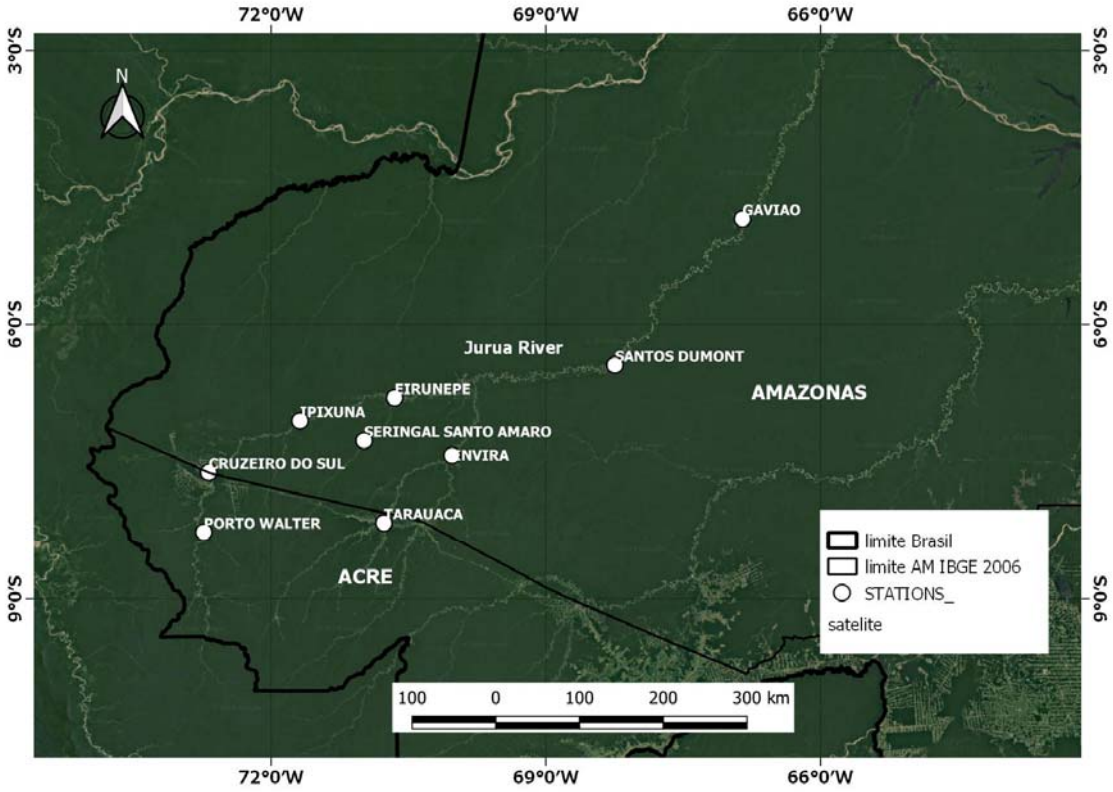

Figure 1: Research area.

Table 1. Hydrology and climatology stations.

Code	Abbreviation	Name	City	State	Lat	Long
00872001	PTW	PORTO WALTER	Porto Walter	AC	-8.2675000	-72.7344444
00772000	CRU	CRUZEIRO DO SUL	Cruzeiro do Sul	AC	-7.6111111	-72.6811111
00771000	IPX	IPIXUNA	Ipixuna	AM	-7.0508333	-71.6841667
00669000	EIR	EIRUNEPÉ	Eirunepé	AM	-6.8000000	-70.6500000
00668000	STD	SANTOS DUMONT	Itamarati	AM	-6.4416667	-68.2438889
00466001	GVO	GAVIÃO	Carauari	AM	-4.8391667	-66.8505556
00870000	TAR	TARAUACÁ	Tarauacá	AC	-8.1666666	-70.7666666
00770000	ENV	ENVIRA	Envira	AM	-7.4280555	-70.0225000
00668000	STA	SERINGAL SANTO AMARO	Ipixuna	AM	-7.2666666	-70.9833333

3. RESULTS

3.1. Discharge

The monthly river discharge in Porto Walter is 1,024 m^3/s in January increasing until April with 1,172 m^3/s when beginning to decrease until the dry season, August, with 64 m^3/s (table 2). Therefore, in the next month, September, the discharge start increasing again, when the region become to the flood season. Cruzeiro do Sul change from 1,378 m^3/s in January increasing to high value 1,762 m^3/s in March and decreasing to 199 m^3/s in September, starting increase again in the October. Ipixuna appear extreme value in April with 2,746 m^3/s decreasing to lowest value 212 m^3/s in September before start increase again (table 2).

The high discharge value in Eirunepé become in April with 3,259

m^3/s decreasing to 389 m^3/s in September. Although in Santos Dumont, the maximum value is 8,389 m^3/s, occurring in April, decreasing to 706 m^3/s in September (table 2). The last station, Gavião, have 9,242 m^3/s in March and 1,559 m^3/s in October when start increase in the next month (figure 2).

The tributary Gregório River have high value in March with 400 m^3/s decreasing to 46 m^3/s during August and September. While Tarauacá river represented by Envira station have 1,292 m^3/s in February and minimum value in August with 57 m^3/s. The average of the annual discharge measured in any station display a regular flow rate increase from Porto Walter to Eirunepé. While in Santos Dumont, there is an anomalous increase in this parameter, 2,395 m^3/s, when the Juruá receive the Tarauacá tributary. Returning to a regular increase in the next station, Gavião (figure 2B).

Table 2. Average discharge of Juruá River. Discharge in m^3/s. Data from years 2000 to 2015.

Month	PTW	CRU	IPX	EIR	STD	GVO
January	1,024	1,378	1,993	2,747	5,960	7,428
February	1,127	1,619	2,245	3,065	7,333	9,161
March	1,096	1,762	2,591	3,180	8,099	9,242
April	1,172	1,688	2,746	3,259	8,389	7,714
May	490	952	1,747	2,712	7,069	6,415
June	203	454	741	1,497	3,425	3,548
July	131	310	393	807	1,488	2,018
August	64	213	239	515	889	1,480
September	77	199	212	389	706	1,567
October	161	393	431	557	996	1,559
November	351	713	917	1,243	2,228	2,950
December	809	980	1,515	2,015	4,139	5,502
Average	559	888	1,314	1,832	4,227	4,882

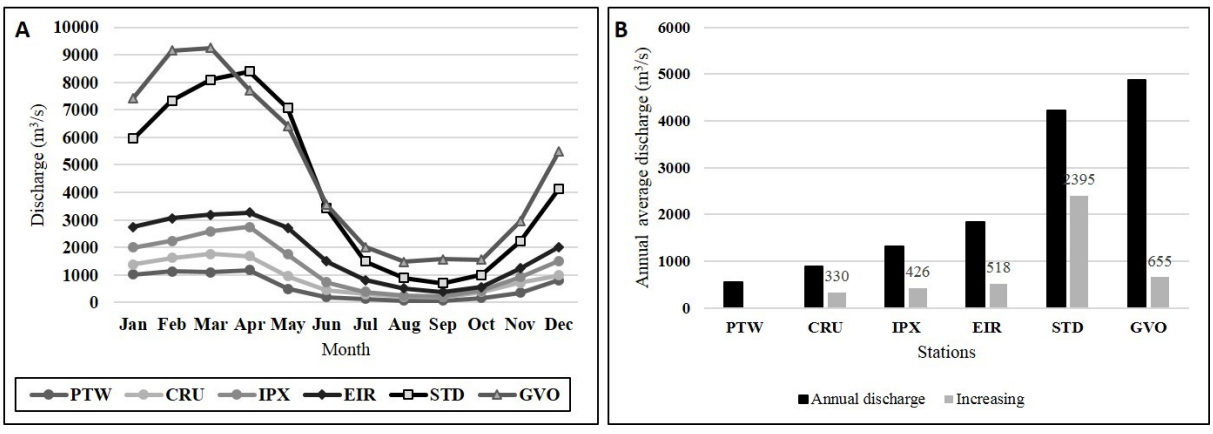

Figure 2:Annual discharge in the Jurua river.

3.2. Channel pattern

The channel classification system of the Juruá River is a meandering river with high sinuosity degree more than 1.26, equivalent with that high-suspended load river. Where in the research area the channel pattern change from single phase to two-phase bimodal bank full sinuosity. Showing an increasing sinuosity degree from Porto Walter to Santos Dumont station along the Jurua, starting 1.65 and finishing 2.43 in the area (figure 3, table 3).

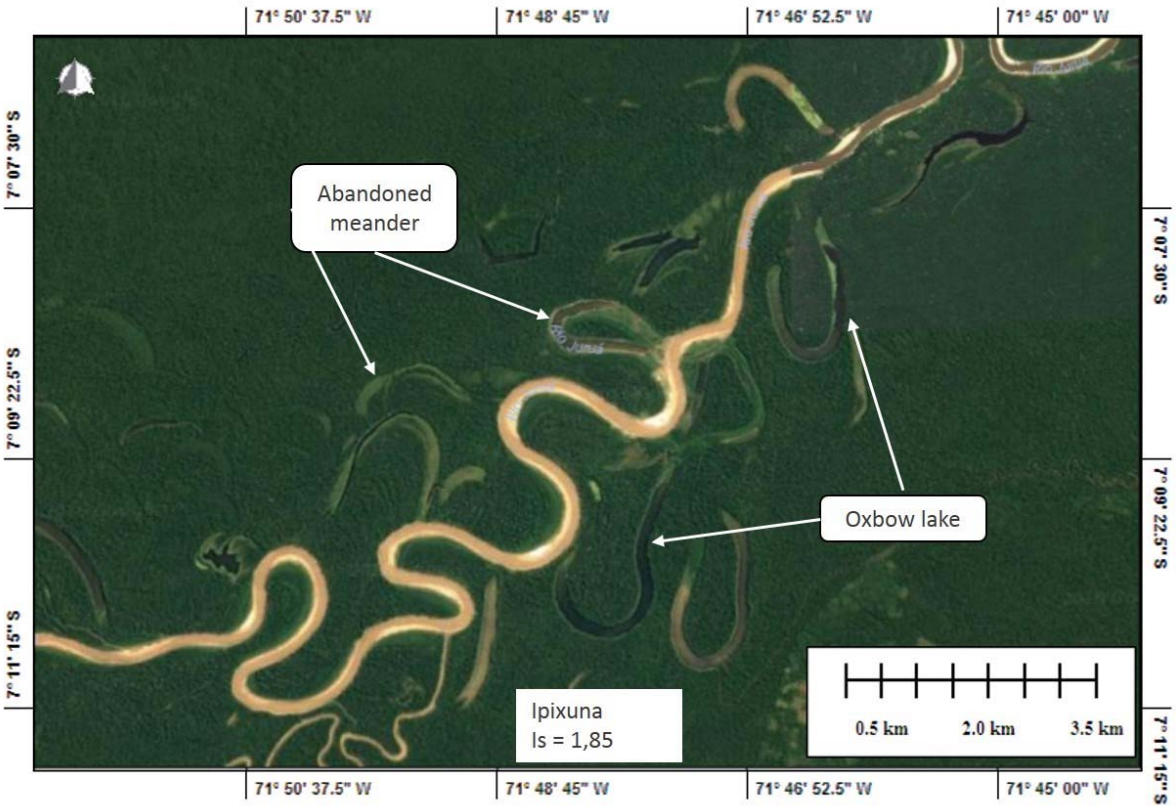

Figure 3: Channel pattern Ipixuna.

Table 3. Sinuosity degree measured next to stations along Juruá and Tarauacá River.

Station	Sinuosity degree
PORTO WALTER	1.65
IPIXUNA	1.85
EIRUNEPÉ	3.23
SANTOS DUMONT	2.43
ENVIRA	2.43

The river display two patterns of meander growth: conversion to a compound meander and neck cutoff, after classification by Brice (1974) (figure 4). Comparing the river changes that become in the last 38 years the figure 4A and 4B display the conversion to a compound meander. Besides, the figure 4C and 4D reveal the channel evolution to a neck cutoff. The meander growth occur following the river direction, designated by the point bar accretion as exposed in the figure 4A and 4B. With a high level of oxbow lakes

built by the neck cutoff and abandoned meanders with no presence of chute cutoff.

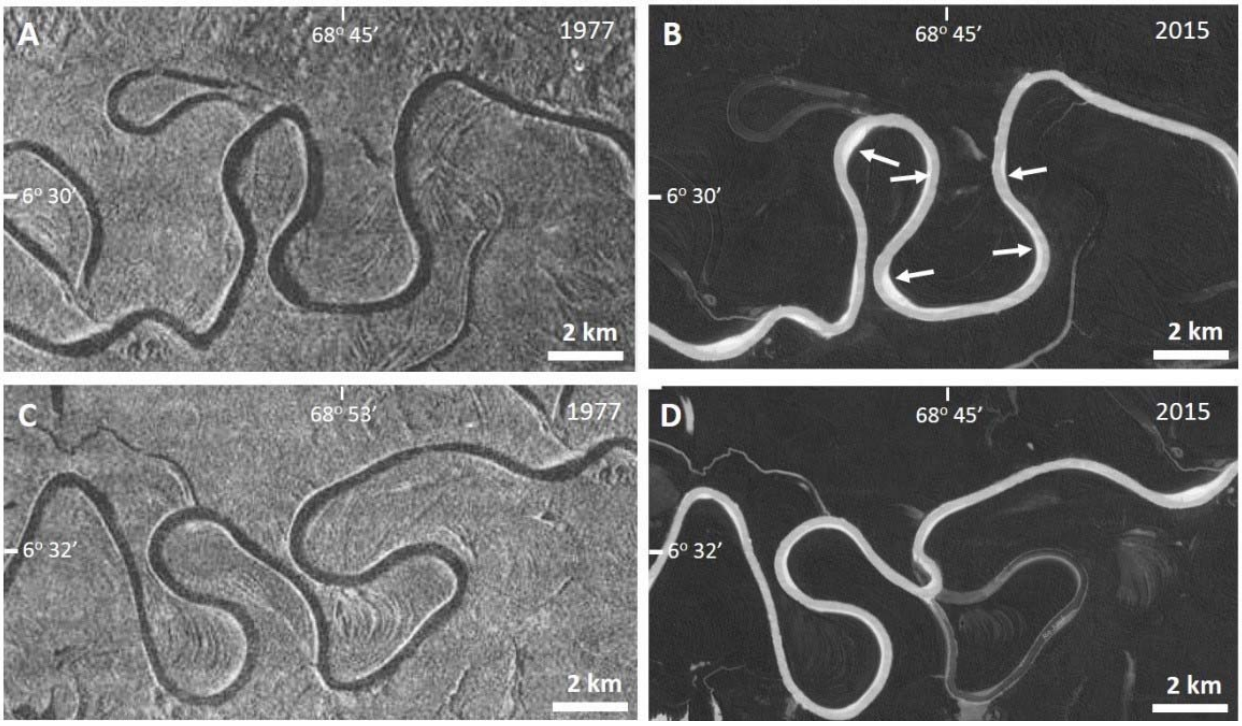

Figure 4: Channel evolution between 1977 – 2015.

The channel slope pattern along the Juruá from Porto Walter to Itamarati is 0.00017, and in the Tarauacá river from Feijó to Eirunepé is 0.00039 (figure 5). The landscape inclination in the first river keep lower along the all analyzed place, but in the Tarauacá, there is a high slope degree next to Feijó until the Tarauacá city where, from this site, become more flat from this point to your connection with Juruá River (figure 5).

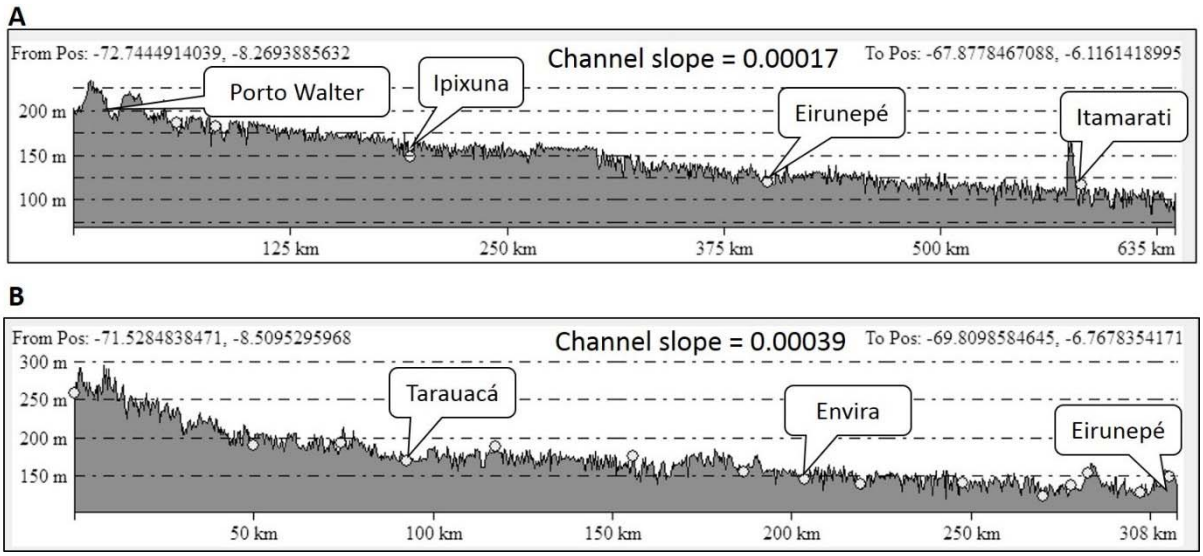

Figure 5: Slop gradient in the area.

When plotted in the Leopold and Wolman (1957) diagram the relationship with slope channel and annual discharge place the Juruá River and your great tributary Tarauacá plot theses rivers in the meandering river system (figure 6). With this diagram is possible observe how the Juruá River is more flat than the Tarauacá according your positions in the channel slope axis.

However, both rivers are under the boundary between the rivers channel patterns.

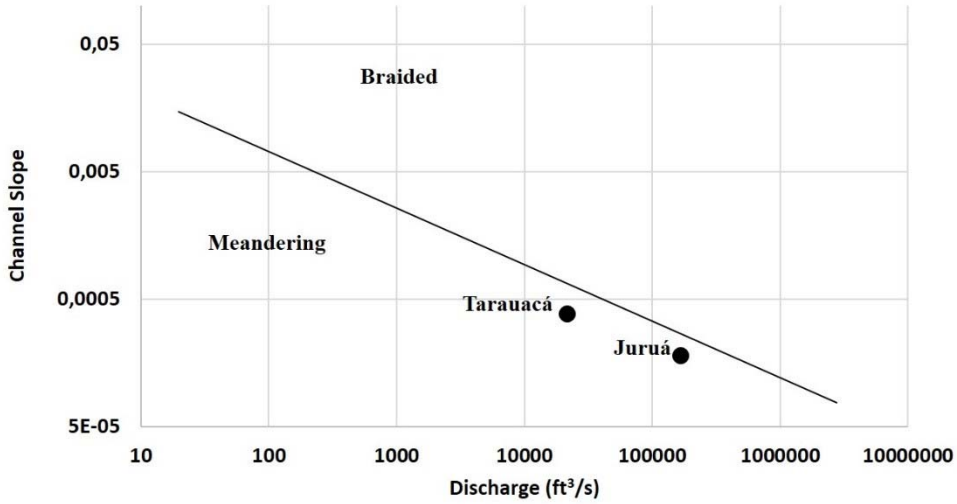

Figure 6: Classification of Tarauacá and Juruá rivers.

4. CONCLUSIONS

The Juruá total river discharge, compared with Amazonas river system in Brazil, is about 4.24 %. High values occur specially in April decreasing until the lowest values between August and September, the dry season in the region. While annual average values varies from 559 m^3/s in Porto Walter until 4882 m^3/s in Gavião Station. Where this mean flow rate in Gavião é more than São Francisco River with 2850 m^3/s, southeast Brazil.

Comparing the increasing rate between each followed station the Santos Dumont flow rate increase 2395 m^3/s from Eirunepé. Changing radically the flow rate and probably the landscape of the Juruá River from this point. Where this change in the river is associated with Tarauacá contributions, the greater tributary, with annual average 674.5 m^3/s. Coming from southwest, Tarauacá increase significantly your water volume when is connected with Envira river, discharging your water in the Juruá River next to Eirunepé City. Resulting in a high water volume increased from this point until the connection with the regional main channel, Solimões River.

According with the analyzed data, Juruá River is a high sinuosity degree meandering river varying from 1.65 in Porto Walter to 3.26 in Eirunepé. Where compared with the Schum (1985) models is a channel type with high-suspended load and relative stability. The sinuosity degree is low in the Porto Walter, starting increase from Ipixuna getting high values in the Eirunepé and stabilizing from Santos Dumont station. Where these high values in Eirunepé may possibly to be influenced by the slightly channel slope

and increasing the suspended load at this part of the river.

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