Delimitation and Codification of Hydrographic Units Through the Use of Geographic Information Systems

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Abstract. Geographic Information Systems (GIS) provide new methods and tools for automatic data processing, which are used by organizations to improve process management. The basin is considered as the basic unit of territorial planification, for which the hydrographic units delimitation is the key for water resources administration. The lack of detail in basins geographical information has to be solved, in order to optimize the decision-making process and related tasks. Using the Pfafstetter methodology, the Jubones river basin was subdivided into level 6. For this purpose, we used the level 5 hydrographic units, the SRTM spatial resolution data model of 30 m and GIS software. At level 5, 13943, 13944, 13945, 13947, 13948 and 13949 hydrographic units were identified. In accordance with the selected method guidelines, 9 drainage areas were coded for each hydrographic level 5 unit. 54 hydrographic units at level 6, of which 30 correspond to inter-basins and 24 to basins, thus updating the geographical information. The total subdivided area was 312,223.06 ha. It is important to replicate the research in other basins and publish the results using the Spatial Data Infrastructure (SDI) platforms.

Keywords: Watersheds · Pfafstetter methodology
Geographic information systems (GIS)

1 Introduction

Advances in computer technology contribute with new tools and methods, allowing the strengthening of the different areas of science. Geographic Information systems (GIS) is the field in which various branches of knowledge interact and are responsible for managing specialized information, within which is related to river basins, which historically were delineated through the maps interpretation or topographic charts [1].

In accordance with [2] river basin is a catchment area in which drains the river and its tributaries. It is formed in the highest relief regions delimited by the river basin surface. According to FAO [3], in the catchment area are the natural resources, communities and their different economic activities.

In 1989, the Pfafstetter method emerged as an international standard for hydrographic units' delimitation and codification [4]. In compliance with [5] the method is hierarchical and based on the field topology. which allows to improve the management

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of river basins and a more control action on those areas. Based on the theoretical foundations, three types of hydrographic units are identified: Basin, inter basin and internal basin [6]. [21] emphasizes that the system is hierarchical and the units are delimited from the junctions of the rivers or from the point of convergence of a drainage system in the ocean.

The GIS implementation for information structuring, storage and retrieval in hydrographical databases was developed by [7]. According to [8], the geo-processing tools use is of great importance for hydrographic water basins delimitation, allowing to optimize time and resources. The delimitation through computational tools requires Digital Elevation Model (DEM) database, which stores the terrain height values.

As claimed by [9] mathematical algorithms and altimetric data can be automatically modeled using a computer, allowing the study and analysis of the Earth's surface in a three-dimensional shape. As stated above, the concept is supported by [10], who placed emphasis on water basin extraction's automated growth using the DEM. Actually, one of the main data models is the Shuttle Radar Topography Mission (SRTM), which in the criteria of [11], was a NASA-led project from which the TOPODATA project was developed through the application of geo-statistical processes.

Several studies have been carried out using GIS, the Pfafstetter methodology and the DEM, among which stand out: [1, 12–15]. In the Jubones demarcation, the main basin is the so-called Jubones River basin, where the geographical information of the sub-basin is important for the activities fulfillment demanded by the integral management of water resources, requiring the sub-basin updated in necessary detail levels, allowing project administration, formulation and planning as well as the correct decision-making and equitable distribution of water resources.

To fulfil the investigation purpose, the following objective was raised: Delimit the Jubones River basin hydrographic units by using GIS software, which allows the correct decision-making and effective water resources management. The following research questions were formulated: what are the methods used for river basins delimitation? What are the hydrographic units to be delimited in the Jubones river basin? What encoding corresponds to each of the delimited hydrographic units?

2 Methodology

2.1 Geographic Location

The Jubones river basin forms part of Jubones hydrographic demarcation. It is located geographically in the southern area of Ecuadorian territory, which can be seen in Fig. 1.

With an area of 431,860.86 ha, the basin covers part of the territory of 3 provinces: El Oro with the cantons Machala, El Guabo, Pasaje, Chilla and Zaruma; Loja with the canton Saraguro; Azuay with Nabón, Girón, San Fernando, Santa Isabel, Oña and Pucará. The metric coordinates WGS84 zone 17 south. The study basin location are detailed in Table 1.

Fig. 1. Project location.

Table 1. Coordinates of the Jubones river basin.

Orientation	X	Y
NORTE	682,099	9,664,777
SUR	686,645	9,588,782
ESTE	730,820	9,638,668
OESTE	612,048	9,643,330

2.2 Base Cartography

The National Water Secretariat officialized through ministerial resolution no. 2011-245, the use of information of basins up to level 5, delimited with the Pfafstetter methodology [16]. The basin delineation process had as its main input the HydroSHEDS, which contains the direction and accumulation of water flow.

The cartography of the hydrographic units in level 5, the hydrographic demarcations, and the HydroSHEDS are part of the information bank of the demarcation. Other available maps are those released by the IGM at a scale of 1: 50,000, among which are the subjects of simple rivers, double rivers, limits and reference points, the which are related to the research and its development process.

2.3 Diagram of the Methodology

The methodology to be applied for the delimitation of hydrographic units is shown in the diagram in Fig. 2.

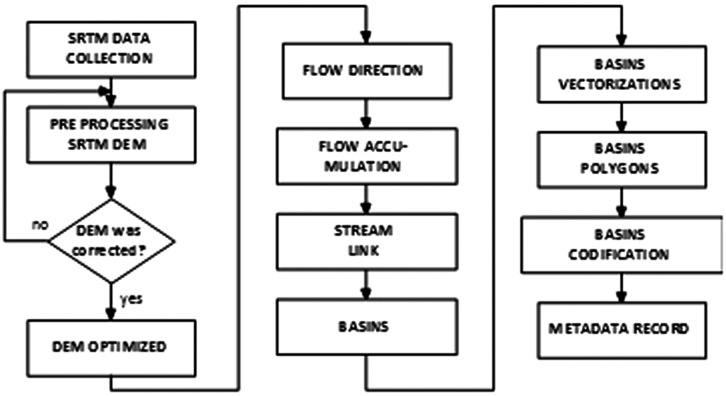

Fig. 2. Diagram of the methodology.

The following describes each of the stages of the methodology:

SRTM Data Collection (NASA): The SRTM data with 30 m resolution were downloaded from the USGS EarthExplorer page (http://earthexplorer.usgs.gov/). The data download viewer graphical interface can be seen Fig. 3.

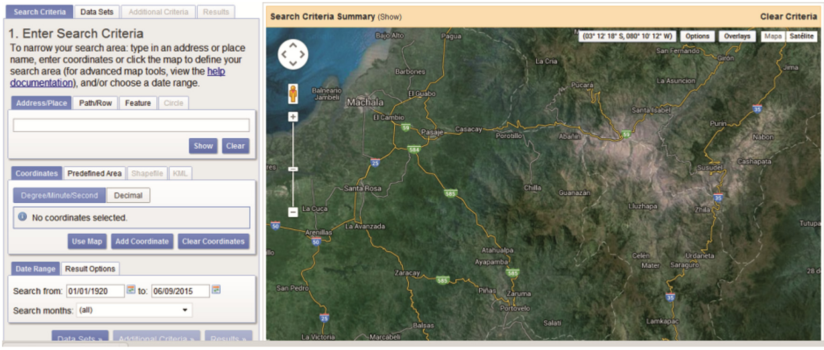

Fig. 3. SRTM data download page.

In the discharge viewer, the coordinates of the basin to be delimited were defined, which allowed only the required area to be discharged. The geographic coordinates established, are structured in Table 2.

Table 2. Coordinates study area in viewer download.

Order	Latitude	Longitude
1	03°00’00”S	80°00’00”O
2	03°00’00”S	78°54’55”O
3	03°45’00”S	78°54’55”O
4	03°45’00”S	80°00’00”O

Once specifying the coordinates in the viewer, the next step was to select the data type to be downloaded, which was achieved through the Data Sets > Digital Elvation > SRTM > SRTM 1 Arc-Second Global tab. The results displayed in the Results tab, for your download in three formats: BIL, DTED or GeoTIFF.

Pre-processing of DEM: The DEM Pre-processing: The pre-processing phase is determined by two specific tasks which are: Creation of the SRTM image mosaic and the exclusion of incorrect values present in the DEM. With the mosaic images are integrated into a single file, covering the total area of the study basin, the utility in ArcGIS with which this purpose was achieved is: Data Management Tools > Raster > Raster Dataset > Mosaic to New Raster.

According to [17], the topography of the terrain area significantly influences the quality of the elevation model data. That is to say errors on steep or mountainous terrain the incidence can be greater, reason why it is essential to correct the imperfections that contains the DEM. [18] mention that the errors in the DEM derived from SRTM data are called sinks.

Flow direction: This step consists to create a raster map of the flow directions. [8] argue that the direction of flow is determined from the hydrographic relationships between the different points of the basin perimeter and considering the terrain characteristics. According to [19], the flow direction map is calculated based on neighboring cells and indicates the steepest drop direction as a function of slope inclination.

The flow direction in ArcGIS is obtained through the Spatial Analyst > Hydrology > Flow Direction.

Accumulation flow: The flow accumulation map is obtained from the flow direction map. According to [20] flow accumulation refers to the hydrographic network, which provides a new matrix with the specific water accumulation values of each pixel. Flow accumulation is based on the number of cells flowing into each cell, where the resulting value of a pixel are is all the pixels that upstream drain it. The accumulation of flow in ArcGIS is obtained through the Spatial Analyst tool > Hydrology > Flow Accumulation [8].

Calculation of threshold and reclassification of accumulation: According to the [21] criterion, the threshold calculation "[…] is an iterative trial and error procedure; Being the easiest way to determine the appropriate accumulation threshold to obtain the necessary tributaries". The determination of the accumulation threshold, allows to identify the main river course and the four contributors, considering that it is enough that a pixel appears, to be considered as a tributary. The calculation of the threshold is based on the water accumulation. In ArcGIS it is done from the Layer Properties > Symbology > Classified > Classify window.

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Drainage network: This stage consists in obtaining the categorized drainage network, corresponding to category 1 of the flow accumulation reclassification performed in the previous phase. According to [23], the process related to the generation of the drainage network is essential for the hydrographic units' determination. [22] state that the Stream Link tool, allows assigning the values to each drainage network section. In ArcGIS the procedure is performed from Spatial Analyst Tools > Hydrology > Stream Link.

Generation of basin: [23] mention that the automatic generation of a basin requires the flow direction and the watercourses network obtained from the map of the flow accumulation. According to the criterion of [8], the automatic generation of watersheds in ArcGIS, is obtained through the Spatial > Analyst Tools > Hydrology > resource. As mentioned in the previous paragraph, the flow address files and the drainage network are required for the process.

Basins Vectorization: The basins vectorization is the process of convertion of raster to vector format (points, lines or polygons), with which the polygons final theme of the hydrographic units delimited in shapefile format is obtained. According to [21] the conversion to vector delimited basins format, is a simple technique that is fulfilled applying the following step:

- *Conversion from raster to polygon:* The raster file of basins generation is the input required to perform the conversion to polygon. This procedure in ArcGIS is done with the conversion Tools > From raster > Raster to polygon tool.

Basins codification: Coding is a hierarchical procedure, which consists in assigning unique codes to the basins. It is important that prior to establishing the coding, the main river of each hydrographic unit is identified, to later codify the basins from the river mouth to the origin according to Pfafstetter criterion.

[24] mention that the Pfafstetter codification is based on two principles: The hierarchization of the hydrographic units according to the drainage area and the hydrographic network preliminary recognition of the four main basins, to which the numbers are assigned pairs 2, 4, 6 and 8, while the inter-basins correspond to the odd numbers 1, 3, 5, 7 and 9. If there are internal basins are coded with the number 0.

The allocation of codes in inter-basins and basins, resulting from vectorization should be done clockwise [25].

Metadata record: Metadata record: According to [26], the term metadata refers to the data structured set, which describe other data and its internal structure, whose objective is that the information they represent is understood, shared and exploited effectively by all types of Users who require their use. [27] argue that metadata are becoming a familiar tool for those working with spatial information, so that in order to define a structure that serves to describe the geographic data, exists the ISO 19115 international standard - Geographic Information Metadata [28].

Standard 19115 was used in the definition of the CONAGE PEM document [29]. In the metadata registry, the main sections describing the hydrographic units vector file in level 6 were: Metadata information, identification, restrictions, data quality, maintenance, spatial representation, reference system, content, presentation catalog, distribution, Metadata extension and application model.

3 Results and Discussion

The basin 13943, 13944, 13945, 13947, 13948 and 13949 were divided into 9 hydrographic units in level 6, of which 4 correspond to basin and 5 to inter-basin. The codes assigned to the new delimited units, can be observed in detail in Table 3, 4, 5, 6, 7 and 8.

Table 3. Watershed results 13943.

Level	Name	Type	Area ha.
139431	Hydrographic unit 139431	Inter basin	3,730.32
139432	Hydrographic unit 139432	Basin	3,625.78
139433	Hydrographic unit 139433	Inter basin	1,901.65
139434	Hydrographic unit 139434	Basin	3,467.67
139435	Hydrographic unit 139435	Inter basin	1,808.85
139436	Hydrographic unit 139436	Basin	13,751.07
139437	Hydrographic unit 139437	Inter basin	5,654.89
139438	Hydrographic unit 139438	Basin	18,196.89
139439	Hydrographic unit 139439	Inter basin	9,532.38

The total area of the hydrographic unit 13943 is: 61,669.50 ha.

Table 4. Watershed results 13944.

Level	Name	Type	Area ha.
139441	Hydrographic unit 139441	Inter basin	7,751.22
139442	Hydrographic unit 139442	Basin	5,600.94
139443	Hydrographic unit 139443	Inter basin	2,667.08
139444	Hydrographic unit 139444	Basin	2,368.76
139445	Hydrographic unit 139445	Inter basin	419.71
139446	Hydrographic unit 139446	Basin	2,806.34
139447	Hydrographic unit 139447	Inter basin	2,527.32
139448	Hydrographic unit 139448	Basin	3,793.48
139449	Hydrographic unit 139449	Inter basin	8,213.74

The total area of the hydrographic unit 13944 is: 36,148.59 ha.

Table 5. Watershed results 13945.

Level	Name	Type	Area ha.
139451	Hydrographic unit 139451	Inter basin	1,057.56
139452	Hydrographic unit 139452	Basin	12,623.61
139453	Hydrographic unit 139453	Inter basin	1,934.66
139454	Hydrographic unit 139454	Basin	2,761.88
139455	Hydrographic unit 139455	Inter basin	3,313.56
139456	Hydrographic unit 139456	Basin	10,781.11
139457	Hydrographic unit 139457	Inter basin	13.04
139458	Hydrographic unit 139458	Basin	25,287.38
139459	Hydrographic unit 139459	Inter basin	4,026.49

The total area of the hydrographic unit 13945 is: 61,799.29 ha.

Table 6. Watershed results 13947.

Level	Name	Type	Area ha.
139471	Hydrographic unit 139471	Inter basin	1,349.56
139472	Hydrographic unit 139472	Basin	1,305.92
139473	Hydrographic unit 139473	Inter basin	385.92
139474	Hydrographic unit 139474	Basin	4,858.65
139475	Hydrographic unit 139475	Inter basin	1,776.93
139476	Hydrographic unit 139476	Basin	928.77
139477	Hydrographic unit 139477	Inter basin	3,477.00
139478	Hydrographic unit 139478	Basin	1,815.55
139479	Hydrographic unit 139479	Inter basin	349.58

The total area of the hydrographic unit 13947 is: 16,247.88 ha.

Table 7. Watershed results 13948.

Level	Name	Type	Area ha.
139481	Hydrographic unit 139481	Inter basin	814.97
139482	Hydrographic unit 139482	Basin	26,815.92
139483	Hydrographic unit 139483	Inter basin	2,105.80
139484	Hydrographic unit 139484	Basin	3,483.52
139485	Hydrographic unit 139485	Inter basin	5,011.33
139486	Hydrographic unit 139486	Basin	3,406.86
139487	Hydrographic unit 139487	Inter basin	389.26
139488	Hydrographic unit 139488	Basin	5,821.13
139489	Hydrographic unit 139489	Inter basin	6,425.00

The total area of the hydrographic unit 13948 is: 54,273.79 ha.

Table 8. Watershed results 13949.

Level	Name	Type	Area ha.
139491	Hydrographic unit 139491	Inter basin	10,027.44
139492	Hydrographic unit 139492	Basin	12,319.18
139493	Hydrographic unit 139493	Inter basin	3,118.92
139494	Hydrographic unit 139494	Basin	19,808.00
139495	Hydrographic unit 139495	Inter basin	624.46
139496	Hydrographic unit 139496	Basin	3,404.94
139497	Hydrographic unit 139497	Inter basin	1,343.36
139498	Hydrographic unit 139498	Basin	9,739.23
139499	Hydrographic unit 139499	Inter basin	21,698.48

The total area of the hydrographic unit 13949 is: 82,084.01 ha.

The next map graphically represents the sequence coding established for each delimited hydrographic unit, with based on the detailed in the Tables 3, 4, 5, 6, 7 and 8 (Fig. 4).

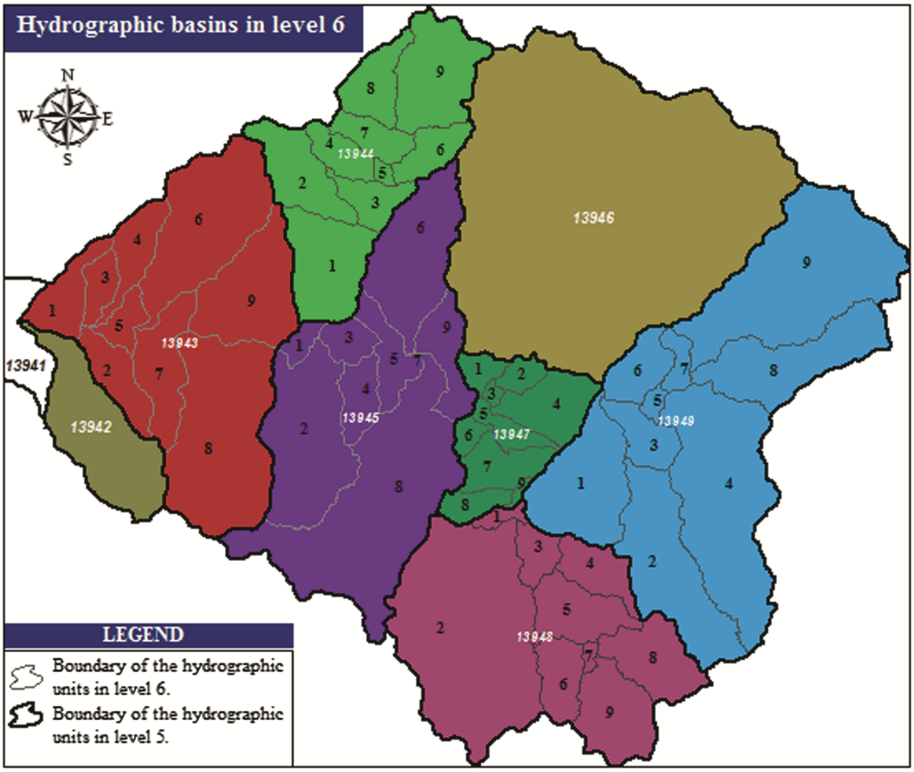

Fig. 4. Map of the hydrographic units in level 6.

With the codification, it is possible to identify the level to which the hydrographic unit corresponds checking the digits number of code, with the which it is fulfilled the fundamental principle of the methodology: The assignment of unique codes to each hydrographic unit. However, the designation of the name of the basin is essential, since its allows to the users of the environment it is become familiar with it quickly.

The hydrographic units coded with the Pfafstetter methodology, allow the continuation of the standard for delimitation established for the South American region [30], as well as at the level of hydrographic divisions of the Water Secretariat. The CNRH proposal [31] defined river basin codes in terms of hydrographic systems, resulting the coding of basins and sub-basins only for Ecuador, while hydrographic units coded at level 6 can be recognized at the level Local and in the countries where the use of the method has been officialized.

In the case of the hydrographic units 13941 and 13946, were not subdivided in this research.

4 Conclusions

Due to its clearly defined methodological approach, the Pfafstetter method was selected and, based on the revision of the theoretical foundations, the stages of the methodology on which the delimitation and codification of the hydrographic units in level 6 of the basin River Jubones. The phases identified were: SRTM data collection, pre-processing of the DEM, flow direction, flow accumulation, threshold calculation and reclassification of the accumulation, drainage network, watershed generation, vectorization, coding and registration of the metadata.

The results of each phase were successful, being elemental the use of the DEM of the SRTM project, which provides significant advantages, compared to the generation of the elevation model, from the information of level contours of the IGM; Also affected by topology errors in its structure. However, in the selected DEM, source errors or "NoData" values were debugged, applying near neighbor interpolation methods. For this purpose we used focused statistics applied to a 10 cell radius, which can change depending on the space or number of pixels that need to be corrected.

The delimited hydrographic units of level 5 were: 13943, 13944, 13945, 13947, 13948 and 13949, the terrain features being an important factor in obtaining the expected results. On the other hand, the 13941 unit, considered to be the mouth of the basin, due to the topographical characteristics of the area, was not defined, since it corresponds to the lower zone of the province of El Oro. Each basin of level 5 delimited resulted in 9 hydrographic units in Level 6, the same ones that are analogous to the denomination of micro-basins.

In total 54 hydrographic units were obtained in level 6, of which 24 correspond to basins and 30 to inter-basins. The coding of the delimited units was established according to the level 5 code. The Pfafstetter code assigned to each hydrographic unit allows the current delimitation level to be determined, by simply counting the number of digits. The code determines the interrelation between the drainage areas of the same level, and allows to establish the spatial relationships with the lower level units.

The subdivision area of the Jubones river basin in level 5 is approximately 312,223.06 ha, corresponding to the inter-basins level 6 an area of 113,450.48 ha, equivalent to 36%, while level 6 basin units comprise A territorial extension of 198,772.58 ha, equivalent to 64%. The delimitation of inter-basins requires particular attention in the calculation of the threshold to obtain the drainage network, due to its characteristics in these units there is no single common drainage point.

The Jubones river basin by its geographical location, territorial extension and caudal, is considered the most important of the demarcation. In this sense the subdivision in level 6, favors the territorial management of the catchment area. The proposed hypothesis is accepted and the results provide drainage areas in greater detail, which contributes to the optimization of the field tasks carried out by the technical staff of the demarcation, facilitating familiarization with the environment, the object of analysis and the Identification of watercourses.

With the hydrographic units in level 6, the geographic information of the basins of the demarcation is updated, allowing the planning and execution of projects oriented to equitably distribute the water resources. Essentially the drainage units obtained strengthen the emblematic project of the demarcation called Participative Inventory of Water Resources (IPRH), executed in the Jubones river basin. The data of the catchment area and code are fundamental for the updating of the bank of the IPRH and for the operative operation of the system of authorizations of use and exploitation of water.

The basins and inter-basins of level 6, allow to identify the communities located in each catchment area, which allows a direct approach with the users, favoring their participation in the training workshops oriented to the care of the flow and water sources. These activities benefit the development of the social water management plan.

The results of this research are related to the National Water Resources Plan, which provides for a diagnosis that allows the conservation of the water resource in the short, medium and long term, considering the micro basin as the minimum unit of analysis. Specifically, the geographical information of hydrographic units at level 6, benefits the elaboration of the plan for the Jubones river basin.

The use of GIS techniques was fundamental, since they allowed to reduce the time required for the generation of the cartography of watersheds. The contribution of this research to cognitive strengthening is related to the management of NASA SRTM data and to the hydrological modeling tools used under the principles of the Pfafstetter methodology. In the shapefile file of the delimited drainage areas, the metadata was registered according to the regulations used by the Water Secretariat, in order to guarantee the access and location of spatial information generated.

5 Recommendations

It is recommended that the demarcation of Jubones officialize and socialize the new level delimited with the GAD, Commonwealth Consortium of the Jubones river basin, other Central Government institutions and users, emphasizing the importance of familiarization and understanding of the code assigned to each unit Area. From its official formalization, it is feasible to plan and execute the delimitation of level 7 of the basin using the Pfafstetter methodology, in order to achieve the permanent improvement of processes related to water resources, as well as to continue the process of delimitation of the level 6 for the other watersheds that make up the demarcation, considering as main input the DEM with 30 m resolution of NASA.

It is also important that the process be replicated for the rest of Ecuador's watersheds, in order to strengthen the National Water Resources Plan of the Water Secretariat, which directly benefits the hydrographic basins. In the new information generated, thematic attributes must be created according to the structure of fields specified in the baseline delimitation levels, as well as to record the metadata of the vector files resulting from the process of delimitation of hydrographic units, considering the standard or ISO standard 19115.

The main institutional management processes of the Jubones demarcation are those related to the water resource of the river basin, where the codification of hydrographic units is fundamental to establish relationships between water sources and drainage areas. New Pfafstetter coding, as well as updating the water use database with the new level 6 codes if necessary.

Taking as reference the study carried out, plans, actions and projects should be undertaken, focused on the conservation of the natural resources that make up the basin, depending on the competencies of each government body, thereby ensuring sustainable development for the community And improvements in the quality of life. The new applications that can be undertaken from the results of the research are: hydrological modeling, water balances, gauging campaigns and determination of water stress.

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