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## **A proposal to integrate the legal definition and official delineation of watersheds in Mexico: eight model case studies**

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### **ABSTRACT**

A hydrological basin is established as a geographic frame to officially determine surface water availability and is basic to confer or deny water rights. In Mexico, the legal definition of a hydrological basin is confusing and inconsistent with the official basin delineation published by the authority. This situation is demonstrated through the analysis of eight study cases located in Hydrological Region 10 Sinaloa. A proposal to define the legal term of hydrological basin, ensuring its consistency with official delineation of hydrological basins is presented. Geographic analysis was performed using QGIS software, by using official sources of Mexico and worldwide data bases. By law, in Mexico a water parting is defined as a borderline of maximum elevation. Nevertheless, the legal definition fails to explain hydrologic basin official boundaries where the basin limit is the location of a hydrometric station. Besides, the presence of this equipment does not mean that a waterbody exists in a hydrological basin, or that the delimited basin is an autonomous differentiated unit, as it is required by the legal definition. Other inconsistencies are presented dealing with the presence of inland water bodies as watershed limits and with groups of independent watersheds incongruously considered as a single basin. An amendment is proposed to harmonize this situation, with a minimum of changes in policy documents. The method proposed can be useful to analyze similar situations in other countries where discrepancies between the legal and official definitions of watershed delineation are also observed, or in countries where no official watershed definition has been established.

**Keywords:** hydrological basin delineation, surface water availability, water parting.



## Uma proposta para harmonizar a definição legal e delimitação oficial das bacias hidrográficas no México: oito casos estudados como exemplo

### RESUMO

Uma bacia hidrológica é estabelecida como um quadro geográfico para determinar a disponibilidade oficial de água superficial. Portanto, a delimitação da bacia hidrológica é básica para conferir ou negar os direitos da água. Apesar disso, em certas regiões, como o México, a definição legal da bacia hidrológica é confusa e não é consistente com a delimitação oficial da bacia publicada pelas autoridades. Isso é demonstrado neste trabalho por meio de oito estudos de caso. É apresentado um esquema para definir o termo legal da bacia hidrológica, garantindo sua consistência com a delimitação oficial das bacias hidrológicas. A análise geográfica foi realizada utilizando o software QGIS, utilizando fontes oficiais do México e bases de dados internacionais. Por lei, no México, uma separação de água é definida como uma fronteira de elevação máxima. Porém, a definição legal não explica os limites oficiais da bacia hidrológica, onde o limite da bacia é a localização de uma estação hidrométrica. Além disso, a presença deste equipamento não significa que existe um corpo de água em uma bacia hidrológica, ou que a bacia delimitada é uma unidade autônoma diferenciada, como é exigido pela definição legal. São apresentadas outras inconsistências que tratam da presença de canos de água do interior como limites de bacia hidrográfica e com grupos de bacias hidrográficas independentes consideradas incongruentes com uma bacia única. Uma alteração é proposta para harmonizar esta situação com mudanças mínimas nos documentos oficiais. O esquema proposto neste trabalho pode ser útil para analisar situações semelhantes em outros países onde também são observadas discrepâncias entre a definição legal da bacia hidrográfica e a delimitação oficial das bacias hidrográficas ou em países onde nenhuma bacia hidrográfica oficial esteja estabelecida.

**Palavras-chave:** delimitação da bacia hidrológica, disponibilidade de água superficial, linha divisória de águas.

### 1. INTRODUCTION

A hydrological basin is an area delineated by nature itself, fundamentally by the borders of surface runoff zones that converge towards a single watercourse (Reis *et al.*, 2015). It is considered the suitable territorial unit to manage water resources, even to manage the whole environment. Watershed management is an essential component of adequate environmental administration (Imperial, 2005). The watershed concept is also considered a risk management unit for hydrometeorological events due to the fact that climate change has made it necessary to develop adaptation programs to maintain and increase surface and ground water availability, with a focus on integrated hydrographic watershed management (Tomer and Schilling, 2009).

Thus, this natural territorial division tends to acquire an administrative connotation: “*The current National Water Bank (NWB) watersheds is basically an administrative application*” (Chile, 2013). Such connotation can even become official as in Chile and Mexico, respectively: “[...] *this watershed delineation is the administrative official delineation of General Water Administration (GWA)*” (Chile, 2013); “*Therefore, it is necessary to specify and publish the watershed limits to provide water users with a higher certitude about the exact localization of the geographic sites where water use occurs and to improve water management*[...]” (CONAGUA, 2016a).

This watershed delineation is an input for governmental instruments for river basin

development planning and management (RBDPM), by which water is distributed among users in a watershed-based territory division. However, *“sometimes political influence is observed in RBDPM boundaries, where the political territorial limits match rather than natural drainage basin delineation”* (Barrow, 1998). In Mexico, the National Water Commission (CONAGUA) recognizes 37 Hydrological Regions whose basin-based frontiers are adjusted to municipal political limits to form the borders among hydrological administrative regions (CONAGUA, 2010). The distribution of municipalities among Mexican watersheds was carried out depending on their socioeconomic, demographic and territorial dynamics (Espejel *et al.*, 2005; Sotelo *et al.*, 2010). In this sense, territorial divisions in natural hydrological basins and administrative hydrological basins do not match: *“The first evident problem, and the most important of all, is the differences between NWB watersheds and real watersheds”* (Chile, 2013).

When natural and administrative boundaries do not match, problems arise in calculating water balances in hydrological basins. Further problems generated by mismatch between natural and official limits affect underground water recharge calculation, hydrogeological modeling, surveillance plan design for water quality norms and aquifer sectorization (Chile, 2013). Therefore, the official delineation of a hydrological basin, as an administrative and a legal instrument, must be consistent with the legal definition of this territorial entity.

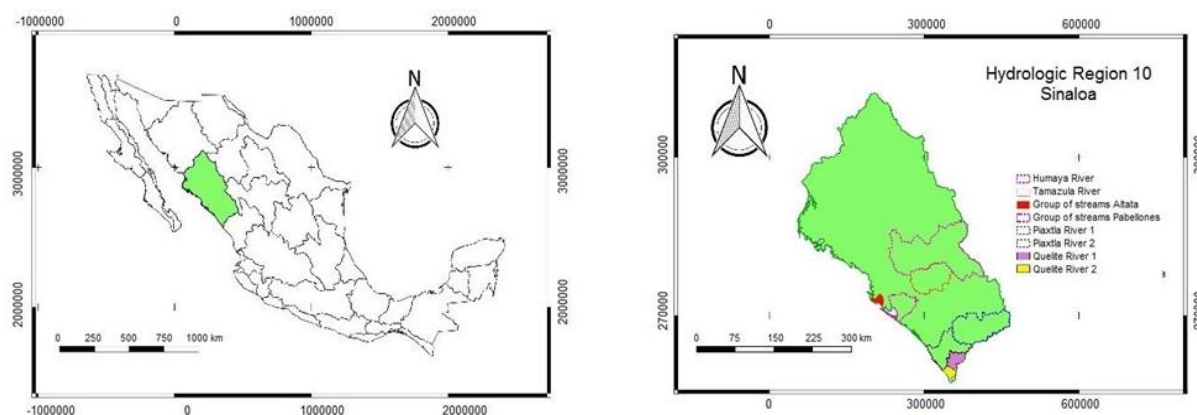
Countries like Argentina (2003), Bolivia (1992), Chile (2018), Colombia (2004), Ecuador (2014), México (CONAGUA, 2017a) and Peru (1969), among others, have their respective legal definitions of a hydrological basin named according to local terminology: *“As a consequence of this lack of conceptual consensus, due to the Spanish terminology, there have been interagency problems about hydrological basin management actions and law formulation deficiencies”* (CEPAL, 1994).

The aim of this paper is to contrast the definition of a hydrological river basin established in the Mexican Water Law with officially delineated basins to determine discrepancies and to present a proposal to overcome them. This is achieved by analyzing eight official river basins in Sinaloa, Mexico. Based on the differences found, a new definition of hydrological basin is proposed with the purpose of harmonizing this situation.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The Mexican territory is divided in 37 hydrological regions. Eight basins were taken as study cases for this paper. All of these basins are in Hydrological Region 10 of Sinaloa (Figure 1).



**Figure 1.** Hydrological regions in Mexico, Hydrological Region 10 Sinaloa and basins under study.

**Sources:** Prepared by authors with shape files from CONABIO (2009) and basin vertices published in CONAGUA (2016a).

### 2.1.1. Humaya and Tamazula basins

These basins are part of the Culiacan River Basin that is located between parallels 26°03'12.98" N and 24°27'09.78" N and between meridians 107°45'38.81" W and 105°48'34.16" W. Culiacan River watershed occupies the second-most important terrain portion of Hydrological Region 10. The Culiacan River is 305 km long; it is a sixth-order stream and has an angular drainage pattern. This basin is exorheic, draining to the California Gulf and has a maximum altitude of 3,207 meters above sea level. Culiacan River Basin occupies territories of the Mexican states of Chihuahua, Durango and Sinaloa. The Culiacan River is the main stream which is formed by the junction of Humaya and Tamazula rivers in the city of Culiacan (Sanhouse-Garcia *et al.*, 2017).

The Humaya River is the largest affluent of the Culiacan River. This river has its origin in Durango state, located at 3,100 m.a.s.l. The Humaya River Basin has a surface area of 11,104.0 km<sup>2</sup>, where its runoff is estimated in 1,907.0 Mm<sup>3</sup> per year (CONAGUA, 2016b). The Adolfo Lopez Mateos dam is situated on the Humaya River upstream from its confluence with the Tamazula River located in Culiacan City. The Tamazula River Basin has a catchment area of 3,307.0 km<sup>2</sup> and a natural runoff annual volume of 755.4 Mm<sup>3</sup> (CONAGUA, 2016b). The Sanalona Dam is located on this river before its confluence with the Humaya River.

### 2.1.2. Group of streams Altata and Pabellones basins

Group of Streams Altata Basin is in an area situated between parallels 24°45'45.54" N and 24°32'27.20" N and between meridians 107°59'37.21" W and 107°46'10.81" W. Its topography is mainly flat, with a maximum altitude of 9 m.a.s.l. This watershed has a surface area of 299.1 km<sup>2</sup> and a natural surface runoff of 17.6 Mm<sup>3</sup> per year (CONAGUA, 2016b). The Group of Streams Altata area has no main stream. Its territory is drained by diverse small watercourses to the sea through Altata cove

Group of Streams Pabellones is an area placed between parallels 24°47'28.51" N and 24°16'17.63" N and between meridians 24°16'17.63" W and 107°05'09.77" W. Its surface area is of 1 818 km<sup>2</sup> and its natural surface runoff is 92.1 Mm<sup>3</sup> per year (CONAGUA, 2016b). The Group of Stream Pabellones area has a mean altitude of 330 m.a.s.l. Because this watershed has no main stream, it is drained by multiple small streams that flow to Pabellones cove that is connected to the Pacific Ocean.

### 2.1.3. Piaxtla River watershed

The Piaxtla River Watershed is located between parallels 23°40' N and 26°30' N and between meridians 105°20' W and 106°50' W. The catchment area is about 7,447.1 km<sup>2</sup> and the natural annual surface water runoff is 1,397 Mm<sup>3</sup> (CONAGUA, 2016b). This watershed is exorheic with a very elongated ellipse shape having a maximum altitude of 3,206 m above sea level (de la Lanza Espino *et al.*, 2015). Its hydrographic scheme is simple. Its main collector follows an approximate southwest direction towards the sea receiving streams on both sides. The Piaxtla River springs in Sierra Madre Occidental ridge above 2,800 meters above the sea.

The Piaxtla River has a longitude of 220 km and an angular drainage pattern. Based on CONAGUA criterion, the Piaxtla River Watershed is divided in two basins: the Rio Piaxtla 1 and the Rio Piaxtla 2 that are described below. Rio Piaxtla 1 basin drains an area of 4,842.7 km<sup>2</sup> and is bordered to the north by the San Lorenzo River watershed, to the south by the watersheds of the rivers Presidio and Quelite, to the east by Hydrological Region 36 Nazas-Aguanaval, and to the west by the Elota River Watershed. Rio Piaxtla 1 basin extreme altitude sites are the source of the Piaxtla River and the Piaxtla hydrometric station. Rio Piaxtla 2 basin drains an area of 2,604.4 km<sup>2</sup> and it is limited at north by the Elota River watershed, to the south by the Quelite River watershed, to the east by the Presidio River watershed, and to the west by the Pacific Ocean.



#### 2.1.4. Quelite River Watershed

The Quelite River Watershed is situated between 23°48'43.85" N and 23°18'16.30" N and between 106°36'57.09" W and 106°10'04.35" W. This watershed has a surface area of 1,194.5 km<sup>2</sup> and its main water course has a longitude of 67 km. It has a natural surface runoff of 154.0 Mm<sup>3</sup> (CONAGUA, 2016b).

The Quelite River watershed has the shape of an irregular four-sided polygon having a very simple hydrographic structure with a single central collector flowing to the southwest. It receives unnamed small streams on both sides. The Quelite River originates in the Sierra del Espinazo del Diablo ridge around 1,050 m.a.s.l. running through Los Naranjos village and six kilometers downstream through El Quelite village, from which this river takes its name (Ramos and Gracia, 2012).

The Quelite River watershed is divided into two basins, Rio Quelite 1 and Rio Quelite 2, as described below. Rio Quelite 1 basin includes an area from the Quelite River origins to the El Quelite hydrometric station. It drains an area of 829.9 km<sup>2</sup> and it is limited to the north and to the west by the Piaxtla River watershed, to the south by the Rio Quelite 2 Basin, and to the west by the Presidio River Watershed. Rio Quelite 2 Basin extends from the El Quelite hydrometric station to the sea. It drains an area of 364.6 km<sup>2</sup> and limits to the north by Quelite 1 Basin, to the east by the Presidio River Watershed, to the south by a marsh zone and by the Presidio River Watershed, and to the west by the Piaxtla 2 Basin and the Pacific Ocean.

#### 2.2. Software and databases

The dataset used in this study was obtained from Mexican government and worldwide databases. Mexican official information includes hydrography, official watershed delineation, and localization of discharge gauging stations. In turn, worldwide databases provided terrain elevations and satellite images.

Maps were generated using QGIS 2.18.3 Las Palmas software. GIS software selection was based on the criterion that this software is an open-source tool. Also, this software is useful and simple and shows a friendly interface that allows for the processing of many file formats (both input and output) and the exchange of information through the publication of cartography. QGIS was executed from the Windows platform. Georeferencing of the basic cartography set was carried out using the WGS84 reference system (World Geodetic System, 1984) and UTM projection (Universal Transverse Mercator), zone 13.

Maps were generated using vector files containing information such as the delineation of basins, sub-basins, watercourses and waterbodies. This information is available from National Institute of Geography and Statistics (INEGI, 2017a). Layers corresponding to Hydrological Region 10 Sinaloa (scale 1:50 000) were downloaded. They are vector files in shape format (\*.shp).

Mapping of the official delineation of river basins in Mexico was performed based on vertex coordinates. Official delineation in Mexico is published in the Official Journal of the Federation (CONAGUA, 2016c) in PDF text format. These coordinates were converted from Adobe Acrobat to Excel files. They were then saved in comma delimited text format and added to the GIS canvas using option "Add comma delimited text layer". Terrain elevation layers were generated from elevation data using GIS tool "Level curves".

Watercourses and water bodies were incorporated into maps by loading vector layers from Hydrographic Network 1:50 000. The Hydrographic Network used in this paper is a drainage model of river basins (INEGI, 2010). This information is stored in a database in geographic coordinates Datum ITRF92 epoch 1988.0 with eight decimal digits of decimal degrees. In some maps, terrain satellite images were used as background to enhance visual perception of terrain. Hydrometric station coordinates were consulted in the Surface Water National Data Bank (CONAGUA, 2017b). In addition, ASTER GDEM v2 Worldwide

Elevation Data with one arcsec resolution (NASA, 2011) and satellite images from Google Earth Pro were used to identify elevations of official river basin boundaries and to display orography as a natural terrain background, respectively. Both data sources were selected as cartographic sources.

It should be noted that neither river basin boundaries nor other hydromorphological features were generated by using digital elevation model processing. This is because the purpose of this paper is to compare official information issued from different governmental sources: official river delineation from the water authority (CONAGUA), hydrography from INEGI and the legal definition of “river basin” from the Federal Official Diary.

### 2.3. Analysis of the legal definition of watershed and watershed official delineation

The definition of watershed established in Mexican Water Law was examined and compared with officially delineated basins. The characteristics that distinguish the official watershed definition were separated and examined in eight basins, which constitute the study cases. They were selected from a representative hydrological region with diverse hydrographic features, like basins with and without water reservoirs, borders established by the presence of hydrometric stations and territories drained by no main streams.

The GIS capabilities were used to prepare maps having official basin delineation and hydrography coming from different data sources. This allowed for the examination of specific characteristics of selected official basins and for the comparison of these with their corresponding concept established in the legal definition of watershed.

Finally, a new watershed definition is proposed, which tries to keep the essence of the original one proposed by the Mexican Federal Government. No changes in official watershed delineation are mandatory for this definition proposal. The eight study cases were also used to probe the suitability of the new definition.

## 3. RESULTS AND DISCUSSION

### 3.1. Legal definition of watershed in Mexico

In Mexico, a legal definition of hydrological basin is established in the National Water Law (NWL) (CONAGUA, 2017a):

Hydrological basin: is a territory unit, differentiated from other units, usually delimited by a water parting or water divide, which is a polygonal line formed by the highest elevation points in that unit, where water courses in different ways and this resource is stored or flows to an outlet point that can be the sea or other inland waterbody, through a hydrographic network of streams that converges in a main one, or it is the territory in which the waters form an autonomous unit or differentiated from others, even without draining water towards the sea. In this space, delimited by a topographic diversity, water, soil, flora, fauna, and other natural resources coexist. The hydrological basin in conjunction with the aquifers constitutes the management unit of water resources. The hydrological basin is in turn composed of sub-basins and they are integrated by micro-basins.

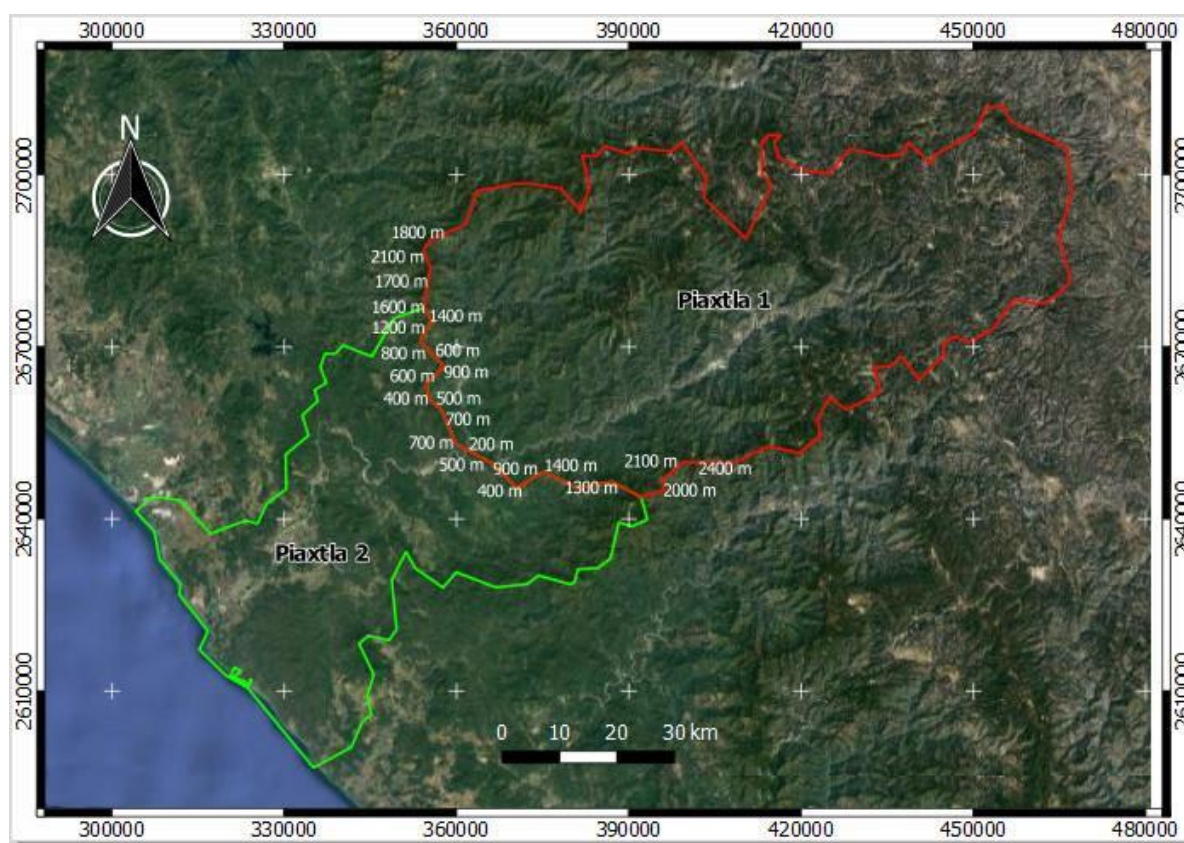
This definition shows inconsistencies with respect to the official delineation of hydrological basins in Mexico, which are published in the Official Journal of the Federation. The territory division in official hydrological basins is used as a geographic framework to determine water availability “*Natural runoff is among the elements considered to update mean annual national water availability in the 731 hydrological basins[...]*” (CONAGUA, 2016d). In turn, official water availability is the base to confer or deny water use rights (CONAGUA, 2017a).

According to official information, 26 new small basins or watersheds were aggregated. Hence, there are 757 official hydrological basins in Mexico (CONAGUA, 2016a; 2016b; 2016c; 2016d; 2016e; 2016f). However, these delimited basins do not meet the characteristics given in the legal definition, as it is discussed in this article through the respective study cases.

### 3.2. Water parting: a line of the highest elevation points

In the hydrological basin definition, the NWL establishes that *"Hydrological basin: is a territory unit, differentiated from other units, usually delimited by a water parting or water divide, which is a polygonal line formed by the highest elevation points in that unit[...]"*

Based on this definition, the word "usually" gives the idea that there are unusual situations. Commonly a hydrological basin is defined as a polygonal line formed by the highest elevation points. However, there are some official hydrological basins in Mexico which are delimited, and they do not meet with this requirement. Official delineation of Piaxtla River 1 and Piaxtla River 2 Basins are shown in Figure 2 (CONAGUA, 2016a).

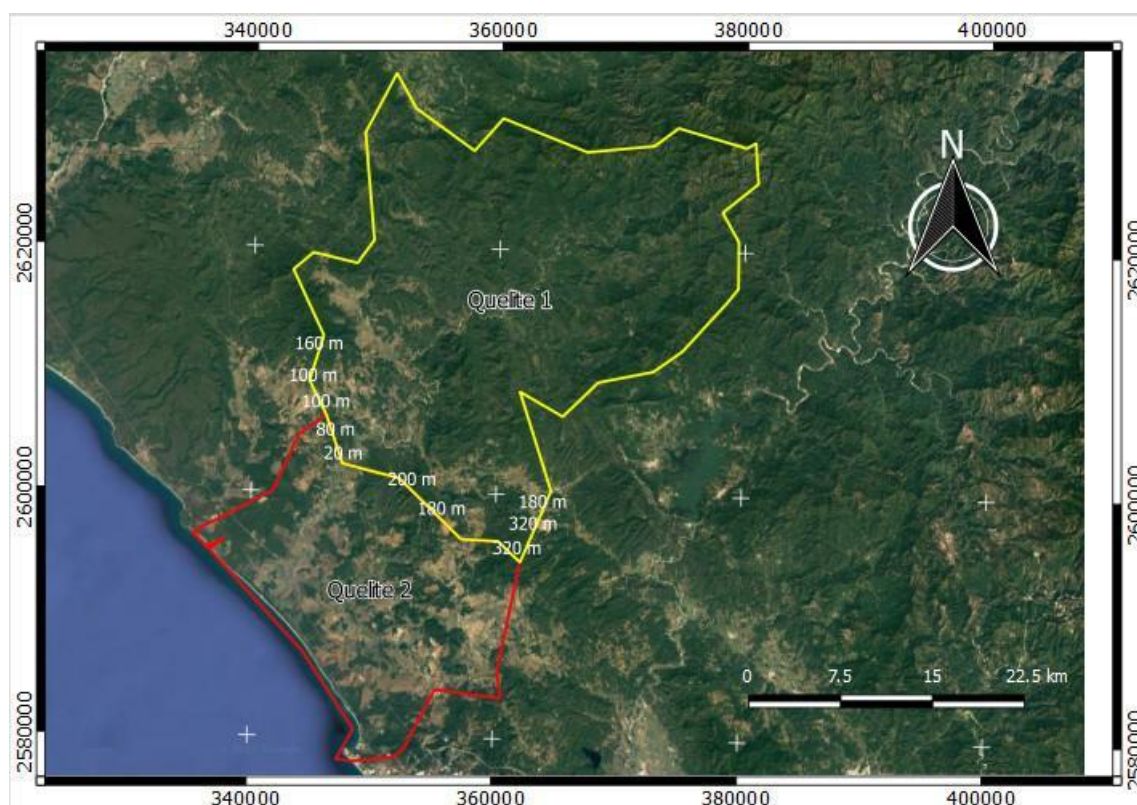


**Figure 2.** Contour lines in the frontier of Piaxtla River 1 and Piaxtla River 2 Basins.

**Source:** Prepared by the authors using Google Earth and CONAGUA (2016a).

Boundary details of both basins demonstrate that delineation boundary dramatically decreased from an elevation of 2100 m.a.s.l. to 400 m.a.s.l. This situation indicates that an important part of the basins' border, i.e., the common frontier, does not meet the hydrological basin definition of the NWL. An arbitrary unnatural delineation was carried out for dividing both basins. A similar situation is presented for Quelite River 1 and Quelite River 2 Basins, as shown in Figure 3. Based on the level curves of the study area, elevations of 20 m.a.s.l were registered as part of the delineation boundaries of these basins.





**Figure 3.** Contour lines in the frontier of Quelite River 1 and Quelite River 2 Basins.

**Source:** Prepared by the authors using Google Earth and CONAGUA (2016a).

### 3.3. Location of hydrometric stations as a criterion for basin delineation

A common practice for hydrographic basin delineation in Mexico is to define its boundaries through the presence of hydrometric stations located on the main stream. In the previous section (Figures 2 and 3), two study cases were present: Piaxtla River Basin and Quelite River Basin. Based on the description of Piaxtla River 1 Basin boundaries, this hydrological basin "[...]starts from the beginning of the Piaxtla River until where the Piaxtla hydrometric station is located." (CONAGUA, 2013a). This hydrometric station is located in the coordinates 106°25'30.0" and 23°56'00.0" (CONAGUA, 2017b). In accordance with official information, the division between these basins was determined by the locations of the hydrometric stations registered in the National Data Bank of Surface Waters (NDBSW). This situation could explain the fact that none of the basins is formed by the highest elevation points. A similar situation occurs for the Quelite River Basin. This hydrological basin: "[...]starts from the beginning of the Quelite River until where the hydrometric station El Quelite is located" (CONAGUA, 2013b). The hydrometric station mentioned above is located in the coordinates 106°29'00" N and 23°30'45" S (CONAGUA, 2017b).

On the other hand, Figures 2 and 3 show that the sea or other interior water bodies are not located at the outlet of the upstream basins (Piaxtla and Quelite). In this sense, these study cases do not fulfill with the definition of hydrological basin of the NWL, which specifies that the territory of a hydrological basin is: "[...]where water courses in different ways and this resource is stored or flows to an outlet point that can be the sea or other inland waterbody". The basins demonstrated that the legal definition of hydrological basin in Mexico is not linked to the official delineation of hydrological basin. Consequently, it is not consistent with the characteristics that legal definition establishes. Furthermore, according to legal definition, a hydrological basin is "[...]the territory in which the waters form an autonomous unit or differentiated from others, even without draining water towards the sea." Piaxtla River 1 and Piaxtla River 2 Basins do not form autonomous units, nor are differentiated from one another.

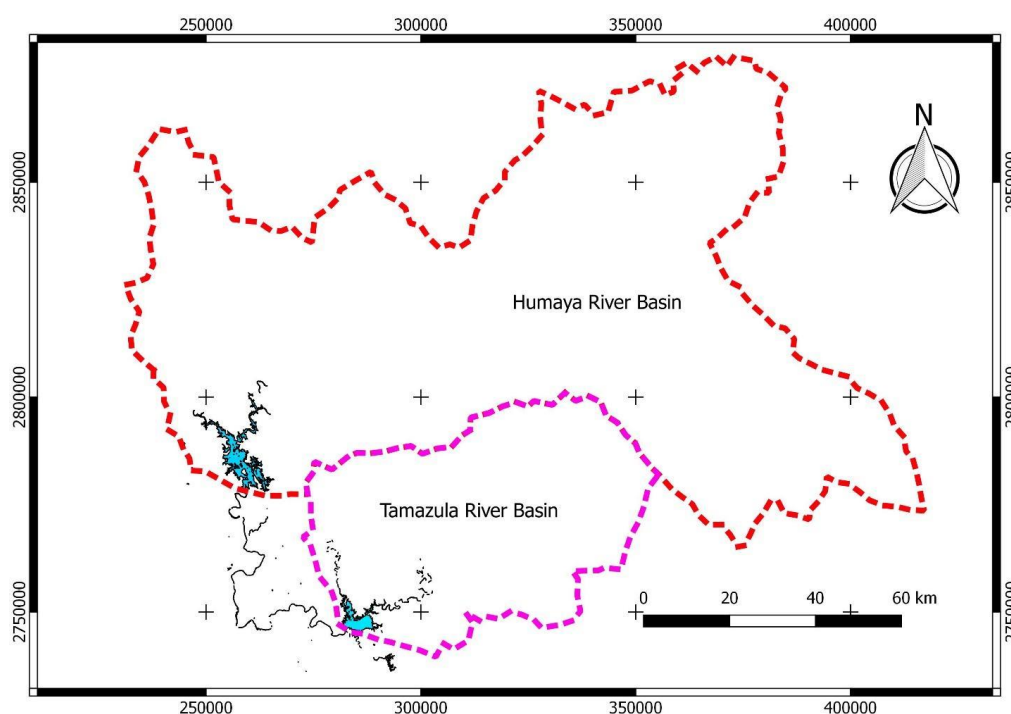
The only thing that distinguishes them is the existence of a hydrometric station located on a site, which is considered appropriate for measurement purposes. A similar situation is presented in the Quelite River 1 and Quelite River 2 Basins. Thus, the legal definition of hydrological basin should be flexible and should include cases such as those described here.

### 3.4. Water bodies as boundaries of a hydrological basin

The National Water Law establishes that surface water in a hydrological basin: "[...]is stored or flows to an outlet point that can be the sea or other inland waterbody, through a hydrographic network of streams that converges in a main one". In this statement, there is a parallelism between the sea and other waterbody as destinations of the water that drains out the basin. This means that neither the sea, nor the "other waterbody" are part of the basin. According to this wording, this receptor waterbody should be located outside the basin, downstream from it.

In Mexico, waterbodies' boundaries are used to define hydrological basins. The presence of water bodies inside a hydrological basin demonstrates that the official delineation of hydrological basin does not meet with the characteristics established by the legal definition. Such a discrepancy is observed specially in hydrological basins with reservoirs. The Humaya River and Tamazula River Basins could be considered as examples. The official description of Humaya River Basin indicates that: *"The available volume of Humaya River basin goes from the beginning of the Humaya River up to the Adolfo López Mateos reservoir"*, while the official description of Tamazula River basin is: *"The volume available of Tamazula River basin goes from the beginning of Tamazula River until where the Sanalona reservoir is located."* (CONAGUA, 2010).

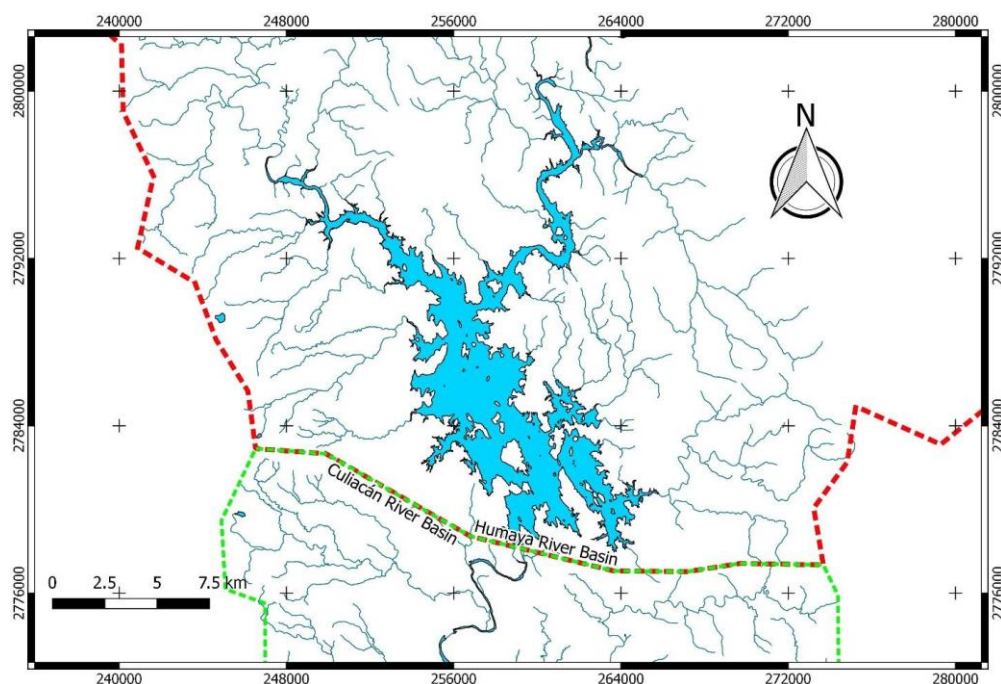
CONAGUA (2016a) provides the vertices of the polygon lines that define these hydrological basins boundaries. This polygon includes Adolfo López Mateos reservoir inside Humaya River Basin and Sanalona reservoir inside Tamazula River Basin, as shown in Figure 4.



**Figure 4.** Humaya River and Tamazula River Basins and their reservoirs.

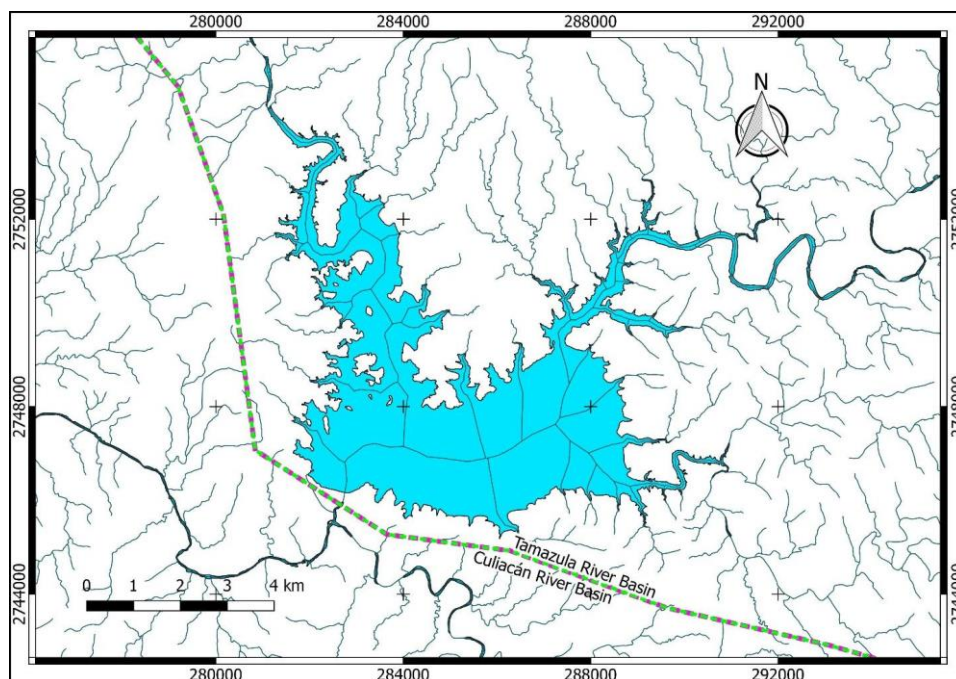
**Source:** Prepared by the authors using INEGI (2017a) and CONAGUA (2016a).

In both cases, the water does not drain towards a waterbody located outside the basin, because the waterbody (reservoir) is inside of it. In addition, some streams belonging to the hydrographic network of the basin do not converge towards a main course but converge towards the reservoir. An inspection of the surrounding areas reveals that there are multiple inputs to each reservoir (Figures 5 and 6). Since each waterbody located inside the basin has multiple inlets, they could be also considered as hydrological basin outlets, including the corresponding to the main stream.



**Figure 5.** Streams draining to the reservoir of Adolfo López Mateos Dam.

**Source:** Prepared by the authors using INEGI (2017a) y CONAGUA (2016a).



**Figure 6.** Streams draining to the reservoir of Sanalona Dam.

**Source:** Prepared by the authors using (INEGI, 2017b) y (CONAGUA, 2016a).



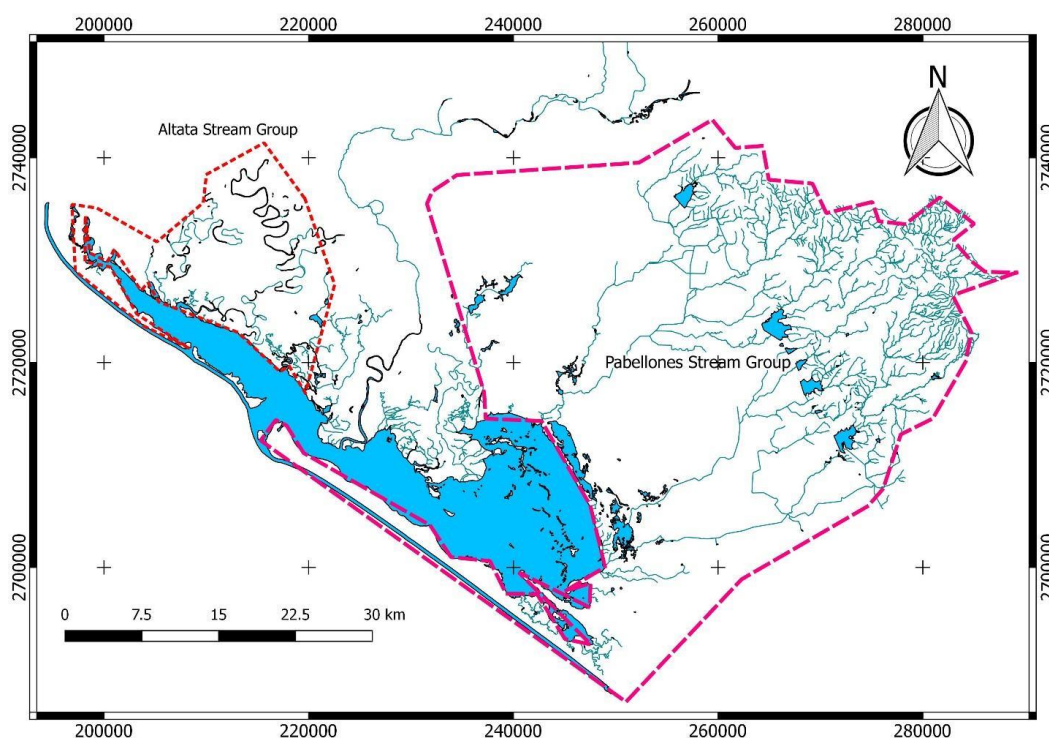
Therefore, if the whole drained area is characterized, maintaining the principle that a basin should have a single outlet point, the first alternative would be to indicate that in the case of a waterbody presence in a hydrological basin: 1) the drained area is constituted by the main stream basin and a set of minor basins; 2) the convergence entity is the waterbody located inside of the basin; and, 3) the boundary of this basin is the output point of the reservoir or where its outflows merge. A second alternative would be to modify the definition of hydrological basin in such a way that this definition could be consistent with the existing official delineations.

### 3.5. Groups of minor coastal basins

In the Federation Official Diary (CONAGUA, 2016a), it is also noted that:

*"[...]within the 37 hydrological regions of the country, there are areas where no perennial streams exist, which are not within the 731 basins identified previously. Hence the identification of 26 new hydrological basins is required to cover the whole national territory."*

In the area under study there are two of these types of areas. This type of terrain is characterized by multiple small watercourses draining to the sea, each of them having multiple drainage points, as shown in Figure 7. These officially-delimited basins do not fulfill with the established in the legal definition, where an only drainage point is required (CONAGUA, 2017a).



**Figure 7.** Group of streams Altata and Pabellones.

**Source:** Prepared by the authors using CONAGUA (2016b).

In order to look for consistency between the legal definition of hydrological basin and these types of drainage entities, which are already defined and officially referred as "new hydrological basins", it is necessary to consider the configuration variability of these territories. Cotler (2007) suggests that:

*"Some hydrological basin boundaries might vary due to the time of the year, an anthropogenic modification of the drainage network and even because of the presence of some special meteorological phenomenon like hurricanes, which could generate the displacement of basin boundaries downstream".*



According to this, the establishment of individual boundaries for each of these basins is not a viable option, given the permanent nature of the official precepts. Gathering them in a single drainage official entity, as a "group of minor basins", could make consistent the natural configuration variability of these basins with official denomination. In addition, this boundary would be at the same time a limit of adjacent basins with more stability in their configuration. "Group of minor basins" is a concept that can be extended to a set of small hydrological basins, which drain into a waterbody located inside a basin.

### 3.6. Complexity of the legal definition

According to the Oxford Dictionary, a definition is: "[...]an exact statement or description of the nature, scope, or meaning of something" (Oxford, 2018). The Dictionary of the Royal Spanish Academy adds "clarity" to the characteristics that a definition must have (Real Academia Española, 2017). The definition of "hydrological basin" in Mexico is provided by the National Water Law. Neither references nor technical fundamentals are specified. However, the wording of this definition is inconsistent with the concept of definition itself. The definition of hydrological basin established in the NWL has a generic character, as being "[...]a territory unit". This could be a physiographic region, a municipality or other natural or artificial zoning.

In the CONAGUA definition of hydrological basin, it is also established that the basin is *usually* delimited by a water parting. The word *usually* refers to the existence of different cases. However, it does not indicate how these cases would be delimited. This wording fails to fulfill the exactitude and clarity that a definition should have. On the other hand, the wording of the hydrological basin definition is comprised of several watershed definitions, as shown in Table 1.

**Table 1.** Definitions contained in the definition of watershed of Mexican National Water Law.

National Water Law	Other sources
"[...]is a territory unit, differentiated from other units, usually delimited by a water parting or water divide[...]"	<b>Watershed:</b> Surface bordered by a water parting so that its runoff flows towards a main water course, or waterbody. It is a subdivision of a hydrological region (Omernik and Bailey, 1997). <b>basin syn. drainage basin, catchment, river basin, watershed (USU):</b> Area having a common outlet for its surface runoff (OMM, 2012).
"[...]a polygonal line formed by the highest elevation points in that unit[...]"	<b>Watershed divide (USU) syn. drainage divide, water parting:</b> Summit or boundary line separating adjacent drainage basins (OMM, 2012).
"[...]where water courses in different ways and this resource is stored or flows to an outlet point that can be the sea or other inland waterbody, through a hydrographic network of streams that converges in a main one[...]"	<b>Exorheic basin:</b> A basin draining to the sea (García-Tortosa <i>et al.</i> , 2008). <b>Endorheic basin:</b> A basin having no outlet to the sea but receiving temporary or permanent streams. That is the reason why a permanent or temporal aquifer exists (CONANP, 2016).
"[...]or it is the territory in which the waters form an autonomous unit or differentiated from others, even without draining water towards the sea."	<b>Endorheic basin:</b> A basin having no outlet to the sea but receiving temporary or permanent streams. That is the reason why a permanent or temporary aquifer exists (CONANP, 2016).

**Source:** Prepared by the authors.

In addition, this definition includes differential characters (CONAGUA, 2017a):

- *"In this space, delimited by a topographic diversity, water, soil, flora, fauna, and other natural resources coexist.*
- *The hydrological basin in conjunction with the aquifers constitutes the management unit of water resources.*
- *The hydrological basin is in turn composed of sub-basins and they are integrated by micro-basins".*

The elevated number of definitions and differential characters in the same paragraph which constitutes a single definition complicates its interpretation. In this sense, hydrological basin definition is not presented with clarity. These differential characters are excluded from the hydrological watershed definition in a new Mexican water law project proposed since 2015.

On the other hand, the Mexican Modern Government Program for 2013-2018 states that the initiatives must be communicated in plain language (*line of action 1.5.2 Diffusion of the progress and results of the programs derived from the National Development Program (NDP) must be in plain language*) (Mexico, 2013). Plain language is: "[...]a simple expression, clear and direct information that readers (public servants and citizens) need to know" (Valdovinos Chávez *et al.*, 2004). This initiative comes from an international effort of several countries, including some Spanish-speaking countries like Spain, Mexico and Chile.

As can be seen, the hydrological basin definition is not expressed in plain language; however, it is "[...]information that readers (public servants and citizens) need to know". This is by virtue of the fact that the definition of basin contained in the NWL is an essential element in determining the average annual availability of surface water (SEMARNAT, 2015). The availability of surface water is one of the central themes of the Water National Program 2014 - 2018 (CONAGUA, 2014), a document that is derived from the NDP.

### 3.7. Proposal of a hydrological basin definition

A proposal for a new hydrological basin definition is presented to harmonize this definition with the hydrological basin delineation published in the Federation Official Diary (FOD). This modification proposal represents minor consequences in terms of: 1) technical work to review the boundaries of the 757 hydrological basins already defined; 2) editing the vertices that do not meet the legal definition; 3) administrative work to review and modify the publications of the FOD that establish the official delineation (CONAGUA, 2016a; 2016b; 2016c; 2016d; 2016e; 2016f); and 4) dealing with technical, administrative and even legal implications on calculation of average annual availability of surface water and consequently with the already given or denied water rights (CONAGUA, 2017).

The proposal has the following characteristics:

- Defines the concept of hydrological basin in a simple way, in a single paragraph and in accordance with the examples of basins analyzed in this manuscript and based on a definition supported by a recognized publication in the hydrology field.
- Considers the concept of "new hydrological basins" and the rest of the concepts that the current definition includes.
- When an area is drained by various minor currents, their basins are congregated in groups and are considered a special unit for the management of water resources (Group of minor basins or sub-basins).

Derived from the above, a proposal for hydrological basin definition is presented in a plain language, followed by six definitions, corresponding to the characteristics that the Mexican authority establishes for resource management purposes:

**Hydrological Basin**

Area that has a single outlet point for its surface runoff (adapted from OMM, 2012).

In addition, the following definitions are proposed to complement this definition; they include the aspects considered in the original definition, as well as the concept that defines published "additional basins".

**Sub-basin**

Next-level subdivision of a hydrological basin.

**Micro-basin**

Next-level subdivision of a sub-basin.

**Group of minor basins**

A land area where surface flow originates entirely within the hydrologic unit and drains to multiple points along a large waterbody such as the ocean, or large reservoir or lake (adapted from SSWD, 2003).

**Water Parting**

Boundary line that separates adjacent hydrological basins (OMM, 2012).

**Exorheic basin**

Drainage basin whose surface water runs into the ocean or into another waterbody having a connection to the ocean (CONANP, 2016).

**Endorheic basin**

Basin whose surface waters do not drain towards the sea but receives temporary or permanent flows. For that reason, a permanent or temporary aquifer is present (CONANP, 2016).

**3.8. Discussion**

The aim of this paper is not to propose criteria to delineate new hydrologic units. Discussion deals with the suitability of the proposed definition for a watershed and its applicability to the current official watershed delineations in Mexico. Countries mentioned in this paper also must deal with current official delineations that are used for administrative and legal purposes. Thus, congruence between legal definitions of watershed and official delineations is an issue that this manuscript addresses.

Strong interagency efforts are needed to establish watershed delineations. *"The delineation shall be as simple as it is practical, and will keep hydrologic units from benefiting a particular agency, program, administrative area or special project."* (SSWD, 2003). Cotler (2007) suggests that this delineation should be determined solely upon science-based hydrological principles to assure a homogeneous national seamless digital data layer.

In this sense, several basin delineations have been carried out by government entities in Mexico. CONABIO (2012) reported 3115 sub-basins in 2001. This entity has also reported different numbers of natural basins for the Mexican territory: 160, 142 and 1,474 (CONABIO, 2008; 2012 respectively). National Institute of Statistics and Geography (INEGI) considered 150 basins and 1,001 sub-basins (INEGI, 2001). National Water Commission (CONAGUA) has also stated a number of basins of 314 (CONAGUA, 1996). In 2007, based upon the *"[...]join effort of INEGI, National Institute of Ecology and CONAGUA to establish concerted and common criteria to delimitate the basins of Mexico and toponymy definition"*,

the Mexican territory was divided into 1,471 basins (Cotler, 2007). This delineation was performed with a rigorous and documented process based on natural criteria such as topography and hydrography. Despite these efforts, CONAGUA published different numbers of basins for Mexico: 718, 728, 722 (CONAGUA, 2009; 2008; 2010, respectively). In 2012, the number of basin was defined in 731 (CONAGUA, 2012). This number of basins and their respective vertex coordinates were formalized in the Federation Official Diary (CONAGUA, 2016d). Later, 26 new additional hydrological basins were set up. Therefore, a total of 757 basins is the currently official number of watersheds in Mexico.

Despite having access to a delineation of 1,471 basins obtained by a rigorous process based on natural criteria (Cotler, 2007), the water authority decided to make a different basin delineation and give it an official status. This is evidence that the working criteria were also different. The 757-basin delineation was configured progressively, probably by technical and administrative departments of CONAGUA. This delineation aims “[...]to give higher certainty to water users with respect to the exact localization of the site where the exploitation, usage or harnessing of water takes place as well as to improve the administration and management of water resources” (CONAGUA, 2016a). In other words, this watershed delineation has a clear administrative purpose with intrinsic legal and technical implications that prevents its drastic modification (Cuevas *et al.*, 2010). This kind of inertia is recognized even in systematic science-based efforts to delineate watersheds: “the diversity of hydrological conditions nationwide, complexity of surface hydrology and the number of factors involved in the delineation process preclude an all-inclusive guideline. Variations will generally be limited to previously delineated units with a long history of use” (SSWD, 2003).

In Mexico, a modification of official basin delineation can motivate important issues to deal with in water administration. Water-right title is a legal document which specifies the basin where water usage occurs (CONAGUA, 2017a). Thus, if a change of basin delineation or denomination is carried out, then a proper legally-valid procedure must be followed. Similar situations can occur with other legal documents, such as discharge of wastewater permits, water quality certificates, among others (CONAGUA, 2017c). Even legal processes against water authorities’ resolutions about surface water availability should be considered before such changes.

The difficulty of modifying the official delineation of hydrological basins was also considered unfeasible in Chile:

[...]it was concluded that new water delineation could be useful in some cases... but being a new delineation, it is very likely to have a different number of watersheds and database with respect to the current NWB System, which means that this new watershed division will be separated from NWB codification. This disconnection would represent that the new delineation will not be used (Chile, 2013).

The proposal for legal definition of hydrological basin in Mexico made in this paper is based on the definition of the World Meteorological Organization (OMM, 2012). The purpose of defining terms separately is to consider the concepts included in the original definition and the results obtained in this study. The proposed definition is expressed in a simple language, which is clear and direct. On the one hand, the hydrological basin definition proposed in this manuscript fulfills with the initiative to express concepts of public interest in plain language. On the other hand, this definition does not establish the maximum elevation points as a criterion to define the hydrological basin boundaries, which offsets the deficiencies identified in the official definition.

Based on the inconsistencies found in this study, the proposed definition establishes that the surface water of a basin should not flow towards the sea or a waterbody, nor should the basin be autonomous from others. Therefore, this definition proposal could adapt to the official delineation of hydrological basins defined by the criterion of hydrometric station



presence. The proposed definition could be also adapted to official delineations where the hydrological basin boundaries are determined by the presence of a waterbody. The area referred to in the proposed definition covers a surface area without including water stored in a waterbody, and the single outlet is constituted by the structures built with the purpose of extracting the water stored in the inland waterbody. The introduction of "group of minor basis" concept refers to an aggregate of basins with reduced dimensions which serves as a management unit of water resources. These are the 26 cases that were recognized by federal authority and called "new hydrological basins". This concept could also be applied to groups of small hydrological basins defined by the presence of a waterbody.

It is also noted that official hydrological basins were defined based on superficial terrain criteria. This situation can be deduced by the fact that its configuration is used to calculate and disclose the average annual surface water availability. The average annual groundwater availability is computed separately from surface water availability (SEMANAT, 2015). Groundwater availability is based on the aquifers' delineation and then it is calculated with an independent method (SEMANAT, 2015). Hence, official definition of hydrological basin in Mexico (CONAGUA, 2017a) is, in fact, the definition of hydrographical basin. According to Moura and Henry-Silva (2015), hydrographic basins are part of larger systems, involving aspects of geology, vegetation, climate and land use and occupation, consisting of a mosaic of functional subsystems interconnected by biotic and abiotic processes. In contrast, the concept of hydrological basin: *"Unlike the hydrographic basins, hydrological basins, besides including the first ones, they also include underground hydrogeological systems. Therefore, hydrological basins could vary in their purely hydrographic limits"* (INECOL, 2005).

In accordance with Campos Aranda (1992), the difference between the territorial delineation of a hydrographic basin (the topographic basin) and a hydrological basin (the groundwater table basin) is reduced to special cases, such as karst terrain or regions with coarser sediment on rock beds. Except in the cases mentioned above, both boundaries should match. Therefore, if discrepancy cases are sought, a detailed analysis is required to determine and compare the aquifer-recharge areas in conjunction with the surface topography. At most, when the water balance in the basins and aquifers is carried out, these differences would be clear and a distinction between the boundaries of the hydrological and hydrographic basins would be required.

Hydrological basin definition is used in the totality of the publications in the FOD dealing with surface water availability, as well as all derived documents of a normative character. Therefore, the use of hydrological basin definition is generalized in this area. Changing this term to hydrographic basin would imply substantial modifications to official, legal, and regulatory documents. A duly substantiated and instrumented superior law would be required to make this change. Hence, if both types of basins are equivalent from the point of view of topographic layout maps, the official delineation can be considered as hydrological basins.

## 4. CONCLUSIONS

Official delineation of hydrological basin is fundamental to determine official water surface availability, which is in turn essential to confer or deny water rights. This delineation must be consistent with the legal definition of hydrological basin, a term that is persistently defined in water laws of Latin America. This manuscript presents a discussion about inconsistencies between the legal definition and the official delineation of eight study cases constituted by hydrological basins in Sinaloa, Mexico.

Based on the analysis of the current hydrological basin definition included in the National Water Law, it is concluded that the legal definition should be amended to establish

consistency with the basins delineated in the Official Federation Diary. This is because significantly less technical and administrative effort is required to modify one definition than to modify the official watershed delineation, as it is also recognized by Chilean experts.

In this article, an amendment is proposed to harmonize this situation, with a minimum of changes in policy documents. This definition preserves the essence of the current legal definition, which highlights the hydrological basin as a management unit of water resources in Mexico. However, it is recognized that it is necessary to confront progressively the proposed definition with study cases of basins located in other parts of Mexico for its further improvement. Besides, for future analyses, it is convenient to use digital elevation models of higher resolution to perform more precise basin delineation.

This paper also proposes a scheme to establish a legal definition of watershed and issues directly associated with it, which can be useful to analyze similar situations in other countries where there is a watershed legal definition and official watershed delineation. In Latin American countries where there is no official watershed delineation to confer or deny water rights, this definition should be used from the beginning to assure consistency between legal definitions and such delineation. This could prevent technical, administrative and even legal problems to manage water resources derived from a lack of consistency between the basin's legal definition and the official watershed delineation.

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