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Water tariff model for irrigation in Antinaco - Los Colorados valley, Argentina

Modelo tarifário de água para irrigação no vale Antinaco – Los Colorados, Argentina

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ABSTRACT: A agricultura realizada em regiões áridas demanda maiores quantidades de água, e seu uso ineficiente afeta a capacidade de recuperação do ecossistema. Na Argentina, a água é considerada bem público, ou seja, para utilizá-la para fins privados, deve-se solicitar permissão às autoridades estaduais, descartando as negociações mediante os mercados de água. O Vale Antinaco – Los Colorados, localizado no centro-oeste da província de La Rioja (Argentina), apresenta-se como uma região de grande importância agrícola na província e com considerável escassez hídrica. O atual sistema de tarifas do serviço de irrigação possui preços fixos baseados na superfície das terras agrícolas, cobra-se um valor fixo por hectare, por ano. Isso dificulta utilizá-lo como ferramenta para abater o consumo excessivo de água, desincentivar estratégias de irrigação pouco adequadas ou evitar poluição gerada no setor agropecuário. Entretanto pode-se propor estruturas tarifarias de água com o intuito de incentivar a preservação do recurso e considerar variáveis ambientais, tecnológicas e culturais. A partir da análise de documentos, dados estatísticos, aporte de especialistas, registros de visitas a campo e utilizando o princípio de poluidor pagador, examinou-se as taxas de irrigação cobradas dos produtores agrícolas no Vale Antinaco – Los Colorados, obtendo-se os seguintes resultados: 1º) o enquadre jurídico das águas a nível nacional e provincial; 2º) a equação matemática da taxa de irrigação vigente; e 3º) a proposta de um modelo de tarifas de água para irrigação para os produtores agrícolas do vale.

Keywords: irrigation rates; agriculture; Chilecito (Argentina); vines.

RESUMO: A agricultura realizada em regiões áridas demanda maiores quantidades de água, e seu uso ineficiente afeta a capacidade de recuperação do ecossistema. Na Argentina, a água é considerada bem público, ou seja, para utilizá-la para fins privados, deve-se solicitar permissão às autoridades estaduais, descartando as negociações mediante os mercados de água. O Vale Antinaco – Los Colorados, localizado no centro-oeste da província de La Rioja (Argentina), apresenta-se como uma região de grande importância agrícola na província e com considerável escassez hídrica. O atual sistema de tarifas do serviço de irrigação possui preços fixos baseados na superfície das terras agrícolas, cobra-se um valor fixo por hectare, por ano. Isso dificulta utilizá-lo como ferramenta para abater o consumo excessivo de água, desincentivar estratégias de irrigação pouco adequadas ou evitar poluição gerada no setor agropecuário. Entretanto pode-se propor estruturas tarifarias de água com o intuito de incentivara preservação do recurso e considerar variáveis ambientais, tecnológicas e culturais. A partir da análise de documentos, dados estatísticos, aporte de especialistas, registros de visitas a campo e utilizando o princípio de poluidor pagador, examinou-se as taxas de irrigação cobradas dos produtores agrícolas no Vale Antinaco – Los Colorados, obtendo-se os seguintes resultados: 1º) o enquadre jurídico das águas a nível nacional e provincial; 2º) a equação matemática da taxa de irrigação vigente; e 3º) a proposta de um modelo de tarifas de água para irrigação para os produtores agrícolas do vale.

Palavras-chave: taxas de irrigação; agricultura; Chilecito (Argentina); videiras.

1. Introduction

Water for irrigation in agriculture should be understood as a finite and vulnerable resource. Therefore, its use based not only on efficiency and effectiveness criteria, but also on environmental and social considerations should be planned, ensuring all users' participation in democratic discussions.

In those areas where the availability of this resource is very limited, such as in Antinaco - Los Colorados valley, water management still requires the adoption of a recognized water policy, accepted by the members of the participating communities, and adapted to the actual resource availability, considering its demand and preservation. It is necessary to address the water issue from a theoretical framework, giving importance to legal regulations, customs, culture, and social aspects, which introduce the dynamics and relationships of these societies with the environment. Taking into account science and culture, the great challenge of discussing the use of water with the whole community should build a possible base on which the impacts of human activities on ecosystems and the limits of water resources on urban, rural, agricultural, and industrial dynamics themselves may be recognized and evaluated. This means focusing on the interrelationship between the environment and the development plans or expansion of human activities in the valley.

Regarding water tariffs for irrigation in the province of La Rioja, socialized research beyond technical reports of government agencies was not found. However, the research of Koleda; Eluani & Poblete (2018) may be mentioned; they propose an irrigation tariff system in the province of Mendoza (Argentina), introducing a critique of the of cost recovery principle, and highlighting the need to consider efficiency factors in water use when imposing tariffs. Following this idea, Alarcón, Mesa Jurado & Berbel Vecino (2012) submitted another tariff proposal applying fines to excessive water consumption differentiated by type of crop; Jiménez (2013) analyzes the relationship between water demand, soil and water quality to define a differentiated tariff system for agricultural farmers in the San Juan region (Argentina); Riera & Bruemmer (2016) studied irrigation tariffs with groundwater considering the incidence of electricity costs in Mendoza (Argentina), so that they do not provide incentives for the efficient use of the resource, nor do they include environmental considerations. The contributions of Gudiño & Cuello Ruttler (2017) are interesting because they include the vision of territorial order in defining tariffs based on social, cultural, agricultural, and economic variables. Finally, there are general reports such as the following: *INTA* Water and Irrigation Management (Moreyra, 2016); Economic Instruments for Water Management in Ecuador by the Water Secretariat (2017) or the Feasibility Analysis of the Water Fund on the Chubut River by Pascual *et al.* (2020), that evaluated the aspects of irrigation water tariffs. All of them conclude that current charging systems, including environmental parameters, should be modified; the new proposed system should consider lowest precipitation rates, climate change, and economic and technical efficiency criteria.

The objective of this paper was to analyze the irrigation rates charged to agricultural farmers in the valley and to propose a water tariff model for irrigation to encourage improved use and efficiency of water resources.

This paper is organized in five sections. Section 1 is the Introduction; Section 2 provides the general characterization of the valley; Section 3 describes the methodological aspects of the research; Section 4 presents the results obtained and the interpretation of the main characteristics of the water tariff system for irrigation managed by the *Consorcio de Usuarios de Agua* (Water Users Association). And in Section 5, the main conclusions and research contributions are reported.

2. Geographic, climatic, and productive characterization of Antinaco-Los Colorados valley

Antinaco - Los Colorados valley is located between Sierra de Velazco to the east, and Sierras de Famatina, Sañogasta and Paganzo to the west. It extends over 180 km, with a maximum width of 35 km and a minimum width of 13 km, with an area of approximately 4,200 km^2 (Sosic, 1971). The valley belongs to the province of La Rioja, in northwest of Argentina, and is located in the districts of Chilecito and Famatina. Figure 1 shows the location of the valley, the main water courses, and urban areas.

The valley has the largest agricultural activity in the province and an incipient agro-industrial development, even after the implementation of laws to encourage the growth of these activities in the last decades of the 20th century (*Ministerio de Economia y Finanzas Públicas*, *MECON,* according to its initials in Spanish, Ministry of Economy and Public Finance, 2018).

When analyzing the agricultural development of the valley, the main issue to be considered is the insufficient availability of surface water, a natural limitation to agricultural development. Both rainfall and river flows are very low in relation to the demand for human activities in the valley. It should be noted that, until the first half of the twentieth century, virtually all surface water was for exclusive use for human consumption and small-scale agriculture.

On productive lands, the main crops are vines, olive trees, stone fruits, and seeds. Depending on the

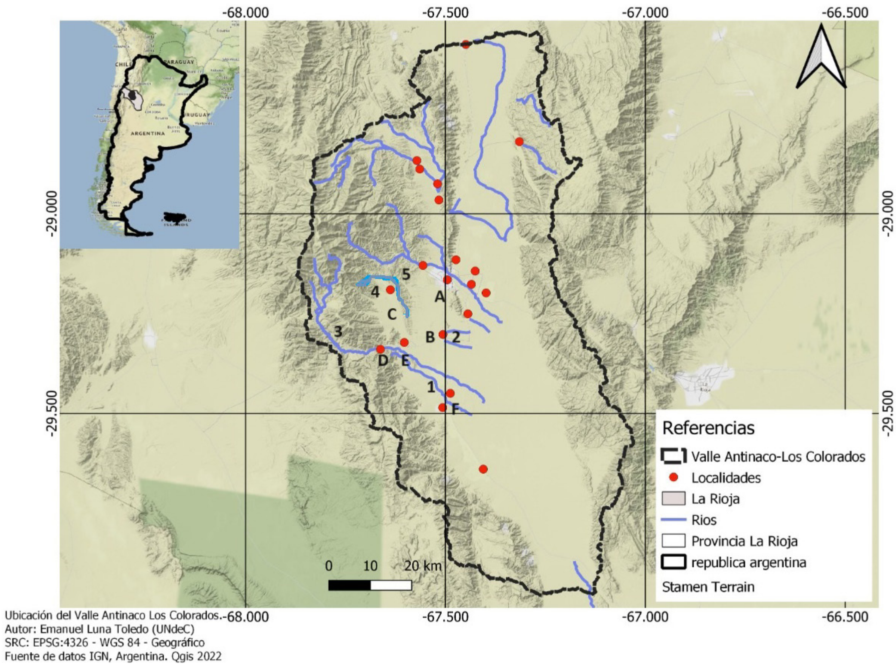

FIGURE 1 – Geographic location of Antinaco-Los Colorados valley, province of La Rioja, Argentina.

NOTE: The letters indicate urban areas: A - Chilecito; B - Nonogasta; C - Guanchín; D - Miranda; E - Sañogasta and F - Vichigasta. The numbers indicate rivers or water sources: 1 - Plaza/Chima water spring; 2 - Bosquecillo water spring; 3 – the Miranda River; 4 – the Pismanta River and 5 – the Amarillo River.

In Figure 1, the Spanish words are translated into English as follows: *Referencias* as References; *Valle Antinaco – Los Colorados* as Antinaco – Los Colorados valley; *localidades* as localities; *ríos* as rivers; *Provincia La Rioja* as La Rioja province; *República Argentina* as Argentine Republic and *Ubicación del Valle Antinaco Los Colorados* as location of Antinaco Los Colorados valley.

SOURCE: map prepared by Luna Toledo.

time of the year, growing vegetables also becomes important. In areas located close to the mountains, where the climatic conditions are suitable, cultivation of walnut trees intercropped with stone fruits from cold areas is important (De la Vega, 2016).

The districts of San Miguel, Anguinán, San Lorenzo, Los Sarmientos, Tilimuqui, Malligasta, La Puntilla, and San Nicolás are part of the first productive ring formed near the city of Chilecito. In this region, agricultural activities are small and irrigation system uses surface water. The four districts of Nonogasta, Sañogasta, Guanchín, and Vichigasta, constitute other productive areas in the south and west of the valley; in this case, to the existing smallholding agriculture, large farms with olive trees, vines, and walnut trees are included, due to the extension of the agriculture frontier and the groundwater exploitation.

As of 1970, the availability of new irrigation technologies together with policies to encourage the development of agricultural companies made it possible to extend the agricultural frontier. Through public policies of agricultural colonization (1967 Provincial Government plan called "Immediate Action Plan for La Rioja" "*Plan de Acción Inmediata para La Rioja*" and national laws of tax benefits of the 1990s), large farmers arrived in the region to appropriate the promising tax benefits and credits offered. These plans included public works of rural electrification and communications and solved the problem of land tenure and water supply through the exploitation of the existing aquifer in the subsoil of the valley. Extension took place in uncultivated land, and mainly with crops of vines, olive trees, walnut trees, and vegetables. According to some expert reports, the aquifer would allow reaching 30 thousand cultivated hectares, affirming that, since the 1970s all the growth of the agricultural frontier of the valley has been based on groundwater (Miguel & Gareis, 2017).

The average rainfall is 155 mm year^{-1} and the seasons are well defined. In the summer of the Southern Hemisphere, between December and March, the average temperature varies between 19°C and 34°C, with maximum recorded values above 40°C, also considered the season with the highest rainfall, above 40 mm per month. In winter, from June to September, temperatures range from average values of 2°C to 18°C; it is the dry season with average rainfall that does not exceed 2 mm per month (*Servicio Meterológico Nacional*, National Weather Service, 2019). In the middle and lower area of the valley, the soils are clayey and sometimes saline. Lateral to the central area of the valley, the soils are clay-sandy; in alluvial areas, soils with sedimentary, coarse to very fine sands, usually with gravel, are found. These soils are suitable for agriculture. At the foot of the mountains, permeable and highly stony soils spread (PROSAP, 2008).

3. Methodology

The research methodology is mainly qualitative, but statistical data are also considered. The inductive approach is the basis of the reasoning, both to characterize agricultural practices applied under semi-desert conditions and to propose a tariff system with general pretensions.

Based on document evaluation, statistical data, expert input, and records of visits to the farms, the main categories included are irrigation systems; distribution systems of water resources; water tariffs; irrigation frequency; socio-environmental conditions, and management of water resources.

Three groups of winegrowers are identified in the valley; depending on the size of the farm, there are small (up to 5 ha), medium (between 5 and 25 ha) and large (≥25 ha) winegrowers.

The working area was made up of the agricultural lands of the districts of San Miguel, San Lorenzo, Los Sarmientos, Tilimuqui, Malligasta, La Puntilla, San Nicolás, Anguinán, Nonogasta, Sañogasta, Guanchín, and Vichigasta, all of them are part of the Municipality of Chilecito, province of La Rioja, Argentina. The farmers located in the Municipality of Famatina were not included in this study.

The selected technical or scientific reports were mainly from governmental agencies. Thus, reports from the National Agricultural Technology Institute (*INTA*), National Universities and National or Provincial Institutes of Research and Statistics, such as the National Institute of Viticulture (*Instituto Nacional de Viticultura, INV,* according to its initials in Spanish), National Institute of Water (*Instituto Nacional del Agua, INA*, according to its initials in Spanish), Provincial Institute of Water of La Rioja (*Instituto Provincial del Agua de La Rioja, IPALaR,* according to its initials in Spanish) were considered. Regarding these reports, some of them such as Sosic (1971), Ministerio de Obras Públicas (1937) and Torres (2016) are older but include relevant updated technical information. On the other hand, other recently published official reports, such as those from the *INV*, provide several statistical data, which are very important to understand the rural dynamics in the valley.

The legal framework constitutes one of the main analysis issues since it establishes regulations regarding the ownership of water resources for the provincial government, as well as the in-force tariff systems in the province of La Rioja. The regulations of national jurisdiction do not apply to the studied region due to the country's structure. The main provincial laws analyzed were the Water Code (1983 Act N° 4,295) and the Law of Water Users Association for Irrigation (1997 Act N° 6,342).

The Rural Extension Reports were prepared by workers from the Chilecito Rural Extension Agency, which belongs to *INTA*, and are a data source about the farmers' actual situation. The reports were generated between 2012 and 2016, and included records about interviews with farmers, agronomic conditions of crops, mainly vines, as well as data on productive structures, such as vine training systems, age of crops, irrigation systems, water distribution systems, productivity, and income.

In order to add information already obtained from the Extension Reports, some visits to the farms were carried out in order to observe the structural conditions of the distribution systems (irrigation channels) and the general agronomic conditions of the cultivated lands.

Regarding water tariff, linear mathematical equations and theoretical foundations of the Polluter Pays Principle, under the concept of Environmental Economics, are applied.

4. Results and discussion

4.1. Legal aspects and environmental specifications regarding water for irrigation

Argentina is a country with 24 provinces, with a federal political structure in which each provincial government establishes its own rules regarding the issue of water. According to Scherbosky *et al*. (2013), at national level, Argentina has no legislation regarding the use of water. However, current legislation includes rules with provisions directly and indirectly related to the matter. The Federal Environmental Pact; the 2003 Act N° 25,688 on minimum budgets which regulates the Water Environmental Management Regime; the 2002 General Environmental Act N° 25,675; the 1992 Decree N° 999; the Civil and Commercial Code; the Mining Code; the Criminal Code; and the national laws covering energy, navigation, transportation and ports are included.

At national level, the Federal Water Council (*Consejo Hídrico Federal, COHIFE*, according to its initials in Spanish) also rules. Since 2003, the country has had a Federal Water Agreement, which recognizes the natural water cycle and its connection with the environment, society, administration, institutional, legal, and economic management (Moreyra, 2016).

Scherbosky *et al*. (2013) explains that in the country, the provinces usually have Water Codes, that grants the power in the regulation of use and preservation of water to the province. Water resources are considered a "public domain resource", preserving water outside the markets (Moreyra, 2016); that means that water resources are inalienable, unattainable, and imprescriptible, except in the cases expressly provided.

The new Civil and Commercial Code, with national jurisdiction, excludes the trend of public domain of all waters and maintains the mixed property system. The in-force legislation describes the public domain heritage and includes rivers, lakes, and even glaciers, periglacial environments, and estuaries. In general, water bodies located on private properties are not considered as public by the new Code (Pinedo, 2018).

In the province of La Rioja, the 1983 Act N° 4,295 approves the Water Code which establishes all regulations about conservation, use, and defense of water, alveoli, hydraulic works, and domain limitations in the interest of its use. Provincial legislation states that there is no right of private property over public waters which is an inalienable and imprescriptible part of the public provincial domain. Thus, any private use of water must be authorized by granting a right to use public water which only provides its usufruct for the purposes and conditions set forth in that law (1983 Argentina Act N° 4,295 Water Code of La Rioja). Furthermore, there is a specific legislation to regulate the consumption, use, destination, and ownership of water resources. Apart from the Water Code, the Provincial Government establishes the Water Policy Law (2011 Act N° 8,871). In Title III, this law creates the Provincial Institute of Water of La Rioja (*IPALaR*) to which the authority to enforce all provincial regulations relating to water resources is granted. There are also collegiate bodies such as the Provincial Water Council (*Consejo Provincial del Agua*) (1997 Decree-Law N° 627), the Regional Board of Water (*Junta Regional del Agua*) (1997 Decree-Law N° 796) and the Interinstitutional Council of *IPALaR* (Art. 63 of Act N° 8,871).

The water use concession can either be permanent or temporary but does not include the source of water resources and defines up to nine priority uses, putting agricultural use in the second place. Every concession must fulfill the condition of public interest and beneficial use within the limits for which it was granted. Only the executing authority has the power to conclude that concession for reasons specified in the same regulation (1983 Argentina Act N° 4,295 Water Code of La Rioja)

Additionally, the Water Code of La Rioja allows concessionaires of usufructuary rights of surface water to associate and to manage or collaborate in the administration of water, channels, lakes, and hydraulic works. These associations are called Water Users Associations (*CUA*, according to its initials in Spanish) and are currently regulated by the 1997 Act N° 6,342. On the other hand, for farmers who irrigate with groundwater in the valley, this type of collective organization does not exist, being subject to the regulations issued by *IPaLaR*.

The *CUA* is a social organization that brings together users located in a geographic area that may be served by one or more water sources. Moreover, they are authorized to provide water supply services, operational maintenance, and conservation activities of the system to which they belong. The geographic area that corresponds to each Association is defined by the regulations of its creation (1997 Argentina Act N° 6,342 Water Users Association of La Rioja). The regulation does not expressly indicate considering the existing hydrographic basins in the province as a criterion to define that area and refers to the category "Utilization System". The Water Code conceptualizes "system" as a territorial area within which the use of a given source is convenient and beneficial. By defining system boundaries, it is possible to establish concessions. These limits can be modified by the executing authority (1983 Argentina Act N° 4,295 Water Code of La Rioja).

According to Torres (2006), the valley has five Irrigation *CUAs*: Chilecito, Guanchín, Sañogasta-Miranda, Nonogasta, and Vichigasta. Table 1 shows some productive characteristics of the Associations. Although there are no updated publications of the data shown in this table, the number of associations has not changed; the *CUA*s continue with their activities. In the associations in Vichigasta and Nonogasta, it is important to point out that the springs are a surface area where groundwater exfiltration occurs (Felippe, 2009).

It is important to emphasize that not all water users associated with a *CUA* are agricultural farmers. From the 1990s onwards, a great number of small lands (<5 ha) was transformed into dwelling places, which results in the expansion of the city over rural areas. The change in the destination of the agricultural lands did not extinguish the concession rights. At present, these new owners use water to irrigate leisure areas, backyards, and gardens. The main factor favoring this urban expansion is the location of small farmers surrounding the city of Chilecito, together with good environmental conditions.

The main crop is the vine and the statistics on winegrowers provide a good estimate about how this sector is developing in the valley. According to a survey carried out by *INV* on the valley cultivated area, it is observed that, between 1995 and 2018, there was a 50% drop in the number of vineyards and, at the same time, an increase in the total cultivated area of 13% (*INV*, 2019). The reduced number of vineyards is due to that half of the small farmers gave up agricultural activities.

TABLE 1–Water User Associations of Antinaco - Los Colorados (Argentina) valley, water withdrawal expressed in liters per second (ls-1), cultivated surface in hectares (ha), number of users and land use (main), 2006.

Association	**Surface Water**		**Underground Water**	**Cultivated Surface (ha)**	**Number of Users**	**Main crop**
	River	ls^{-1}	**ls^{-1}**			
Chilecito	Amarillo**	550	85	1,000	800	Vine
Guanchin	Pismanta **	60	0	380	18	Walnut
Sanogasta-Miranda	Miranda**	120	45	600	426	Walnut
Vichigasta	Plaza/Chima*	55	15	80	130	Fruit Trees
Nonogasta	Bosquecillo*	450	0	930	47	Vegetables
Total		1,235	145	2,990	1,721	

NOTE: (*) it identifies springs of watercourses. (**) it identifies rivers that come from Sierra del Famatina (meltwater).

SOURCE: Table adapted from Torres (2006).

4.2. Water distribution in Antinaco - Los Colorados valley

Firstly, it is necessary to differentiate between "water distribution systems" and "irrigation systems", to analyze water tariffs in the valley agricultural lands. The distribution systems refer to the way in which water resources are directed from surface water collection in rivers or springs to the agricultural land.

In this paper, when the farmer uses water from the aquifer or groundwater to irrigate, it is considered that he does not have a distribution system; he only has an irrigation system since the exploration wells are located in his land. As for the irrigation systems located within the farm or plantation, it refers to the way in which farmers supply water to the crops.

The water distribution systems for irrigation were managed by the national government until 1992. In those years, the management was in charge of the state company "*Agua y Energía Eléctrica*" of the *Ministerio de Obras Públicas de la Nación* (National Ministry of Public Works). After the political changes in the 1990s, these services were transferred to the provinces and managed by the aforementioned provincial agencies (Torres, 2006).

To irrigate the farms surrounding the city of Chilecito, as well as the towns Nonogasta, Vichigasta, and Sañogasta, an open-channel system is used: the water is directed to the land, taking advantage of the natural slope of the valley.

Figure 2 shows the water collection network from Los Sarmientos river, formed by Amarillo and Agua Negra rivers, to the west of the valley. The river water intake is 12 km from Chilecito, in the town Santa Florentina. According to a report from the National Institute of Water (1979), this river has a dam to collect the water and direct it to a main channel, subdivided into two secondary channels, which are later subdivided into tertiary channels (*INA CRAS*, 1979).

The channel system has existed and has not changed since the 1930s. According to a report dated 1936, by the *Ministerio de Obras Públicas* (*MOP*, according to its initials in Spanish), it shows that the irrigation infrastructure of Chilecito has a matrix or primary channel with 1,220 ls^{-1} flow, two secondary channels, one left-bank oriented and the other, right-bank oriented, each with 610 ls^{-1} (Figure 2). Therefore, these channels are divided on the left bank into four tertiary channels and on the right bank, into three tertiary channels with a capacity of 150 ls^{-1} each, all they completely covered with stones. The river flow is distributed in equal parts between the sections, in which the water is supplied to the farmers in shifts, at a rate of two hours and forty minutes per hectare, every 20 days (*MOP*, 1937). In 2020, Jaular (2021) estimated that the tertiary channels have a length of 39 km and irrigate a surface of 1,300 hectares approximately.

In Figure 3, the channels forming the Left Bank network (referenced in the *MOP* report) are observed. These channels irrigate the districts San Lorenzo, Los Sarmientos, La Puntilla, San Nicolás, Tilimuqui, and Malligasta (*INA CRAS*, 1979).

It is pointed out that the water distribution depends on the environmental conditions, because, both in spring and in summer, river flows decrease. Besides that, the irrigation shifts are spaced out, the scarcity of water is intensified by interruptions in irrigation due to the frequent flow of sediments brought by the river, with a lot of sand and fine gravel.

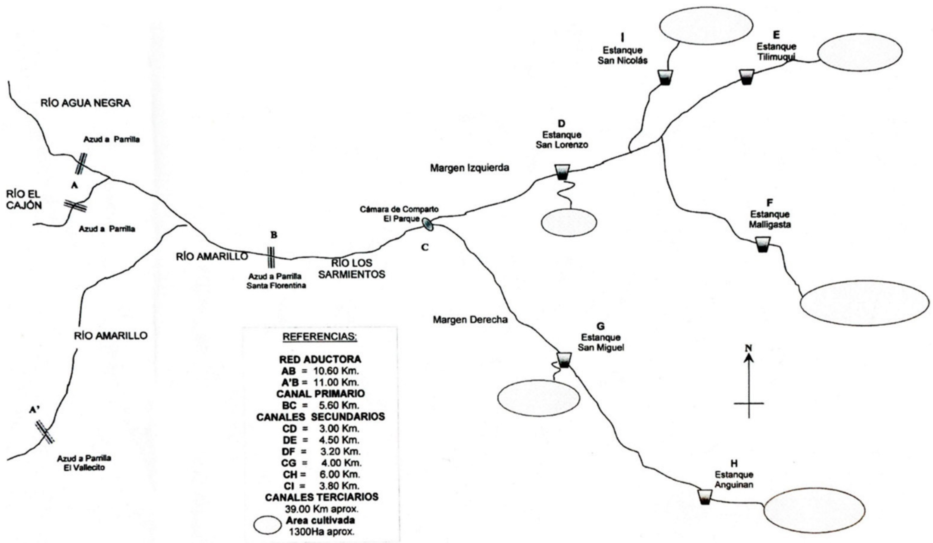

FIGURE 2– Water collection network on Los Sarmientos river, showing the main and secondary channels, in the region of Chilecito, province of La Rioja, Argentina.

NOTE: In figure 2, the words in Spanish are translated as follows: *Río Agua Negra* as Agua Negra river; *Rio El Cajón* as El Cajón river; *Río Amarillo* as Amarillo river; *azud a parrilla* as grated weir; Rio Los Sarmientos as Los Sarmientos river; *cámara de comparto El Parque* as El Parque water distribution chamber; *margen izquierdo* as left bank; *margen derecho* as right bank; *Estanque San Miguel* as San Miguel irrigation water reservoir; *Estanque Anguinán* as Anguinán irrigation water reservoir; *Estanque San Lorenzo* as San Lorenzo irrigation water reservoir; *Estanque San Nicolás* as San Nicolás irrigation water reservoir; *Estanque Tilimuqui* as Tilimuqui irrigation water reservoir; *Estanque Malligasta* as Malligasta irrigation water reservoir; *Referencias* as References; *red aductora* as water conveyance network; *Canales Primario* as Main irrigations channel; *Canales Secundarios* as Secondary irrigations canals and *Canales Terciarios* as Tertiary irrigations canals; Km aprox. as Km approx.; Área cultivada as cultivated/irrigated area and Ha aprox. as Ha approx.

SOURCE: Jaular (2021).

Floods spread water through the sandy riverbed, where infiltrate to the water table, which means that cannot be used for irrigation (*MOP*, 1937). Based on the records, the situation that was described almost a century ago accurately shows the current problems of the *CUAs* in the rainy season. Briefly, this means that the irrigation interval may extend for up to 40 days from late spring to late summer. It is also important to point out that, based on the records of extension activities by *INTA* Rural Extension Agency, farmers complain about the decreased flows between the collection stretches in the rivers and the agricultural lands. Very old channel networks, lack of permanent maintenance, equipment breakdowns, and high evaporation rates are the reasons of this phenomenon. Jaular (2021), comparing the flows of the main rivers in the valley between the 1940s and 1970s, proved flow increases; however, in the last decades of the 20th century, the volumes of water were again similar to those of the 1940s. It is explained that when there was an increase in the river flow, the expansion of agriculture in the valley using surface water was noticed.

FIGURE 3– Channel matrix in Santa Florentina and network of small channels that irrigate agricultural lands in the District of Malligasta, Antinaco - Los Colorados valley, Argentina.

NOTE: Figure 3A shows the main channel; Figure 3B, a secondary channel in the Santa Florentina district; and Figures 3C, 3D and 3E, the tertiary channels passing through the agricultural lands of the Malligasta district.

SOURCE: Photos taken by the research team, November 2019.

Besides the distribution problems, the use of irrigation methods without considering the water balance for crops occurs. In the case of vines and fruit trees which lose their leaves in winter, the water demand is minimal; on the contrary, high temperatures and evapotranspiration explain the greater demand for water in summer. However, small farmers usually irrigate their land all year round; even though water flows are higher in winter than in summer, farmers do not have reservoirs to store water for low flow periods.

The channel system has several water reservoirs as shown in Figure 1. In Figure 4, two of them, located in the districts of Malligasta and San Miguel can be found. The Reservoir of Malligasta is supplied with underground water through channels; it is a practice often applied in hot months. The Reservoir of San Miguel presents little maintenance; the abundant mud deposited by the surface waters that comes from the mountains of the Famatina System can be noticed.

Water scarcity produces two types of effects to small farmers. It both prevents the replacement of aged plants with a negative impact on productivity levels and on the sector's productive growth, and maintains healthy vines since the lack of water does not promote diseases in crops. In the valley, the vines do not show fungi or weed infestation, and the application of fungicides and herbicides is not needed. However, these good environmental conditions favor the urban expansion over rural areas. Urban families may live next to farmers without environmental conflicts in these agrochemical-free environments (De la Vega, 2016).

The dynamics of the distribution and irrigation systems demand improved management of water resources. Thus, systematized statistical and technical data from the various public agencies related to water management are needed for assertive decision-making. A redefinition of the *CUA* management models, as well as the services offered to the community, is required. Existing collegiate bodies (*e.g.*, Provincial Water Council and Regional Water Board) should participate as main actors in the sector and incorporate processes for evaluating the efficiency and water resources destination. Changes in water management should set clear objectives in this regard to propose production plans based on the

FIGURE 4– Water reservoirs of the Surface Irrigation of the Water Association in San Miguel and Malligasta, Antinaco - Los Colorados valley, Argentina.
Figure 4A shows the Reservoir of Malligasta and Figure 4B, the Reservoir of San Miguel.
SOURCE: Photos taken by the research team, November 2019.

interrelationship of technical, social, environmental, management, and political issues.

4.3. Irrigation methods and strategies in the Antinaco - Los Colorados valley

Water scarcity and water resources pollution are the major problems in the valley. The two main causes of water pollution in the valley are water and soil salinization due to poor irrigation practices. There are many studies related to the causes of water and soil salinization; most of them agree that the problem derives from excessive irrigation affecting soils and groundwater (Lavado, 2007).

Irrigation should be carried out owing to the scarce level of rainfall in the valley. Thus, any irrigation system may be planned to control its efficient use and pollution levels. The negative impacts on the environment may be reduced by improving irrigation strategies.

The classification of irrigation systems into superficial and pressurized is well known, *i.e.*, using water from rivers or aquifers. The small farmers use the surface irrigation system with water provided by the *CUAs*. The large-scale agricultural farmers may use water from aquifers located on their lands and apply any irrigation system, depending on their economic level.

Water in the valley does not contain excessive salts but it may be a negative factor in the polluted ecosystem. If the soil salt is increased due to excessive gravitational irrigation, leaching will pollute the aquifer. If the system is pressurized, salinization occurs around the humid area, *i.e.,* the form of a bulb in the roots of the plants, generating redistribution of salts around this bulb. On decreasing irrigation levels, salts are concentrated in the roots, causing toxic effects. For small farmers, the problem does not derive from excessive irrigation but from long interval irrigation, causing the emergence of salts on the surface (De la Vega, 2016).

Another source of soil salinization is fertilization. In some cases, large-scale farmers with pressurized systems combine fertilizers and irrigation. The addition of chlorinated compounds causes this negative effect on the soil. In pressurized systems, salinization may cause another problem: irrigation nozzles salt clogging. Chlorinated acids are used to clean them, but this activity changes the chemical composition of the soil. In an *INTA* survey, it was demonstrated that medium and large-scale farmers employ cultural cropping practices to minimize soil salinization due to economic reasons, thus avoiding the use of chlorinated chemical products. However, there is no local legislation that regulates these agricultural practices (De la Vega, 2016).

In a macro analysis of the excessive water consumption in the valley, a demand higher than the aquifer recharge capacity occurs. Reduced groundwater table levels show an over-exploitation of water resources due to the lack of control of water flows extracted from the wells, and the low capacity of natural recovery of the aquifer. It also refers to the number of existing water extraction wells and cultural practices with excessive irrigation. These situations are mainly observed in large-scale farmers that have underground water wells.

Monitoring carried out by *INTA* at its Experimental Station in Chilecito, in three agricultural colonies (Tilimuqui, Malligasta, and Anguinán), showed changes in the regional directions of groundwater flow from Northwest-Southeast in 2005 to North-South in 2015, together with the deepening of groundwater levels of -25 m. Also, an increased concentration of nitrate in several perforations was demonstrated. It is assumed that the irrigation returns or the agrobusiness residues are affecting the quality of the groundwater table. This situation may be deteriorated even more in the short and medium term (Gonzalez Ribot & Miguel, 2018).

4.4. Current water tariffs in the Antinaco – Los Colorados valley

The Water Code specifies a "Financial Regime" to regulate water rights charges. These payments include paying off rates, taxes, and contributions for service improvements and are calculated based on the concession granted. This Code also provides fees, reimbursement of works, fines, and other penalties. Payments may be done cash, in goods or handcraft, based on several variables in a given situation. It is interesting to point out that the Code establishes a parameter to determine the charges for water rights, differentiation of locations and regions grouped according to the socioeconomic characteristics of the exploitation areas. Furthermore, the Code states the application of interest and monetary adjustment in inflationary contexts (1983 Argentina Act N° 4,295 Water Code of La Rioja). Currently, the amount of rates paid by users of water services for irrigation is defined per year by the *IPALaR* through laws and regulations about public finances.

The tariffs charged on agricultural farmers for irrigation services are the same for any user and are established by *IPALaR*. The legislation only states general water management criteria, such as comprehensive management of water resources, permanent hydrological cycle, water interconnection, etc. In particular, the Section 8° of the Water Code provides that the cost of water will be defined per year by the application authority, for each of the irrigation areas, based on the costs of construction, administration, conservation, and maintenance of works and distribution (sic). Likewise, the Section 81° states that, in concessions for the consumptive use of water (which uses the resource and does not return it to its source), the allocation will be delivered for a certain volume, time, or area (FAO, 2015).

The tariff for irrigation rate, which is per year per hectare, is published by the *DGIPLR* (according to its initials in Spanish: La Rioja States Revenue Department) based on the Annual Provincial Fiscal Law. This law only provides the value of irrigation rates for agricultural activities throughout the province and varies according to the operation status of the existing water infrastructure works. Thus, for the *CUAs* of the valley, in 2022, the rate was ARS 22.00 per hectare per year (Approximately USD 0.15, according to the exchange rate of USD 1 = ARS142). For Vichigasta district, the price was lower: ARS 11.00 per hectare per year (approximately USD 0.08, determined by the same ARS per USD exchange rate). Regarding groundwater, the rate is ARS 80.00 per hectare per year throughout the province (USD 0.56) (Argentina Act N° 10,469 Tax Law of La Rioja 2022, 2021). Unfortunately, the *CUA* accounting statements of the valley have not been published; so, it is not possible to know their revenues, costs, expenses, and expenditures and the financing sources. Moreover, the hectares under irrigation of each association and the mentioned annual rate allow the calculation of the resulting revenue which is less than the value of an annual minimum wage. Certainly, water tariffs are not designed to cover costs and generate profits for the *CUA* and consequently, the government pays the expenses of the water distribution system. This has been a long-standing government policy in the valley.

Besides, it could be interesting to analyze the impact of water tariffs on the price formation for agricultural products. It is possible to deduce that the water price is lower than the costs of other productive factors without carrying out an exhaustive cost study. However, it should be noted that failure to pay the water tariff implies the service cutting-off. Similarly, in this very arid region, the lack of irrigation water means the loss of harvests or even worst, damage to the crops, for the farmers. It is relevant to consider how sensitive the water demand is facing farmers' reaction with respect to tariff variations. The price elasticity of demand for water in agriculture shows little or no sensitivity, depending on whether crops are permanent or perennial, respectively. Jiménez (2013) confirmed the inelasticity of water demand in a survey conducted in the province of San Juan (Argentina) with production conditions similar to those of the Antinaco – Los Colorados valley. The author explains that the inelasticity of the demand is due to cultural issues about the rational use of water, the impossibility of consumption changes due to the rigid agricultural conditions of the crops, and restrictions imposed by the desert region. This author concludes that, in order to encourage the water rational use, its demand should be associated with the requirements of crops. This is possible due to an efficient irrigation plan and a positive impact on the soil and environment. Another survey carried out by Torres-Sombra *et al*. (2013) points out that the inelasticity of the water demand price increases due to government subsidies granted to the agricultural sector. These authors emphasize that, in order to achieve a small reduction in water consumption, tariffs should be increased between 40% and 80%, which would affect farmers´ profitability.

Briefly, the equations of current tariffs for irrigation water are shown below. They should be established based on the operability of the irrigation water harvesting system, the channel network, and the operating service costs. These operating costs are fully subsidized by the provincial government. The equation 1 shows the surface water tariff charged to irrigation water users per year per hectare.

Equation N° 1:

$$Ti=VOId*Qh$$

WHERE: Ti = irrigation rate; and VOId = operational value of facilities for collecting and distributing surface water; and Qh = number of hectares of irrigated rural land.

NOTE: the initials are in Spanish followed by the explanations in English.

The groundwater rate which is fixed per year per hectare is shown in the equation 2.

Equation N° 2:

$$Ti=TF*Qh$$

WHERE: Ti = irrigation rate; TF = Fixed Rate; and Qh = number of hectares of irrigated rural land.

NOTE: the initials are in Spanish followed by the explanations in English.

4.5. A proposed irrigation rate for the Antinaco – Los Colorados valley

Irrigation is a production means and, therefore, the cost of water as an input, is essential to define whether the production is profitable or not. Thus, projects should keep the cost of water within certain limits, related to the expected value or profitability (Zappi, 2014). Based on this concept, the tariff modification proposals do not change the current values; they only consider incorporating components that will be used in case of inappropriate irrigation practices.

Irrigation rates should be built from a dynamic structure and be based on the three main components of the water use for agricultural purposes, as follows:

a) Distribution
b) Irrigation
c) Water source

Medium-scale and large-scale agricultural farmers use pressurized irrigation systems which obliges them to calculate a water lamina according to a maximum evapotranspiration. This water lamina is expressed in m^3ha^{-1} (cubic meters per hectare) and defines the technical specifications and costs of irrigation equipment. So, the water balance for irrigation control should be assessed. It is an adaptation of the sequential climatological water balance. Water balances do not need state-of-the-art computing resources. It is only necessary to measure rainfall and the meteorological elements required by the method for estimating the reference evapotranspiration. In general, it is essential to know the phenology of the crop and its water demand which varies according to meteorological conditions in an irrigation project (Pereira, Angelocci & Sentelhas, 2007). The data for calculating the water balance may be obtained from the National Weather Service, *INTA* and FAO, etc.

The equation 3 shows proposed irrigation rates for groundwater users.

Equation N° 3:

$$Ti = TF*Qh + TsE + TP$$

WHERE: Ti = irrigation rate; TF*Qh = fixed control tariff; TsE = exploitation tariff, and TP = pollution tariff.

NOTE: the initials are in Spanish, followed by the explanations in English.

The equation is composed of three elements. The Fixed Tariff for Control (TF*Qh) includes the distribution and maintenance costs of the execution or management body, as well as the expenses to control the water flows exploited from the aquifer per hectare. The Exploitation Rate “TsE” will be charged if the farmers use excessive water, based on the water balance and records of the irrigation equipment. Finally, the Pollution Tariff “TP” will be charged if salinization is observed on the surface of agricultural plots or plant death due to saline toxicity. Thus, the tariff includes a fixed and a variable part in accordance with the Polluter Pays Principle.

The implementation of a new tariff structure that encourages the rational water use is needed for small farmers. The *CUAs* have to work together with research institutions in rural extension services because the scarcity of surface water requires the implementation of more efficient irrigation practices and strategies, technical data on crop water demand, soil conditions, crop phenology, and climate. Nevertheless, the major problem with irrigation tariffs for small farmers is related to the surface area of agricultural lands. The surface limits the production levels that are sufficient for family living, rather than for productivity purposes. Small farmers apply non-profitable working practices; quite the contrary, they follow family and social traditions that have been kept since the colonization of Antinaco – Los Colorados valley, in the first decades of the last century (Carrizo & Manzo, 2014). Thus, when proposing changes in irrigation tariffs, these sociocultural considerations should be strongly valued. The new tariffs do not include additional payments by irrigation water users, except when their practices are harmful to the environment. A social approach prevails in the tariff design that seeks to maintain a productive unit in small-scale agriculture, based on the values of cooperation, equity, and solidarity.

The proposed tariff is made up of two parts: the first includes the distribution cost "CD" and the second, the tariff for the use of water inside the agricultural land "TU". The tariff is shown in the equation 4 and the two mentioned components are integrated by other smaller concepts, explained by the equations Nº 5 and Nº 6.

Equation No. 4:

$$Ti=[CD*Qh-VS]+TU$$

WHERE: Ti = irrigation tariff; CD = distribution cost per hectare; Qh = number of irrigated hectares; TU = use rate; and VS = value subsidized by the provincial government.

NOTE: the initials are in Spanish followed by the explanations in English.

4.5.1. Distribution cost component (CD) and the value component subsidized by the provincial government (VS)

Water Resource Distribution Costs (CD*Qh) include expenses for the channel system maintenance, administrative expenses, salaries, and minor tools. These expenses are subsidized by the provincial government and should be included in the collection invoices so that the population knows the value of the subsidy received. Thus, the VS component with a negative sign, serves to offset distribution costs and avoids charging them. The CD*Qh component is determined including the operating costs of distribution and improvements, calculated per hectare, as shown in the equation 5.

Equation No. 5:

$$CD*Qh=CO+TO*I+DI$$

WHERE: CD*Qh = distribution cost; CO = operating costs; TO = Facility operating rate; I = Value of Investment in the water distribution system; and DI = Investment Depreciation.

NOTE: the initials are in Spanish followed by the explanations in English.

Operating costs refer to the expenses and tasks to keep the distribution channels available. The TO component is estimated by the value of investment in surface irrigation infrastructure. Depreciation may be determined by straight-line. The investment values refer to machines and tools, improvement of installations and in the channel network, dam, water intakes, and headquarters. These investment goods can be given a value according to the acquisition cost or the production cost.

4.5.2. Use Rate component (TU) of equation No. 4

This use rate component about the use of water inside the farm, whose elements are detailed in the equation 6, has variable collection behavior, according to the irrigation way. It is composed of a positive value, the General Use (UG) and three others: Productive Use (UP); Organic Use (UO) and Increased Productive Use (UPro), which will compensate whenever the water rights are productively used and without harming the environment.

The first component of the tariff, the general use of water (UG), in the valley, introduces three situations to be considered:

a) Used on dwelling places to irrigate backyards or gardens for non-productive purposes;

b) Waste on farms without crops or agricultural activities; and

c) Used in smallholding agricultural production.

The main cause of the first two mentioned situations is the connection between water rights and land ownership. After a farm is sold, water rights are included in the sale to the new owners, regardless of the land use purpose. This process has been intensified since the economic crises of the 1980s onwards. There is a constant transformation of agricultural lands into dwelling places, in districts where vines and vegetables do not longer exist. Consequently, the UG component will have a value based on the assumption that all users of irrigation water use it to irrigate backyards and gardens. However, users with productive purposes will benefit from the discounts given by the UP, UO, and UPro components. The farm surface, the irrigation time, and the number of times they irrigate per year should be considered to determine the annual water consumption for measuring UG component. Therefore, this annual consumption is quantified according to the average theoretical flow supplied by tertiary irrigation channels. These data are known by *CUA* and *IPALaR*. As these flows are expressed in m^3year^{-1}, their price may be estimated by the price of m^3 of tap water, being the substitute good in urban irrigation. Families would pay the price per m^3 of tap water to irrigate their gardens if they did not have irrigation water rights.

Equation No. 6:

$$TU = UG - UP - UO - UPro$$

WHERE: TU = use rate; UG = general purpose; UP = productive use; OU = organic/agroforestry use; and UPro = increased productive use.

NOTE: the initials are in Spanish followed by the explanations in English.

Considering that the UG value represents the total tariff value (UG = 100%), 30% will be discounted for each time of the UP and UO components, and 40% for the UPro element. Those who irrigate the land without productive purposes will pay a higher tariff. Each water user should obtain a certificate of use by the *CUAs* to carry out this discount, following these specifications:

Productive Use of Water (UP): it considers the use of water to irrigate areas intended for vegetables or orchards in order to generate family income.

Organic or Agroforestry Use of Water (UO): it considers the use of water for productive purposes, with the condition of not using polluting substances.

Increased Productive Use (UPro): it considers the use of water for productive purposes and employing organic practices; it also increases the production to generate extra income through the sale in agricultural markets or for agro-industrialization. This means an increased productive levels of the land as a consequence of using improved agricultural practices within a sustainable system.

It should be noted that the three components "UP", "UO" and "UPro" are presented as subsidies to small farmers for improving their production systems. In addition, each component of the price of water seeks to encourage the use of irrigation water for productive purposes.

For the implementation of this tariff proposal, four main criteria were considered:

a) Specific information availability,

b) Technical (physical and human) resources availability,

c) In-force regulations,

d) Investment programs.

The availability of information for water users is limited; however, the CUAs may initiate systematization and recording processes of water use, irrigation strategies employed by users, current channel network status, irrigation water intake, dams, and channel flows. The *CUA*s have employees who control the channel network and are in permanent contact with users, that is why most of the above-described information could be recorded. In water balances, statistical data, efficient irrigation methodologies, non-contaminant adequate crop management may be obtained through rural extension services, in partnerships with technical institutions such as *INTA*, *IPALaR*, *COHIFE*, local organizations of agricultural farmers and universities in the province. In item b) technical resources availability, it is understood that they should concentrate their efforts on the preparation of specific reports for the local agricultural area, the institutional administration, and the participation in the definitions of water policies in the province. It is understood that *IPALaR* has these technical resources, but the *CUAs* should create technical-professional teams through the incorporation of qualified employees or through partnerships with technical institutions. In the case of current regulations, the 2011 Water Policy Act 8,871 states several tools, *i.e.*, Provincial Water Plan and Annual Water Report; System of Control, Prevention and Mitigation of Water Pollution; Environmental Impact Assessment of Water Works; Water Resources Information System; Promotion for Voluntary Systems to Protect Quality and Efficiency in Water Use; Promotion of Investment in Efficient Technology; Strengthening of Research about water and the Education and Training in the Culture of Water; and Water Quality and Efficiency Use Certificate. Regarding item d) , at national level, there are two plans: the National Irrigation Plan and the National Program of Provincial Agricultural Services, which finance, advise, and assist in the sustainability of irrigated lands in the country; in strengthening water management; education and training in irrigation; hydrogeological and economic research about the irrigation impact on agricultural production; as well as investment and credit plans for infrastructure and irrigation projects, etc. Briefly, the implementing costs of a new tariff structure mainly require a management strategy focused on changing some agricultural practices, raising awareness of water scarcity, efficient use of subsidies and government programs, meeting in-force regulations and water policies. It is possible to conclude that the costs of a tariff change may imply efficient use of physical, financial, and human resources rather than incorporate new budget items.

5. Conclusion

The main contributions of this study are the modelling of irrigation rates by mathematical equations and the proposal to modify the tariffs charged to water users in the Antinaco – Los Colorados valley, based on a legal, technical, and cultural framework.

The new tariff structure includes irrigation systems, distribution, and use of water as main parameters, as well as productivity and environmental pollution. It is also an attempt to bring to light the relationships of these irrigation systems with some conditions of sustainability in the use of soil and water. The tariff structure by components aims at encouraging improved irrigation strategies regarding the monitoring of harmful practices for the ecosystem.

A change in the tariff system for water resources implies recognizing that most agricultural farmers need to incorporate new irrigations strategies, be adequately and technically informed, prioritize the use of water in rural farms, and modify the management systems by the collegiate bodies. For agricultural farmers with smaller lands and limited technology, irrigation systems can be improved in relation to the types of crops and the production purposes. Based on the high scarcity of water resources in the valley, preservation and sustainability strategies are needed. Efficient criteria adapted to the socio-productive conditions of farmers should be assessed.

The tariff change implies the incorporation of new working dynamics for farmers that makes them adopt adequate scientific techniques and strategies to improve irrigation practices. It is necessary to connect institutions and organizations with the agricultural sector, so that their services and knowledge become available through rural extension service. These extension activities should be planned based on the farming sectors according to production parameters, size of the agricultural farm, income, and environmental impacts, etc.

In order to carry out this proposal, the collegiate bodies, among which the *CUA*s stand out, should have a leading role. It is necessary to take into account the serious scarcity of water resources and its implications for the expansion of the agricultural sector. The implications of the water uses and its effects on social, economic, political, and cultural dynamics should be considered.

This new tariff system for the use of water should be framed within the new concepts of anthropic activities; hence, the environmental sustainability parameters and information systematization should be seriously considered. It is important to take into account the relevant relationship between science and culture to introduce better models in the water resources management. The agricultural activity which is highly dependent on the ecosystem should be systematized since it should offer an adequate level of quality and safety to consumers, industry, and families. Agriculture which represents the production of food, inputs, and income should be supported because it leads to the economic and social advance of the valley.

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