Science helps to solve international water conflicts
Case: The Mauri River

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Abstract

The sustainable management of water resources is essential for achieving development goals, poverty alleviation, protection of ecosystems and social and political stability in the region. Water management in transboundary basins is a potential source of conflict increasing in the last decades. In the past 50 years, in the world, there have been 37 serious disputes involving violence in relation to water in transboundary basins (United Nations, 2004).

International agreements on water courses need to be more specific, an agreement for better cooperation involves identifying clear allocations, but flexible and water-quality standards, taking into account both hydrological events, changes in watershed dynamics, social participation and international law as the political agenda in the region and the countries involved.

In South America more than 60% of the territory belongs to transboundary basins where unresolved international conflicts related to water are installed in part of the southern cone region of the Americas (Argentina, Bolivia, Chile, Paraguay and Peru) some dating back several decades and others are emerging in this century. These conflicts coupled with the strong increase in demand on limited freshwater resources and the increase in the variability of supply due to climate change scenario projected a potential international crisis and insecurity in our region.

In water management on transboundary basins, interests come to play sensitive issues and there must be found equitable solutions in both political and social development approaches and practices and encourage closer cooperation for mutual benefit of the peoples on both sides of the border.

Under the situation that Perú and Chili are already transferring water from the upper basin of the Mauri river to the Pacific coast and there are proposals and pressures to extract and transfer more water to Peru, the watershed of the Mauri River has been chosen for the discussion of this paper. The case is a matter of three countries: Bolivia, Peru and Chile, where the situation is even more complicated because of the natural contamination with boron and arsenic that suffer the river. Under the present extraction it is added that there are points of contamination that affects also the wetlands. Moreover, this water is used in many traditional irrigation systems through the Desaguadero river from which the Mauri river is the most important effluent.

The present paper describes the problem of the Mauri river and the approach that is taken to arrive into a solution that can be reasonable for all the parts in the dispute.

Keywords

- Transboundary
- Treaties
- River

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1. Introduction

The Mauri river is the main effluent of the Desaguadero river and it is part of the TDPS system (Titicaca, Desaguadero, Poopó, Salares) that drains the water of the Central Altiplano region of Southamerica.

The trinational basin of Mauri rises in the foothills of Mount Llallagua in Peru, it is fed by the tributaries of Chiliculco, Kallapuma, mammoth, Chilu, Cano, and Uchusuma Pucarani in the Peruvian territory and rivers Putani and Caquena in Chile, before arriving to Bolivia.

The Mauri River enters Bolivia by José Manuel Pando Province, Department of La Paz. (17 ° 23 '30 "S, 69 ° 28' 30" W), and runs 124 kilometers from the Bolivian central plateau before flowing into the river Desaguadero (17°17'S, 68°37'W) near Calacoto. The population of the watershed is on its majority Aymara. Mauri river and its tributaries, the rivers Caquena, Villca Palca, Putiri, Sopocachi, Achuta Chico, Cusi cusini, Berengaria and Challu-maintain aquatic habitats, aquifers and about 2.372 acres of wetlands that generate 2.48 m^3/s of water. In addition, the Desaguadero River recharges the lake Poopó, the most important water body of Central Altiplano, declared as RAMSAR site.

Since the last century, the Peruvian government plans to build waterworks and infrastructure to transfer water resources in the upper basin of the Mauri river to supply the city of Tacna, without preventing direct and indirect impacts to stocks and aquatic ecosystems in the short term.

It is estimated that the transfer of shared rivers in Peru reduces between 26% and 77% of the rate in the Mauri river, an international river of successive course and not "lost in the salt flats of Bolivia", as the PET in Peru affirms. In the contrary, this river is of vital importance to thousands of farmers, herders and fishermen living in the lower watershed.

2. Methods

a. Background analysis and description

In 1867, the Peruvian government authorized Fernando Hugues to begin the construction of a canal to carry 3000 cubic feet of water per minute from a tributary of the Mauri, the river Uchusuma, Guanacague to the stream.

In 1876, Kruger proposed to divert 5,000 liters per second from a point distant 15 kilometers from Peru and 40 from Bolivia to irrigate over 3,000 hectares of sugar cane, cotton and vegetables in the valley of Tacna.

In 1913, Chilean Foreign Minister Agustin Edwards commissioned a group of engineers to analyze the draft Kruger, adopted by the Sugar Industry Company in Tacna, in 1914 the Chilean government requested legislative authority to issue three million dollars in bonus to finance works, and in 1919 authorized the Industrial and Sugar Company Tacna divert water from the Mauri river.

Between 1920 and 1921, Chile sought to justify the unilateral diversion of the flows of Mauri under the so-called "Plan Tacna", to the detriment of a population of (312 inhabitants) in five communities and 24 farms in Charaña, Avaroa, General Perez Camacho and Calacoto, but the Bolivian government objected that the use of a river course should not prejudice future owners in the downstream. However, in 1950 Peru diverted the entire flow of the river sub Uchusuma (to a maximum of 1.00m3/s in the dry season) and in 1960 began to build (channels, wells ...) in the basin of the river Kallapuma without the consent of Bolivia.

On December 29, 1961, the Embassy of Peru informed that the Foreign Ministries of the Peruvian Parliament and Bolivia were analyzing a draft law which empowered the executive to recruit Japanese companies to plan the "hydroelectric and irrigation works in the department of Tacna using water of the Mauri.

On February 9, 1962, Bolivia's Foreign Ministry reiterated its reservation in 1921: The "Bolivian Government is expected to express the enlightened government of Peru, which invariably has argued, first that the use of the waters of a river must not harm the interests of the owners of the lower and second part in the watershed, second, that the international flow of a river should not be altered by moving waters from a basin that is geographically the natural creditor to a different geographical basin".

In the late 1961, the Peruvian government undertook to report to Bolivia before starting to work, in compliance with the Declaration of Montevideo of 1933. Nevertheless, they continued to build almost in secret, transfer infrastructure to divert 20m^3/s of water from the basin of the river Kallapuma Uchusuma canal, which amounted to an average flow of 0.70m^3/s, with variations from 0.50m3/s and 1.00m3/s.

Between 1970 and 1995, 13 boreholes were drilled of about 40 and 70 feet deep to extract groundwater aquifer of El Ayro, located in the basin of the river Uchusuma.
Since 1993 the project Vilavilani is implemented to increase the supply of water to Tacna. The most important work of the project is the channel Calachaca - Chuapalca - Patapujo that divert waters to the stream Mauri Vilavilani, receiving its flows from dams and Ancomarca Chuapalca (11.98 Hm3),wells of The pampas of Ayro, and Casiri. The channel Calachaca - South Huaylillas has a length of 143 km.

In 1994, the Peruvian government ended the Kovire tunnel at the headwaters of the main channel of the Mauri. The tunnel decanted an annual average flow of 1 to 5 m^3/s in the rainy season, and less than 0.10 m3/s in the dry season. The aim was to increase resources of the lagoon Aricota, located in the basin of the department of Tacna Locumba.

For both of the governments and the stakeholders, it is evident that any future extraction in the Mauri basin must be analysed and defined taking into account the environmental impacts, the rights of the downstream users and the international law.

b. Description of the study area (Mauri river basin)

The study area includes the river basins and the lower part of the Desaguadero river basin. The Mauri river is the main tributary of the Desaguadero river and is part of the TDPS (Titicaca, Desaguadero, Poopó and Salar), which drains its water from the central plateau region of South America. The study area occupies part of the departments of Puno and Tacna in Peru, part of the department of La Paz and north east of Oruro in Bolivia and the First Region of Chile.

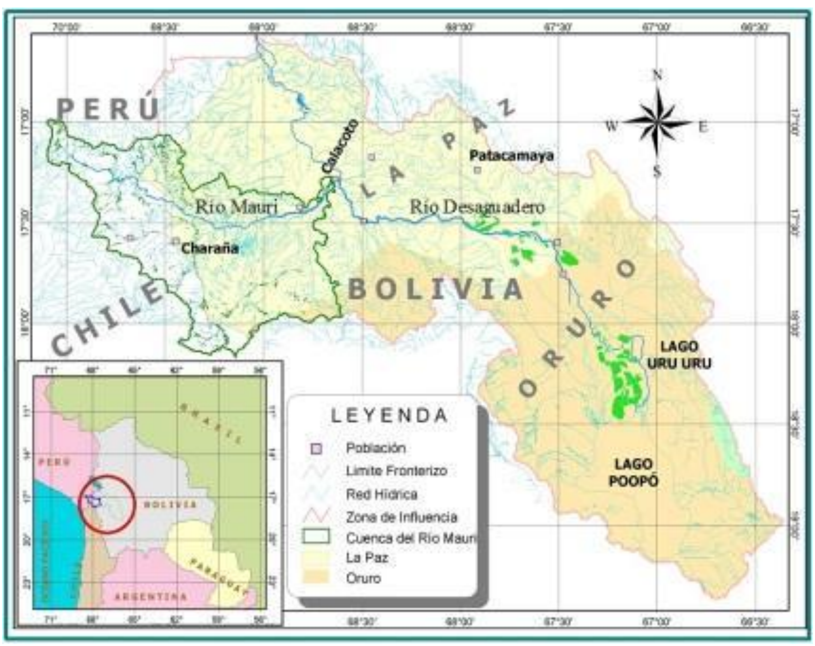


Fig. 1 Map of the Desaguadero river basin and the Mauri river basin within the three countries, Bolivia, Perú and Chile (Molina Carpio & Cruz, 2008)

The Mauri River begins in the western mountains of Peru, and then enters Bolivia. It follows a course from west to east (Figure 1), and in the vicinity of the Abaroa town receives the river Caquena, born in Chile. This course joins the Desaguadero near the town of Calacoto after draining a sub-basin of 9802 km2. The population in the region is Mostly of Aymara origin. (Molina Carpio & Cruz, 2008) The population density is low, approximately 3 hab/km2. In the Bolivian sector (province Pacajes) of the basin, the population was 8892 inhabitants in 1992, estimated to be reduced today, having a rate negative growth (ALT, 2003). The illiteracy rate is around 15%.

c. Description of the problem

i. Water diversion to the Pacific Coast

As mentioned before on several occasions, the Bolivian government has requested information and made observations on the projects of water diversion where they mention their concern for the alteration of the water courses. According to the data obtained from different sources, Peru now draws about 1600 lit/sec from the upper river basin Mauri, and it is planned to extract more in the near future. However, the situation is complex and the actors involved are more numerous.

The case of Kovire project, which derives Mauri waters of the lagoon Aricota Locumba basin, is paradigmatic. The tunnel has a capacity of 10 m3/sec, much larger than the 0.3 m3/sec (300 lit / sec) are captured in the intake Kovire, located at the beginning of the tunnel.

It has already been observed some deterioration in the water quality of rivers Caquena and Mauri. The diversion of the river in Peru Kovire significantly increased pollution of water with boron (30 mg/l) and arsenic (5 mg / l). It is also noticeable the loss and deterioration of aquatic ecosystems, including wetlands in Ayro. The wells have dried at least 600 hectares of wetlands in Bolivia, while refilling Uchusuma river wiped out 800 hectares of wetlands near Charaña.

The magnitude of the decrease in the flow of the Mauri and shared several tributaries of course varies by river or water body. It is anticipated that the course of the Mauri decreases between 26% in the border during the rainy season and in wet years, and almost 77% in the drought season and dry years. The diversion will also reduce the river flows Cano (90%); Caquena (33%), and Ancomarca (up to 73%).

The reduction in flow will impact negatively in the biological cycles of aquatic fauna (benthic, fish and others) flora (plankton, seaweed, etc.) and in the rest of the food chain (birds, vicuna, fish etc.). The lower soil moisture and cultivation of wetlands and native grasslands will reduce fertility, degradation, salinization, and soil erosion sodification. Production and quality of food as potatoes, beans, quinoa, will drop and the pressure on pastures will increase.

It is anticipated the rise of the concentration of salts, bore and arsenic in the waters of the Mauri river with an increased peak between 50 and 41% in the dry season and in dry years. Even when the concentration of these toxic elements is naturally high in the rivers of the basin, the strong increase attributable to the transfer projects will cause other social and environmental impacts.

It is feared serious socio-economic damage such as a drastic fall in production, lower income, increased conflict, migration and loss of identity and family ties.

Fig. 2 Wetland in the Mauri River Basin

ii. The Peruvian interests

The project Vilavilani II stage means for Tacna, the water solution to their demands.

- ✓ Tacna Wants to Develop and agro industrial complex in the most desert area of the world.

  "Mister President, our project consists in bringing water to our region (Tacna) from the exccess of Mauri an Desaguadero rivers – that actually are lost in the salts of Bolivia" (Ordinary session of December 20th, 2005- Consejo Regional del Gobierno Regional de Tacna)"

Fig. 3 Kovire project, second stage

- ✓ …. In every electoral campaign in Peru candidates make promise to the electors in Tacna that the diversion of Mauri River will become a reality…..

- ✓ In 2003 Peru and Bolivia established a bilateral commission in order to determine the maximum discharge that could be diverted without affecting Bolivia. The commission never ended with a common conclusion

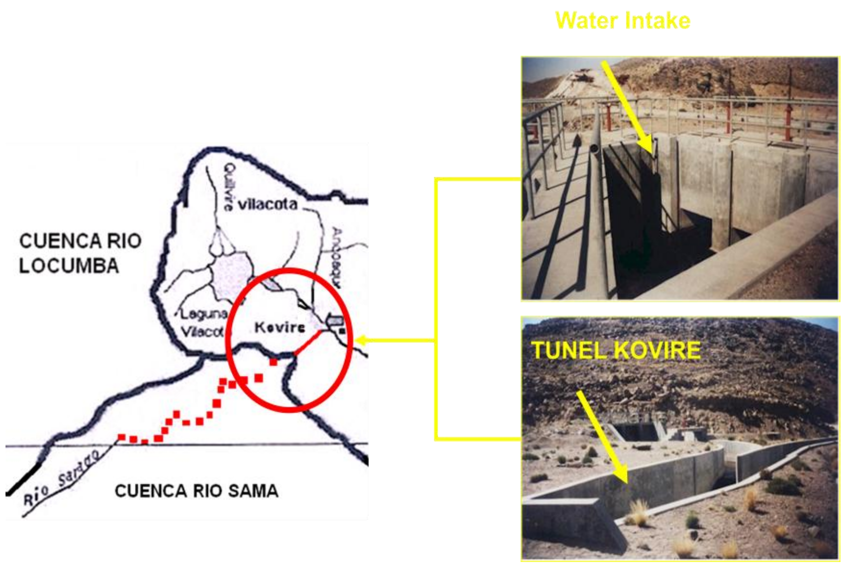


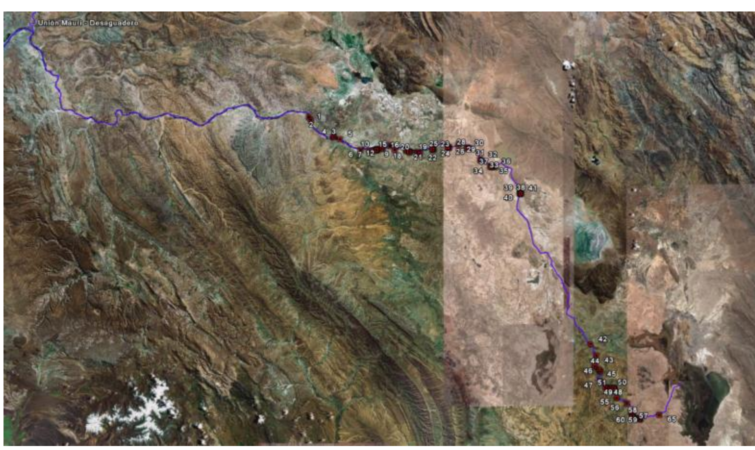
Fig. 4 Kovire water infrastructure

d. Diagnostic Research

The main objective to be studied in this case is the determination of dependence of water from the communities in the watershed, for this purpose, a methodology created by the NGO Agua Sustentable was established as the procedure to determine water rights in the Bolivian part of the watershed Figure 5 shows a chart with obtained information and its respective method. The method has been applied to identify the water rights in the Mauri and Desaguadero rivers and the uses and costumbes related to the use of water sources in the studied basins. The key assignment is to collect information required to calculate the water demand (type of crops, area, irrigation seasons and other variables) and to give the input for the Mike Basin Model and the consultation meetings. Figure 6 shows the water dependent population and livestock in the study area determined by water rights methodology.

Obtained Information	Methodology
Location of wáter intakes (Mauri and Desaguadero)	• Field georeferencing
Location of Crop áreas (Desaguadero)	• Ikonos and Landsat satellital images, google earth • Georeferencing of questionable areas in field
Surface of crop and number of cattle (Desaguadero)	• Surveys of irrigation key actors • Analysis of consistency through: a) Comparison with data from the Environmental Audit of the oil spill (1999) b) Comparison with surfaces obtained in the GIS
General information of water rights, organization, management and other information (Desaguadero)	• Surveys t okey actors • Meetings with base users
Location of wetlands áreas (Mauri)	• Ikonos and Landsat satellital images, google earth with field verification
Livestock management in wetlands (Mauri)	• Surveys t okey actors • Workshop with community representatives (speaker maps, inofrmation matrixes)

Fig. 5 Water rights methodology and information obtained. (Agua Sustentable, 2009)



Specie	Quantity	Fibers Kg.	Meet Kg.	Leather
	Number	By year	By year	units
Llamas	75.460	39.589	284.110	7.548
Alpacas	47.392	58.282	142.170	4.739
Vicuñas	.2.425	--.--	--.--	--.--
Ovinos	37.748	.9.390	122.620	4.774

Fig. 6 Dependency of irrigation and livestock

i. Community Collective Water Rights

Collective Rights of irrigation are related to access to the source, which means that any community within its territory may make a work for the benefit of the entire community. This figure may have several variants, for example:

- Various communities come together to join forces in the construction of canals, though the water intake that is located on the territory of one community from the river to negotiate the passage of easements and their decision and channel located in the territory of other communities. This means that access to the source is not limited to coastal communities, with the only difference that remote communities are subject to negotiate the passage of easements.

For the case of study, the first irrigation systems were built in the fifties

- The systems were built for the initiative of the communities
- They used only hand work no machinery
- There didn´t receive any help from the government
- In the decade of the 60's, new systems are incorporated in the region of La Paz and after that, more systems were incorporating to the present.

The following chart shows the irrigation users in the system by the year of construction and the number of users in each system, the chart was determined by the water rights methodology.

Nombre del sistema	Nombre de la toma	Fecha de construc.	No Usuarios
Asociación Canal de Riego 4 Comunidades	Canal 0	1983	170
Sipa Pampa Laura, Sipa Ayviri Piti	Toma Vila Chullpa	1990	16
Sistema Jaq'e Phekeña	Toma Jaque	1976	47
Comunidad Achaviri	Toma Achaviri	1970	38
Comunidad Laymini	Toma Laymini	1963	27
Comunidad Capitán Castrillo	Canal 7	1963	0
Comunidad Capitán Castrillo	Canal 8	1963	11
Comunidad Capitán Castrillo	Canal 9	1963	0
Comunidad Capitán Castrillo	Canal 10	1963	11
Comunidad Capitán Castrillo	Nuevo	2005	8
Comunidad Santa Ana	Canal 11	?	60
Comunidad Colque Amaya Alta	Canal 12	1963	19
Comunidad Colque Amaya Alta	Canal 13	1963	12
Comunidad Colque Amaya Alta	Canal 14	1966	19
Comunidad Colque Amaya Alta	Canal 15	1966	0
Comunidad Colque Amaya Alta	Canal 16	1966	0
Comunidad Colque Amaya Alta	Canal 17	1983	32
Comunidad Luky Amaya	Lukyamaya	1991	27
Comunidad Colque Amaya Baja	Canal 20	1954	57
Comunidad Colque Amaya Baja	Canal 21	1963	36
Comunidad Unupata	Centro Unupata	1984	50
Comunidad Jankoicho	Canal 24	1982	58
Comunidad Bolívar	Canal Bolívar	1978	42
Comunidad Alto Rivera	Canal Grande Norte	?	26
Comunidad Alto Rivera	Canal Pequeño Sur	?	15
Comunidad Alto Rivera	Canal Familiar Mamani	?	1
Comunidad Tuluma Rivera	Lado Norte	?	40
Comunidad Centro Rivera	Canal 26	1985	80
Comunidad Centro Rivera	Canal s/n	1990	75
Comunidad Rivera Alta	Canal Rivera Alta	1956	54
Comunidad San Miguel	Canal San Miguel	1975	32
Comunidad Janko Piti	Canal Janko Piti	2003	16
Comunidad Janko Piti	Canal Solares	2006	10
Asociación de Regantes Titusa Alta	Titusa	1996	5
Asociación de Regantes Titusa Alta	Titusa	2001	11
Asociación de Regantes Titusa Alta	Titusa	2003	8
Asociación de Riego Huancaroma	Canal Huancaroma	1980	50
Central Challacollo	Zona Norte y Sora Chico	1986	464
Comunidad Canalización Chambi Rancho Ch	Chambi Rancho	1964	170
Central El Choro y Unificada	Toma Central	1952	659
Chaytavi	Chaytavi	1975	0
TOTAL			2456

Fig. 7 Irrigation users in the system

Origin of collective rights

The first irrigation systems in the Desaguadero date from the decade of 50. Until then, most of the area was occupied by native grasslands and reduced irrigated crop areas.

The first water intakes and canals were constructed in the area of Oruro initiated by the communities themselves. Long journeys were dug manually by the villagers and until recently did not receive any support in cleaning or maintenance.

In the decade of the 60 new systems in the area of La Paz and then incorporating new systems will gradually until the date.

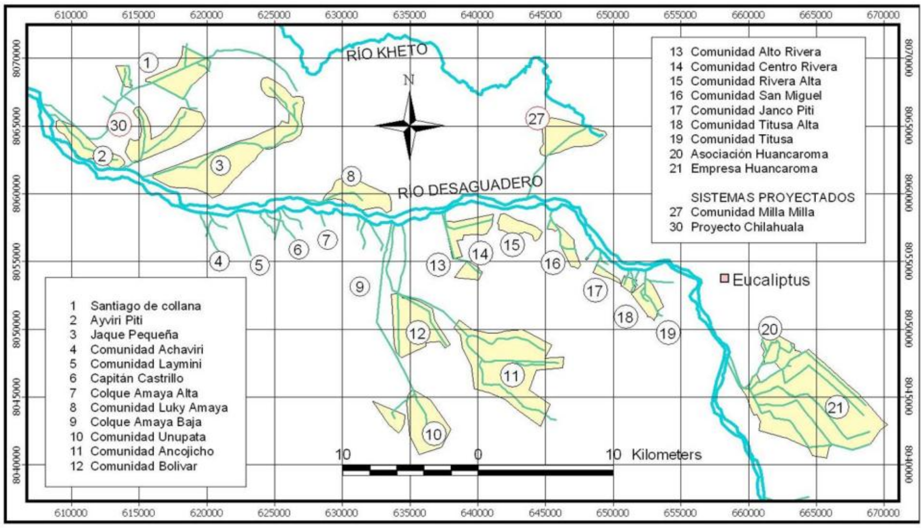


Fig. 8 Crop areas and irrigation channels in the north region

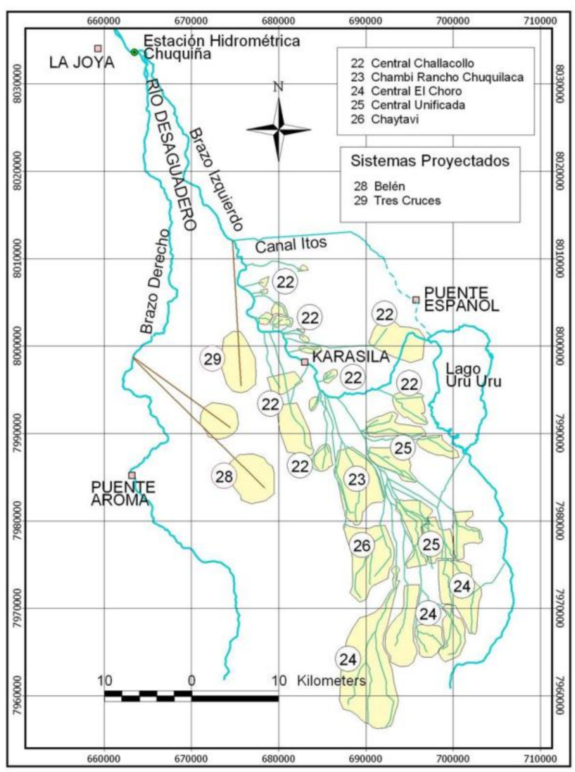


Fig. 9 Crop areas and irrigation channels in the south region

In the area of Desaguadero, the main water uses are irrigation, livestock and human consumption.

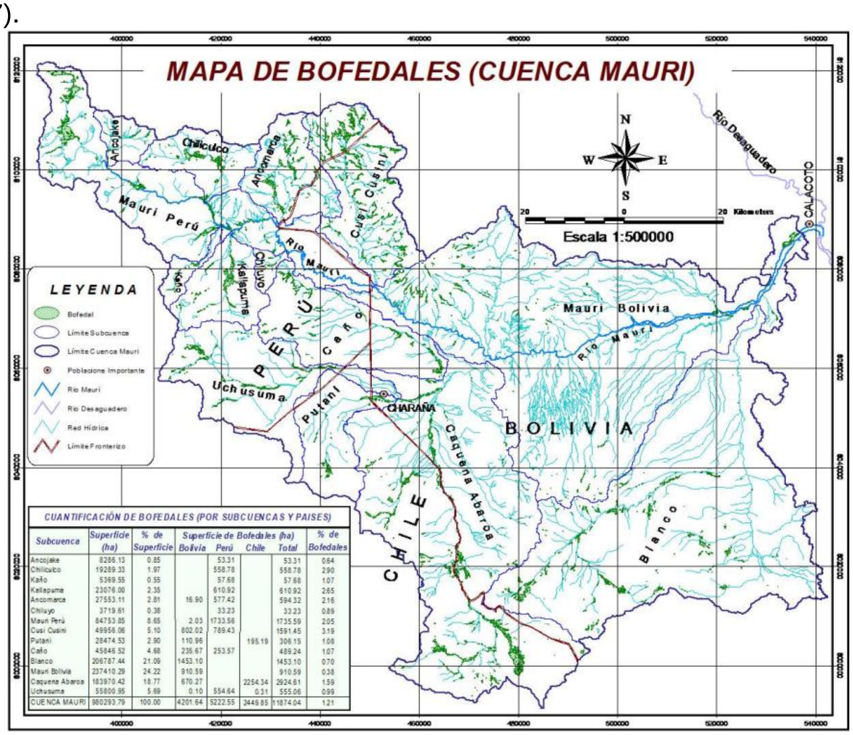
The first two applications are totally dependent on the river outlet, while human consumption is the alternative groundwater.

Irrigation activity is relatively new (year 50). This activity has changed significantly productive activities and the configuration of the ecosystem (decline of native grasslands, introduction of fodder, etc). The villagers believe that irrigation has helped greatly to improve living conditions.

"This place was poor, humble, despised, have sought to survive half, irrigation" (Irrigation Chaytavi, interview 2006)

ii. Wetlands Use

Based on the digital processing of satellite imagery, field visits and evaluation other works and studies have determined that the wetlands in the basin of Mauri occupy a total area of approximately 11 874 ha, of which 5 222 ha are the Peruvian side, 4 202 ha in Bolivia and Chile 2 449 ha, which together account 1.21% of the total area of the basin. Figure 10 shows the location of these wetlands (in green color) and the table shows the sub-surface wetlands and country as well as percentage that represents that area in relation to the sub-basin. In the wetlands located on the banks of rivers, the settlers constructed a series of water intakes and canals to ensure water supply. An inventory of wetlands made by ALT located 87 outlets in different sub-basins in Peru and Bolivia (Orsag, 2007).



CUANTIFICACIÓN DE BOFEDALES (POR SUBCUENCAS Y PAISES)

Subcuenca	Superficie (ha)	% de Superficie	Superficie de Bofedales (ha) Bolivia	Perú	Chile	Total	% de Bofedales
Ancojake	8286.13	0.85		53.31		53.31	0.64
Chilicubo	19289.33	1.97		558.78		558.78	2.90
Kaño	5369.55	0.55		57.68		57.68	1.07
Kallapuma	23076.00	2.35		610.92		610.92	2.65
Ancomarca	27553.11	2.81	16.90	577.42		594.32	2.16
Chiluyo	3719.61	0.38		33.23		33.23	0.89
Mauri Perú	84753.85	8.65	2.03	1733.56		1735.59	2.05
Cusi Cusini	49956.06	5.10	802.02	789.43		1591.45	3.19
Putani	28474.53	2.90	110.96		195.19	306.15	1.08
Caño	45846.52	4.68	235.67	253.57		489.24	1.07
Blanco	206787.44	21.09	1453.10			1453.10	0.70
Mauri Bolivia	237410.29	24.22	910.59			910.59	0.38
Caquena Abaroa	183970.42	18.77	670.27		2254.34	2924.61	1.59
Uchusuma	55800.95	5.69	0.10	554.64	0.31	555.06	0.99
CUENCA MAURI	980293.79	100.00	4201.64	5222.55	2449.85	11874.04	1.21

Fig. 10 Wetlands use in the watershed

iii. Water allocation and their representation

Mathematical modeling in the field of water resources begins from the system concept; a system can represent reality with a number of variables of elements that interrelate between each other. The central problem of mathematical modelling is the evaluation of system behaviour. Models help to study how water is allocated within a water system using a variety of initial conditions and frameworks, from analysis to the conflict-negotiation of integrated water management at basin level. Each framework incorporates different degrees: social-human components, physical and biological. Among the wide range of models taking into account existing and the objectives of the study, the decision to adopt a water management model is made. (Molina Carpio & Cruz, 2008)

Water management at the basin can be seen as an attempt to identify the best use of available water resources, considering certain conditions / social restrictions, legal, technical, land and environment. Generally, the basin is used as a management unit, not only because it is the territory that captures and concentrates water from rainfall, but because of the same Physical characteristics generate a strong interrelationship and interdependence between uses and between them and their environment.

To estimate the supply of water in the basins of the Mauri and Desaguadero, a hydrological study and water resources was conducted taking into account the goals of the project from different sources in the form of continuous series of monthly flows for a sufficiently long period (1965-1905). The period mentioned includes dry and wet years, which made possible to evaluate the impacts of diversion works and new irrigation projects on users for different situations. To meet the goals of the hydrological study, two techniques were applied: models river basin management and statistical modelling.

Figure 11 and 12 show the average monthly flows in the form of hydrographs for Calacoto (Mauri) and 3 other stations on the Desaguadero River. While there is strong variation between months, it could be observed that the base flow appears to be important (dry season), especially in the Río Mauri.

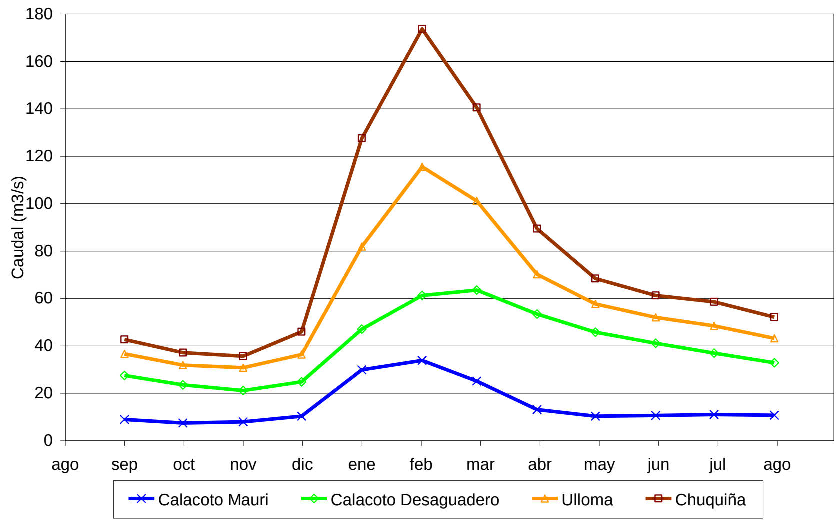


Fig. 11 Discharge Variation in Mauri river watershed

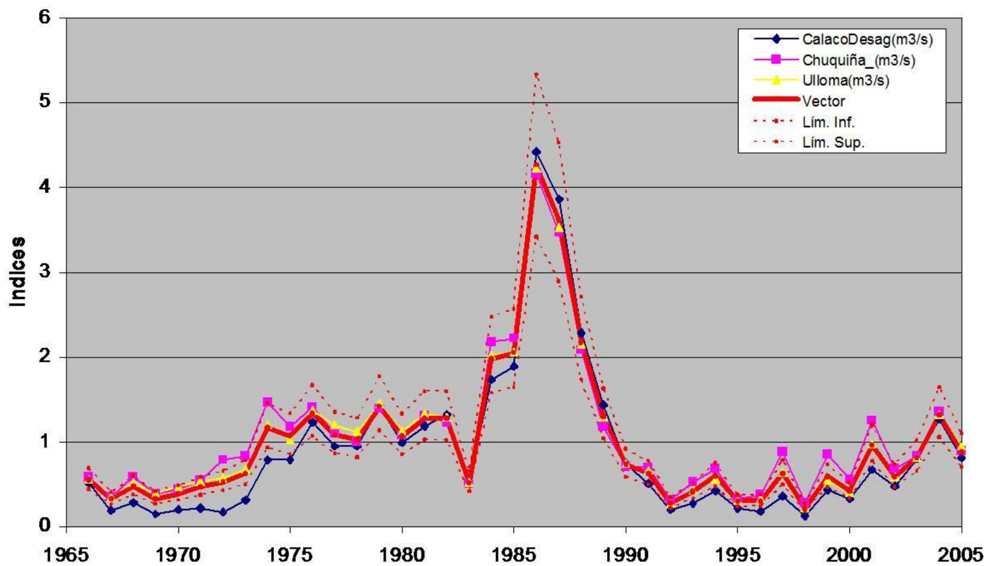


Fig. 12 Discharge variation in the Desaguadero river

iv. **Build and run a management model**

For the purpose of the study, as mentioned in previous paragraphs, scenarios were built in order to represent the entire system Mauri-Low and Desaguadero under current conditions, that is equivalent to a baseline to which are other scenarios were compared.

For the current scenario, the basic water network was created and performed in the model calibration with MIKE BASIN. For calibration, flow series monthly period 1965-2005, obtained from the Hydrology were used.

The information collected during the study and the current scenarios for comparison have been integrated in a management model and modelled in different scenarios considering the variable of growing infrastructure, three scenarios were simulated from the current scenarios.

For all scenarios, the implications of the new water deviations on Bolivian water users of the river basins Mauri and Low Desaguadero were assessed. For irrigation users along the Desaguadero, two sub-scenarios were considered: with and without implementation of new irrigation projects. We also evaluated the consequences on wetlands located on the Peruvian side of the river basin Mauri.

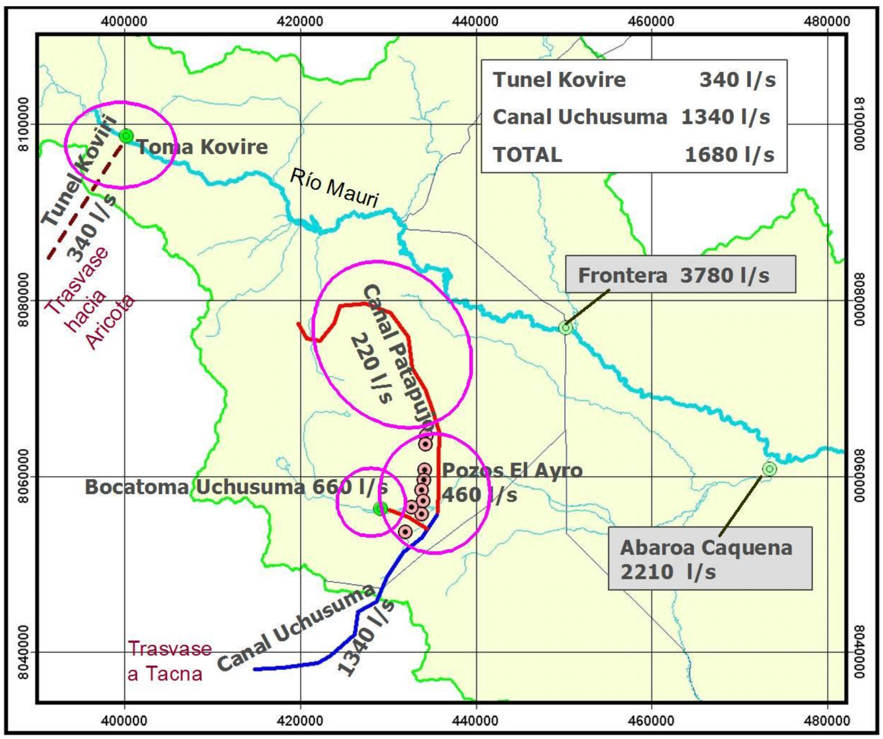


Fig. 13 Current scenario

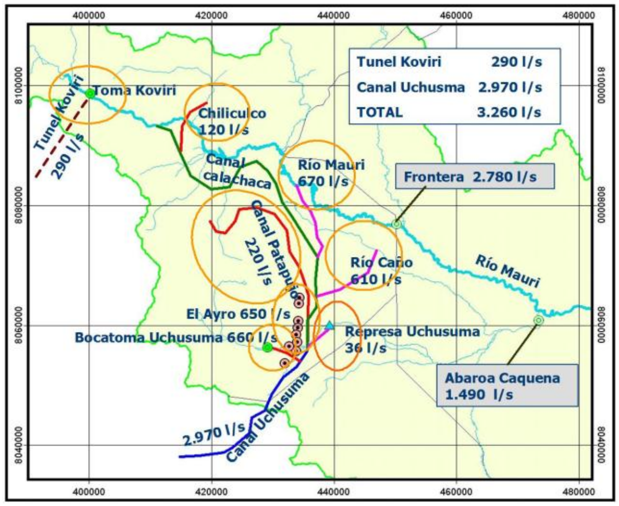


Fig. 14 Scenario I – Close Future

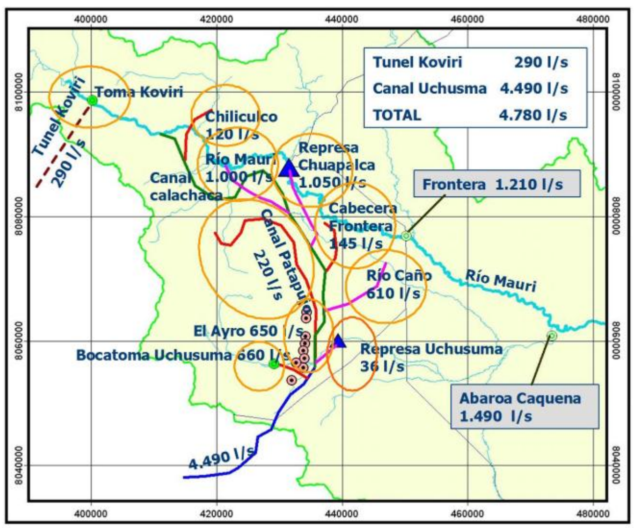


Fig. 15 Scenario 2 – Middle term

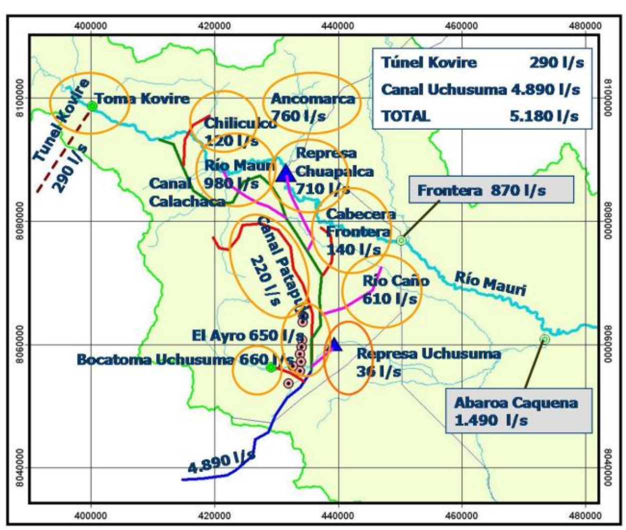


Fig. 16 Scenario 3 – Future

3. Conclusions

The water balance and management model utilized shows that the Bolivian communities in the lower part of the basin have a strong dependence from the water of the Mauri river.
This information and conclusions of the study, together with the principles of water sharing have been crucial in the last talks between the governments of Bolivia and Peru (October 2010) where both governments have been decided to implement hydrometric binational stations to jointly monitor the water sharing of Mauri River, it has been also decided to build a management mathematical model using Mike Basin and WEAP, in order to establish the amount of water that corresponds to each country without causing arm to the other.
Both countries have been decided to conclude the study in a period of 10 months endings with a permanent agreement till September 2011. The presidents of Peru and Bolivia have signed an agreement in that sense on October 19, 2010.
The methodology and results of Mike Basin have been crucial in putting on the negotiation table the principles of water sharing and international law and to stop the international crisis between Bolivia and Peru
The approach of the case studied could help to solve other similar transboundary river cases in the region.

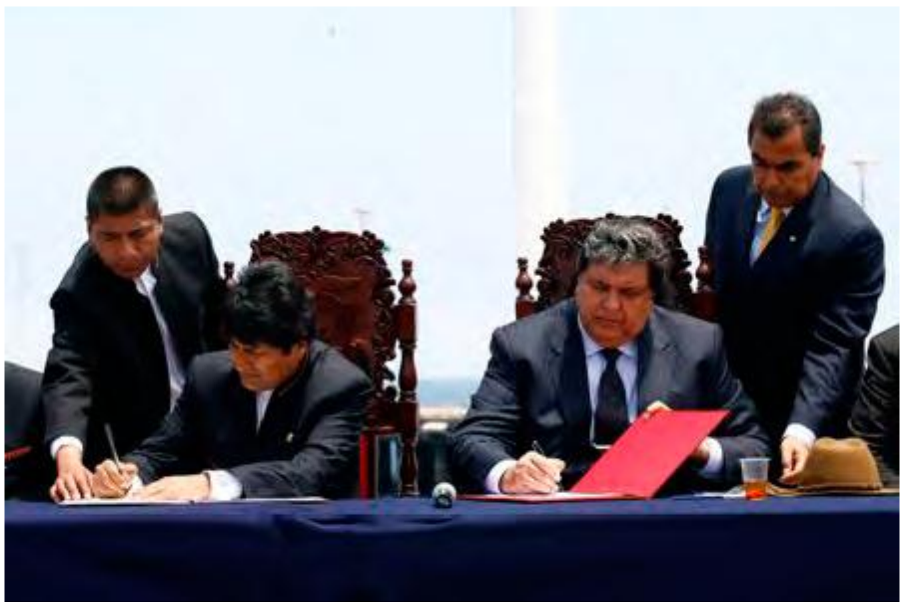


Fig. 17 Picture of the Agreement signature between Bolivian President and Peruvian President

4. References

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