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# Boundaries as tools for sustainable water management

**draft**

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## Abstract

Across river basins water can have different types of values according not only to its production costs but also due to changes in the willingness to pay across the territory. The generalized view that integrated water management must be made through a centralised mechanism does not consider those facts and often assumes that command and control policies are the only tool available and effective. Therefore the functioning of river basins tend to be simplified with dams and the research agenda has been directed to design major models with powerful decision support systems for one coordinator body to decide. Nevertheless the effects of these centralised and controlled systems have not been able to address the unpredictability of human and ecosystem behaviour. The hypothesis we would like to test is that boundaries and negotiation between boundaries can be good tools for sustainable water management. First we review the literature on cases studies of basins' management trying to discuss the relation between boundaries. Then we develop a formal model with upstream and downstream regions and try to understand in what conditions boundaries can be good for sustainable water management. Finally we try to introduce the concept of boundaries in a particular river basin and simulate the solutions for a centralised planning body and for a decentralised negotiation system.

## 1 - Introduction

From the demand perspective water can be exclusive, private, common or public. From the supply point of view water can be produced, transported and distributed by the environment, by diffused land users or by large or small institutions that manage pipes and reservoirs.

Nevertheless water is much more than an economic good. It is a designer of adapted spaces and channels, it is in the essence of life and, last but not the least, it is an implicit and explicit tool of power.

The prevailing idea is that integrated water management must be done by institutions able to control all the river basins. This idea is also supported by those keen to implement economic and political integration between countries because they think that integrated water management can only be undertaken by supranational entities.

In this paper I try to prove that boundaries can be useful tools for water management. First we look at the environmental, institutional, economic and technological features of water management. Then we review the prevailing policies, their underlying concepts and, based on the existing literature, their impacts around the world. Afterwards, we develop a formal model with upstream and downstream regions and try to understand in what conditions boundaries can be good for sustainable water management. Finally we try to introduce the concept of boundaries in an applied model for a particular river basin and simulate the solutions for a centralised planning body and for a decentralised negotiation system.

## 2 - Features of Water Management

### 2.1 - The Environment

Water supply can be produced, transported and distributed by large or small institutions that manage pipes and reservoirs and also by diffused land users. Nevertheless the main production factor is the hydrological cycle. The hydrological cycle is a system of continuous circulation of water through which enormous quantities of water are cycled each year although only a small part is available for human use: from the skies to the ground through precipitation, in the ground the water flows across rivers, aquifers and oceans, and from these into the skies through evaporation.

Available supplies are based mainly on the management of surface water flows and of ground water flows although it is possible to increase precipitation and to obtain water directly from the oceans. Average demand is lower than the average available supply. Nevertheless there are huge regional problems on the management of surface water flows and mainly on ground water flows (Tietenberg, 2003).

### 2.2 - Adapted Spaces

Water is much more than an economic good, with its supply and its demand. It is a designer of adapted spaces and channels and it is in the essence of life.

Cities need water and are usually located near the confluence of water flows or .in the sites of distribution of water flows. Valleys and chains of mountains, structured by geology and water flows, are designers of roads and channels either by restraining their passage or by defining preferable roads along the valleys and mountains.

Life lives on water and each ecosystem is strongly affected by the features of the water cycle that passes through it. Man transformed ecosystems into agricultural adapted spaces by changing water flows using irrigation, through the control of species and through the integration of fertilisers.

### 2.3 - Economic Tissues

Water is the support of many economic activities: agriculture, energy production, housing, industry, tourism, transport, leisure, recycling of emissions, climate control and enabler of ecological functions.

These multiple uses are associated with conflicts and complementarities across space an time.

The construction of dams to produce energy reduces the amount of water for agriculture and shifts the employment capacity from irrigated areas in the country to industrial and tourist areas close to the cities.

The construction of dams changes the ecological functions of water and has impacts in the climate at the micro level.

The pollution of rivers, lagoons and oceans have a great impact on the functioning of the ecosystems and in the availability of water.

Furthermore there are cumulative effects in the economic tissue which determines rising and uncompressing demand for water with a strong spatial feature.

### 2.4 Institutions and Policies

Water is an implicit and explicit tool of power and each policy measure, even with the same effect in terms of the water supply, has quite different impacts in which concern the distribution of power and the allocation of costs and benefits.

The administration of taxes an subsidies implies a strong institution able to allocate water, monitor consumption and undertake financial procedures.

The creation of property rights involves the clear definition of those rights and its control.

The establishment of water quality standards and water quotas also leads to the creation of powerful institutions with enormous power over the population.

Summing up, water management determines the creation of powerful institutions, involving various authorities and entities, which usually tend to have well defined spatial boundaries.

## 3) Concepts and Policies

### 3.1) Purposes

Water management existed ever since man came to being. Efforts to monitor and control rivers date back 5000 years (Barrow, 1998). These actions are associated with the development of agriculture, the creation of cities and the rise of countries.

There are many types of water management structures which concepts and policies derived from the purpose of the management (Figure 1).

- Economic purposes aimed to allocate water resources between various purposes and users: flood control, hydroelectric generation, irrigation supply, domestic supply. Demand is private and the supply is static.

- Comprehensive purpose target to manage not only the water flow but also the land use that have an impact not only in the quality and quantity of the water flow but also in regional economic development. Demand is private but supply can increase (or decrease) with land use management.

- Integrated purpose goes beyond the comprehensive purpose as far as water management is seen as a tool for economic development of the river basin. Demand is private and public, due to externalities, and supply not only can increase (or decrease) with land use management by these changes have externalities in the economy.

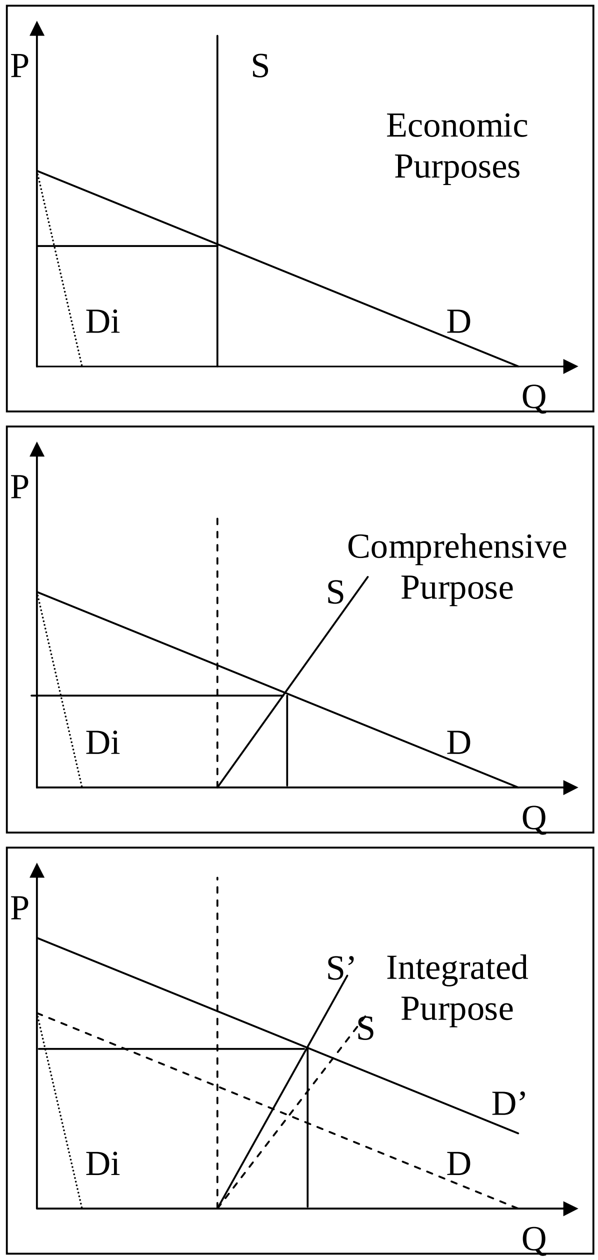


Figure 1: Purposes for Water Management

### 3.2 - Transboundary conflicts with economic purposes

Assuming that there are only two countries (Upstream and Downstream) with similar demands for water (Du, Dd). The supply of water is given for the Upstream Country (Su). There is water recycle by the environment (Es) so that water supply for the Downstream is given by [Sd=Su(1-β)], where q is the percentage of water recycled.

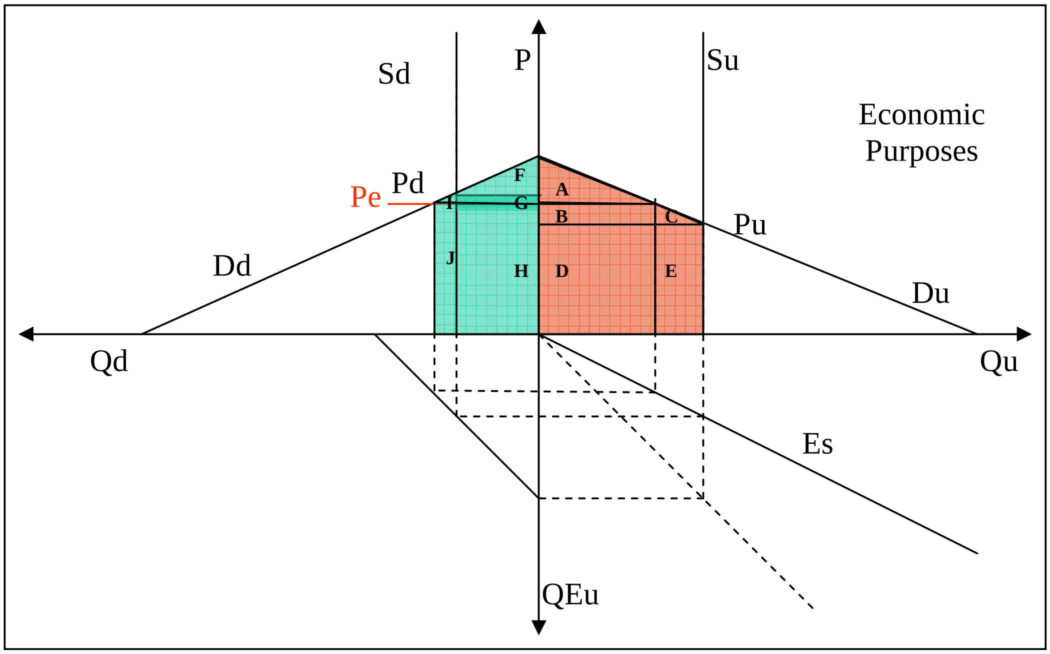


Figure 2: Transboundary conflicts with economic purpose

We analyse three types of solution for the management of water:

a) Without agreement the consumer surplus of the Downstream Country is (F) and the total economic value associated with the water provision is (FGH). On the other hand the Upstream Country gets a consumer surplus of (ABC) and a total economic value of (ABCDE).

b) With an agreement between countries the consumer surplus of the Downstream Country would be (FGI) and the total economic value associated with the water provision is (FGIJH-CE) because Downstream Country must compensate the Upstream Country for its losses. This country gets a consumer surplus of (A) and a total economic value of (ABCDE).

c) A third solution admits a central regulator to define the allocation of water between the two countries. The central regulator obtains a surplus of (JHBD), the Upstream country gets (A) and the Downstream country gets (FGI).

| | Central Planner | Upstream Country | Downstream Country |
|---|---|---|---|
| No agreement | - | ABCDE | FGH |
| Agreement | - | ABCDE | FGHIJ-CE |
| Central Decision | JHBD | A | FGI |

Table 1: Pay-offs of transboundary conflicts with economic purposes

Two remarks are possible.

- First, solutions (b, agreement) and (c, central planner) are not always better than the solution of no agreement (a, no agreement); actually, only with quite rigid water demands and with reduced water recycling (q close or greater than 1) the non-agreement solution is worse.
- Second, centralised solutions can only be adopted with an appropriate distribution of the regulator surplus which in fact is the economic rent of the natural resource.

### 3.3 - Transboundary conflicts with comprehensive purposes

We consider now the same two countries (Upstream and Downstream) with similar demands for water (Du,Dd). The supply of water can be improved with a cost both in the the Upstream country (Su) and for the Downstream country. This means, for instance, that we can ask farmers to change land use to produce water paying them the opportunity cost of the lost crop. There is also water recycle by the environment (Es) so that initial water supply for the Downstream is given by [Sd=Qu(1-β)], where β is the percentage of water recycled by the environment.

We try to analyse three types of solutions for water management:

a) Without agreement the consumer surplus of the Upstream Country is (AB) and the total economic value is (ABC). On the other hand the Downstream Country gets a consumer surplus of (E) and a total economic value of (EFG).

b) With an agreement between countries the consumer surplus of the Upstream Country would be reduced to (A) and the total economic value associated with the water provision is (ABCD) The Downstream country gets a consumer surplus of (EFH) and a total economic value of (EFGHI-D) because Downstream country must compensate the Upstream country for its losses (D).

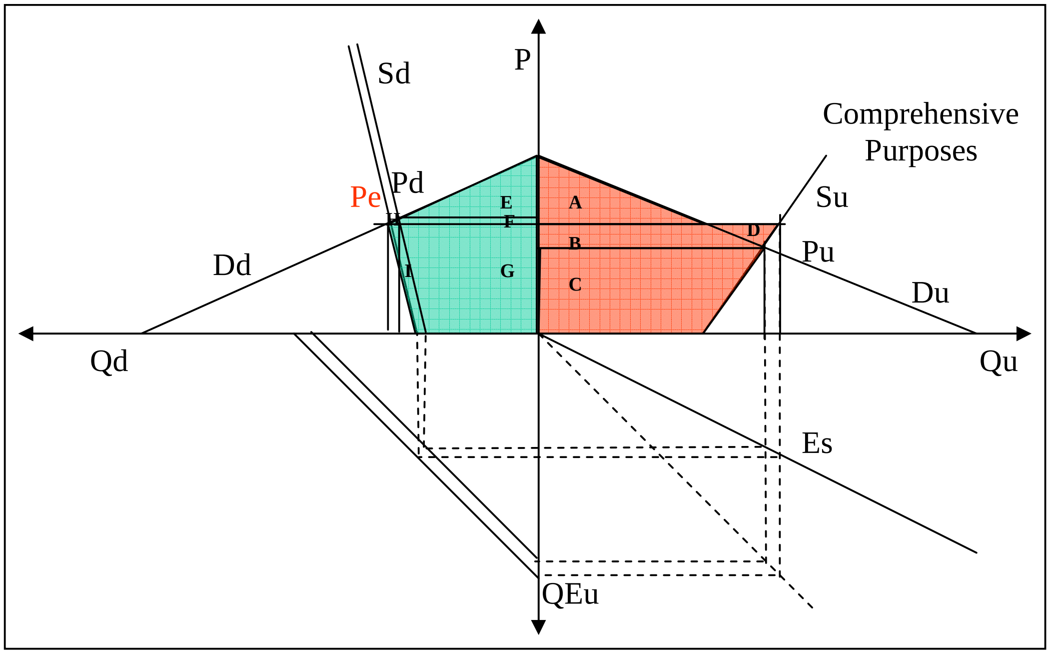


Figure 3: Transboundary conflicts with comprehensive purposes

c) The third solution admits one central regulator to define the allocation of water between the two countries. The central regulator obtains a surplus of (IGBCD), the Upstream country gets (A) and the Downstream country gets (EFH).

| | Central Planner | Upstream Country | Downstream Country |
|---|---|---|---|
| No agreement | - | ABC | EFG |
| Agreement | - | ABCD | EFGHI-D |
| Central Decision | IGBCD | A | EFH |

Table 2: Pay-offs of transboundary conflicts with comprehensive purposes

Summing up, with a comprehensive view of water supply, where farmers can produce water trough changes in the land use, there is an improvement to the previous model of allocation of a fixed amount of water. Furthermore, the need to choose an agreement or a common regulator, as opposed to no agreement, is dependent not only on the amount of water recycled by the environment and on the water demand but also in the water production in both countries.

**3.4 - Transboundary conflicts with integrated purposes**

To understand the transboundary conflicts with integrated purposes we continue to assume that there are only two countries (Upstream and Downstream) with similar demands for water (Du,Dd) but, this time, water demand include externalities of water consumption. The supply of water can be improved with a cost both in the the Upstream country (Su) and for the Downstream country (Sd) but there are external costs associated with these efforts in both countries. Therefore we can ask farmers or industries to change their direct and indirect use of water paying them the opportunity cost but we must also pay for the external costs, such as decrease in local economy due to income multiplier effects.

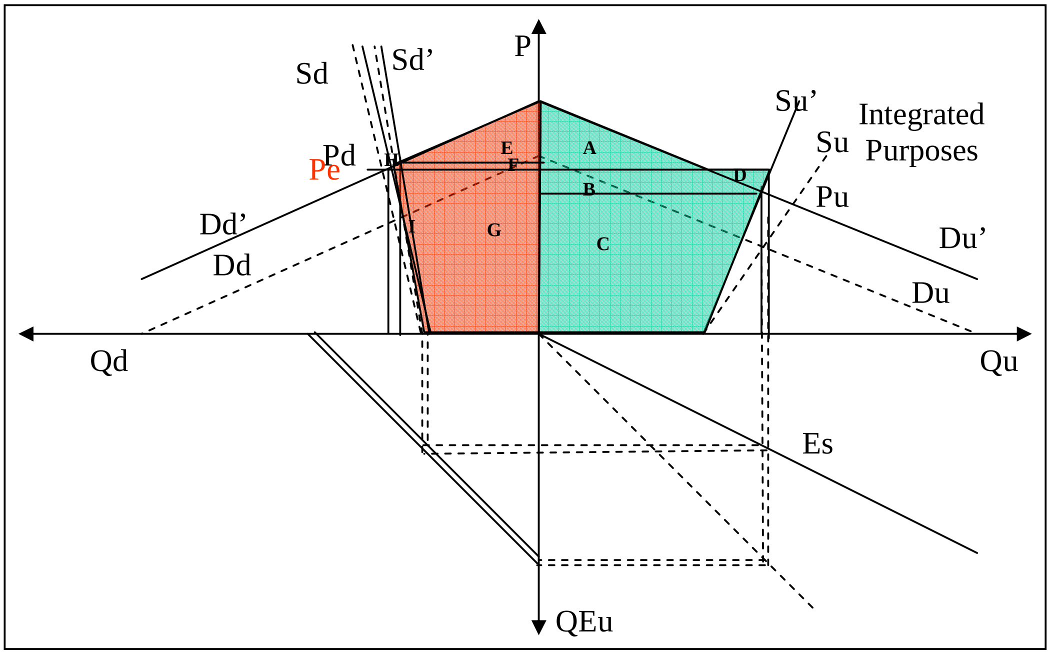


Figure 3: Transboundary conflicts with integrated purposes

There is also water recycle by the environment (Es) so that initial water supply for the Downstream is given by [Sd=Qu(1-β)], where β is the percentage of water recycled by the environment. We study also three types of solution for the management of water:

a) Without agreement the consumer surplus of the Upstream country is (AB) and the total economic value associated with the water provision is (ABC). On the other hand the Downstream country gets a consumer surplus of (E) and a total economic value of (EFG).

b) With an agreement between countries the consumer surplus of the Upstream country would be reduced to  (A) and the total economic value associated with the water provision is (ABCD) The Downstream country gets a consumer surplus of

(EFH) and a total economic value of (EFGHI-D) because Downstream country must compensate the Upstream country for its losses (D).

c) The third solution admits one central regulator to define the allocation of water between the two countries. The central regulator obtains a surplus of (IGBCD), the Upstream country gets (A) and the Downstream country gets (EFH).

| | Central Planner | Upstream Country | Downstream Country |
|---|---|---|---|
| No agreement | | ABC | EFG |
| Agreement | | ABCD | EFGHI-D |
| Central Decision | IGBCD | A | EFH |

Table 2: Pay-offs of transboundary conflicts with integrated purposes

As a whole there is an improvement of the Total Economic Value with an integrated purpose. Nevertheless the centralised solution for management could have some problems. On the one hand it transfers the rent of the water to the central entity as also happened for the comprehensive and economic purposes. On the other hand it can be quite difficult to valuate the positive and negative externalities at a central level since the public demands can be quite different from one country to the other.

**4. - The Case**

The Seven Cities Lake in the Island of Saint Michael (Azores) is located in a volcanic crater that forms the hydrologic basin of the lake. The size of the basin is 1923 ha of which 25% is water. The dry areas (1448 ha) are occupied by pasture 32% (458 ha), wild forest 31 % (454 ha), timber forest 26% (379 ha) and other uses 11% (157 ha).

Intensified dairy production has successively resulted in depletion of the lakes mainly due to unsustainable farming and logging practices. The increased frequency of logging and use of fertilisers on pastures and forages has already destroyed several small lakes through eutrophication and sedimentation. The issue became a public concern when eutrophication and sedimentation increased in two of the major lakes in S.Miguel Island.

Land is currently used for intensive farming/dairy production, which results in deforestation, soil erosion and sedimentation of the lake. Soil erosion increases the flow of nutrients and fertilisers in the Lake which contributes directly to eutrophication. Until now, the increased sedimentation has resulted in a decrease of the depth of the lake by 10 meters. Continued sedimentation and eutrophication will have two major impacts: 1) degradation of the landscape aesthetics and; 2) reduced water quality and availability.

The problem became a public concern when the degradation of water quality and landscape became a threat for tourism and also for urban development outside the basin. The conflicts are between agriculture and tourism, the small village and the major town. For the small village, 700 cows produce 3.8 million litres of milk and provide direct employment to 67 farmers and induced employment to more 50 actives. For the city, these cows and their forages generate 600 kg of phosphorus per year which increases the eutrophication process which can lead to a reduction of 15% in tourism (Dentinho & al, 2001) and to negative effects on employment outside the basin of 250 employees.

To address this problem we identify consistent scenarios and then evaluate them with a multicriteria analytical toll.

To obtain consistent scenarios, we formulate, calibrate and integrate three models: an environmental model of the lagoon, an agro-environmental model of the basin and an economic model of the village.

The various scenarios result from the combination of four types of policies: preventive measures, corrective measures, social measures and economic measures.

- Preventive measures are related to changes on land use and defined according to the effect on the emissions to the lagoon.
- Corrective measures involves the deviation of the polluted water to outside the basin and can also be associated with changes in the emissions to the lagoon.
- Social measures are due to compensate the loss of employment in the village that result from the changes imposed on land use.
- Economic measures aim to compensate the loss of income by the farmers due to changes imposed in the land use.

To evaluate all the scenarios we use a decision support system and select three dominant scenarios based on twelve economic and environmental criteria.

The criteria and their hierarchy presented was established through a dialogue with the main stakeholders (regional, local and communal entities, farmers' association and NGOs).

With the three models we get a table of 14 impacts descriptors for each one of the 29 alternative scenarios.

With the multicriteria analysis we obtain a selection of the dominant scenarios

The scenario chosen accounts for 600 cows that produce 3.0 million litres of milk and provide direct employment to 53 farmers and induced employment to more 40 actives. Furthermore the deviation of one of the main water streams that feeds the lagoon will allow a reduction of 63% of the phosphorus load on the lagoon. Compensatory measures, economic and social, will compensate the farmers for their losses and the community for the lost basic employment.

The solution proposed by the Plan envisaged an agreement between the village and the city trough the mediation of the regional government. The village would keep its base employment through the compensation of 17 employments lost in agriculture by 17 employments that can be gained in tourism and public education. On the other hand the touristic employments in the city will be maintained. This is due: 1) First to the existing of a clear border between the interests of the village, with its farmers and people, and the interests of the city, with its tourist operators, its population and its visitors; 2) Second, to a clear integrated approach through which all the interests and capabilities are present.

| Economic | Central | Village | City |
|---|---|---|---|
| No agreement | - | 67 | - |
| Agreement | - | 67 | 80 |
| Central City | 40 | 30 | 62 |
| Central Vilage | - | 67 | - |

Table 3: Pay-offs of transboundary conflicts in Sete Cidades

| Comprehensive | Central | Village | City |
|---|---|---|---|
| No agreement | - | 67 | 20 |
| Agreement | - | 67 | 100 |
| Central City | 40 | 30 | 82 |
| Central Vilage | - | 67 | 20 |

Table 4: Pay-offs of transboundary conflicts in Sete Cidades

| Integrated | Central | Village | City |
|---|---|---|---|
| No agreement | - | 117 | 50 |
| Agreement | - | 117 | 250 |
| Central City | 40 | 100 | 200 |
| Central Vilage | 40 | 117 | 10 |

Table 4: Pay-offs of transboundary conflicts in Sete Cidades

Other purposes and regulations would lead to different results either in terms of efficiency or in terms of equity. For instance the result would have been quite dramatic for the village if we assume an economic purpose with a centralised management and water property rights belonging to the city.

**5) Conclusion**

Water is a natural resource that generates rent. Water is an economic good with enormous externalities. Because rents distribution and valuation of externalities are spatially rooted, geographical boundaries for integrated water management can be an essential tool.