Water reclamation and intersectoral water transfer between agriculture and cities – a FAO economic wastewater study

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ABSTRACT

Cost–benefit studies on replacing conventional agricultural water resources with reclaimed water in favour of cities are still rare. Some results of a study under auspices of the Food and Agriculture Organisation (FAO) are presented. By means of an illustrative example at Lobregat River basin in Spain, it could be proved that reclaimed water reuse and intersectoral water transfer can result in economic and environmental benefits at the watershed level. The agricultural community faces cost savings in water pumping and fertilising, increases in yields and incomes; the municipality benefits from additional water resources released by farmers. Farmers should be encouraged to participate by implementing adequate economic incentives. Charging farmers with the full cost of water reclamation may discourage farmers from joining water exchange projects. Particularly in regions with water scarcity, investments in reclaimed water reuse and water exchange arrangements usually pay back and are profitable in the long term.

Key words | cost–benefit analysis, intersectoral water transfer, irrigated agriculture, municipal water supply, wastewater reuse, water exchange, water reclamation

INTRODUCTION

In arid and semi-arid regions, treated wastewater (reclaimed water) reuse is an effective measure to tackle water scarcity problems. This applies particularly to countries where irrigated agriculture, usually the biggest water user, plays a major role in the economy. It is also of note that in most cases treated and untreated wastewater is still being discharged into rivers causing adverse environmental and even health impacts. Certainly, there are many regions where reclaimed water reuse is already practised for irrigation and other purposes. Irrigation with reclaimed water helps to grow more food and preserve water resources. It is quoted that at least 10% of the world’s population is thought to consume food produced by irrigation with wastewater (WHO-FAO-UNEP 2006). In southern countries of Europe, 2% of the total treated effluents are reused after reclamation, mainly for agricultural irrigation. In the Mediterranean Region, reuse is increasing at a rate of 25% per year (Jiménez & Asano 2008). In Spain, Lazarova & Bahri (2008) claim that 22% of the collected wastewater is reused in agriculture. With increasing water scarcity and growing populations, the importance of water reclamation and reuse will rise. In addition, our thesis is that scarcity problems in cities can be mitigated by intersectoral transfer of freshwater replaced by farmers who use treated wastewater with economic benefits both for farmers and the society.

Wastewater treatment and reuse projects require effective technical infrastructures and economically efficient and socially acceptable solutions: reuse projects must be financially feasible and affordable. An economic framework including assessment criteria is barely needed for the evaluation of economic and financial feasibility of wastewater reuse projects (Asano et al. 2007).

Numerous publications in the field of wastewater reuse technologies exist. Many applications worldwide are described in Jiménez & Asano (2008). One example can be found in Virginia, South Australia, where the effluents from...
the Bolivar wastewater treatment plant in Adelaide are transferred to the Virginia area, north of Adelaide, for irrigation of horticultural crops. The water reclamation plant incorporates dissolved air flotation and filtration processes. Apart from it, measures to increase the amount of reclaimed water available such as the development of an aquifer storage and recovery system have been investigated (Marks et al. 2002). In the US, agricultural irrigation is the biggest water reuse activity. In the State of California, 46% of the total volume of reclaimed water is used for this purpose (California State Water Resources Control Board 2002). For example, the city of Santa Rosa treats to a tertiary level the effluents of five different cities in the Sonoma County. More than half of the water produced is used to irrigate approximately 2,310 ha of farmlands. During the winter months when there is no demand for irrigation, the effluent is used to recharge an aquifer and produce electricity using the energy from geysers (California Energy Commission 2002; Asano et al. 2007).

Some economic analyses of wastewater reuse for different purposes, such as agricultural and landscape irrigation, industrial applications and potable reuse, can be found. They address both the costs and the benefits of water reclamation (Aquarec 2006a, b; Asano et al. 2007). Farmers who convert to reclaimed water can lower their expenses on irrigation if the cost of reclaimed water is cheaper than that of conventional sources. Additional economic benefits can occur thanks to the improved availability of reclaimed water, which may allow increases in yields and sales revenues; especially in water shortage periods, farmers can prevent losses.

Moreover, farmers can release conventional water for cities by replacing it with reclaimed water generated by those or other cities. Such a water exchange (or intersectoral water transfer) can result in manifold benefits for municipalities, such as cost savings in water extraction, water delivery, water resources development, drinking water treatment, and removal of nutrients in wastewater treatment (Seguí et al. 2008). Further benefits may include improvements in the economic development of urban areas due to increased water availability (e.g. industries, tourism). Beneficial impacts on nature on water bodies and aquatic habitats can result from reduced overexploitation of aquifers, rivers and lakes, from less wastewater discharges and from prevented seawater intrusion (Mujeriego et al. 2007). However, not all of those impacts can be simply evaluated in economic terms (Aquarec 2006b).

On the other hand, environmental and health risks can decrease the benefits if the prescribed legal requirements for reclaimed water quality and application are not met. Wastewater reuse for irrigation is practised worldwide, often without any treatment or with a combination of only partial treatment, sometimes without wearing personal protective equipment (shoes, gloves) or washing of produce to protect consumers of raw vegetables (WHO-FAO-UNEP 2006; Asano et al. 2007). The biggest irrigated area using untreated wastewater in the world is located in Mexico, D.F., where the majority of this water is reused for agricultural irrigation (Jiménez 2008a). In the area presently receiving wastewater, the Mezquital Valley (named also Tula Valley), a century ago agriculture could not be developed due to the lack of water. Currently, around 74,000 farmers irrigate 76,000 ha using mainly the wastewater from Mexico City. Wastewater with organic matter and nutrients for plants is greatly appreciated by the farmers. Due to its fertilising content, leasing prices of wastewater irrigated agricultural land increased by a factor of nearly three compared with rain-fed agricultural land, and it is further possible to grow two or three crops per year instead of just one. The disadvantage is the potential negative effects on health: a 16-fold increase in morbidity by helminths in children in comparison to unexposed nearby areas has been reported (Jiménez 2008b). Even though there exists a self-purifying capacity of water (flowing in pipelines, channels, and streams and through the soil, as well as when it is stored in impoundments), it is not enough to reach good quality for irrigation without hazards. Additional treatment plants are being planned to treat Mexico City wastewater, which will improve the sanitary conditions in the area and will increase the cost of water supply.

As cost–benefit studies on intersectoral water exchange are still rare, some of the results of a research project, funded by the Food and Agriculture Organisation (FAO), will be presented (Heinz et al. 2008). In this research project, eight case studies were carried out in Spain and Mexico. One of them, located at the Llobregat River Delta in Spain, will be used as an illustrative example.

**MATERIALS AND METHODS**

The Llobregat River Basin is situated in the North-East of Spain close to the city of Barcelona. During the last decades, the river Llobregat has been highly polluted by industrial and urban wastewaters and experiences periodic floods and droughts. Overexploitation, and furthermore the occurrence of natural salt formations and the corresponding mining exploitations in the upper basin, are causing an increase in the water salinity and consequently salinisation of the
aquifers. Since 1991, a comprehensive programme of wastewater treatment plants has been implemented along the Llobregat River Basin. A water reclamation programme has been planned and in part already implemented (Agència Catalana de l’Aigua 2007). In the considered area, there are two main wastewater treatment plants: the Sant Feliu de Llobregat plant and the Prat de Llobregat plant, both with tertiary treatment. Especially the latter plant – with a wastewater generation of around 120 Mm$^3$/yr one of the biggest treatment plants in Europe – is typically a multi-purpose project that aims also to recharge aquifers, improving the stream flow and quality of the river, irrigating wetlands and preventing seawater intrusion with the adequately treated effluents.

In the following, the first plant has been selected as an example to show the potential economic efficiency of the water reclamation and intersectoral water transfer. The effluent from this plant of 19 Mm$^3$/yr could be used for irrigation purposes in an agricultural area of more than 600 ha, with mainly herbaceous crops. The existing tertiary treatment consisted only of sand filter and disinfection, and only a few farmers use this water due to its high conductivity of 2.95 dS/m on average. Due to the high salinity of the effluent the farmers mix it with well water. The farmers prefer to use the aquifer and the Llobregat river water as the main resources. In drought periods, however, the farmers have to use it compulsorily to a greater extent. Normally, the permission to use water from the Llobregat river is 1.5 m$^3$/s. In water shortage periods, however, the use is reduced to 0.8 m$^3$/s. In order to make the tertiary effluents more acceptable for the farmers the conductivity must be reduced by upgrading the treatment plant.

Furthermore, the Catalanian Water Agency (ACA) initiated the construction of a seawater desalination plant with a capacity of 60 Mm$^3$/yr in order to augment the water availability for the municipality of Barcelona.

In order to assess the economic efficiency of the wastewater reuse the cost and benefits must be compared. The cost components include the capital cost, the operation and maintenance costs of the upgraded tertiary wastewater treatment and the cost of conveying the reclaimed water to the fields. The economic benefits for the farmers include not only the cost savings in water pumping (e.g. groundwater) and in fertilising (due to the nutrient content of reclaimed water) but also increases in yields. A surplus of the economic benefit above the cost can lead to additional income of farmers. However, the actual income increase depends on how much they have to pay for the reclaimed water. If the cost exceeds the benefit, the water reclamation project would not be economically efficient, unless there are further beneficial impacts. As mentioned already, they can result from the water exchange between cities and farmers, who replace freshwater with treated wastewater.

The economic efficiency of such a water exchange depends on the costs of extraction, storage and conveyance of freshwater to the cities and on the cost savings in municipal water services in the entire area of influence, such as reduced expenses in groundwater abstraction, in drinking water treatment due to reduced pollution of rivers and in water resource development.

Another methodological approach refers to the economic value of the increased municipal water supply. This approach does not differ substantially from the first one. The water value indicates both the cost of and the willingness to pay for obtaining additional water. If $FW$ is the freshwater released and $u$ the unitary (marginal) value of water, the economic benefit of water transfer $H$ to cities can be computed by

$$H = FW \times u$$  \hspace{1cm} (1)$$

The water value $u$ is naturally influenced by the costs of water infrastructures (mainly supply and sanitation). The value can change in the course of time. It may rise due to growing cost of intersectoral water transfer or it may decrease due to the water user’s reduced willingness to pay as a consequence of the increased urban water supply. In the long term, $u$ rises with increasing water scarcity if precipitation diminishes or water demand is growing. Scarcity costs may be interpreted as scarcity rents that emerge wherever the water availability does not satisfy water demands (Heinz et al. 2007); they reflect the costs needed to reduce the water shortage in the future.

**RESULTS AND DISCUSSION**

The investment cost of upgrading the tertiary treatment at the Sant Feliu de Llobregat plant to make the effluent better suitable for agricultural irrigation, plus the cost of a pipeline network, amounts to 1.112 M€. Pumping the effluent to the fields would cost 208,390 €/yr. As Table 1 shows, the total cost of water reclamation (column 5) exceeds the total added value for farmers (column 4). So, this wastewater reuse project would not be economically efficient in the mentioned circumstances. However, the question arises whether there are further benefits resulting from intersectoral water transfer. Even in such a case the farmers will reject converting to
The net benefit of water exchange is the sum of the value added in agriculture of 461,100 €/yr minus the total cost of water exchange of around 1,608,900 €/yr (column 1).

Table 1: Costs related to water reuse – an example in the Llobregat River Delta, Spain

<table>
<thead>
<tr>
<th>Cost savings in water pumping (1,000 €/yr)</th>
<th>Cost savings in fertilising (1,000 €/yr)</th>
<th>Increase in sales revenue (1,000 €/yr)</th>
<th>Added value in agriculture* (1,000 €/yr)</th>
<th>Cost of reclaimed water** (1,000 €/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.6</td>
<td>10.4</td>
<td>388.1</td>
<td>461.1</td>
<td>798.2</td>
</tr>
</tbody>
</table>

*The added value includes the cost savings in water pumping and fertilising and the increase in sales revenue.

**The total cost of reclaimed water of 798,216 €/yr includes the annual capital cost of 77,384 €/yr and 512,442 €/yr, the operation and maintenance cost of wastewater treatment, plus the cost of conveying the reclaimed water to the fields of 208,390 €/yr. The annual capital costs are computed by multiplying 1.122 M€, the investment costs of the new tertiary treatment plant and pipeline network, with the capital recovery factor of 0.06897 (average service time 35 years and rate of interest 6%).

reclaimed water if they would have to pay the full cost. In contrast, as Table 1 indicates, they would be better off if they were charged in part, such as with the conveyance cost only, resulting to an income increase of around 253,000 €/yr. The question remains whether this is a sufficient economic incentive to use reclaimed water instead of conventional resources.

Table 2 shows the results of the cost–benefit analysis for the same wastewater reuse project as described above, but modified by the consideration of intersectoral water transfer. At this example, the current domestic water price of 1.11 €/m³ in the research area is used as a lower estimate of the economic value of the released freshwater. To some extent this price contains infrastructure, scarcity and environmental costs. Water users in Catalonia are charged a special tax (around 26% of the domestic water price) in order to guarantee the long-term water supply of towns and to improve the quality of both surface and groundwater (Agència Catalana de l’Aigua 2007).

In contrast to the results shown in Table 1, wastewater reuse in agriculture becomes economically efficient as the benefits of the city are additionally regarded. The added value or economic net-benefit of water exchange between agriculture and municipality can be estimated to be more than 6.9 M€/yr (Table 2).

As mentioned, environmental costs and benefits and other impacts should be considered as well; however, they are difficult to monetarise. In literature, many approaches can be found to evaluate such so-called “intangible” impacts or “externalities” (Griffin 2006; Aquarec 2006a). In principle, the externalities can be evaluated by expressing the importance people give to the impacts concerned (such as the value of wetlands irrigated by wastewater). The usual approach is to explore the willingness of people or communities to bear the cost of obtaining the benefits or of preventing adverse impacts. If impacts cannot be monetarised easily or not at all (e.g. certain health risks) they should be taken into account by using physical impact measures.

The unitary cost of water exchange of around 0.22 €/m³ may be compared with the domestic water price of 1.11 €/m³ as a lower estimate of the water value. Obviously, there is a big gap between this cost and the willingness to pay for water. This difference indicates a lower estimate of the unitary benefit added for the citizens. Water exchange between farmers and the city would provide additional water for high-valued purposes at considerably lower cost. In terms of cost–benefit analysis, an expansion of the intersectoral water transfer could be worthwhile until a maximum net benefit might be achieved. However, constraints such as the limited availability of freshwater used by farmers and financial barriers must be taken into account.

Water prices should cover both the infrastructure and the scarcity costs as far as possible. In reality, this is not the usual case for political reasons (for instance, due to low income of poor families). There are many examples where even the infrastructure costs are not fully recovered by water prices.

Table 2: Net benefits of intersectoral water transfer – an example

<table>
<thead>
<tr>
<th>Cost of water exchange* (1,000 €/yr)</th>
<th>Value added in agriculture (1,000 €/yr)</th>
<th>Economic value of improved water availability for the city** (1,000 €/yr)</th>
<th>Net benefit of water exchange (1,000 €/yr)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,608.9</td>
<td>461.1</td>
<td>8,103</td>
<td>6,979.8</td>
</tr>
</tbody>
</table>

*The total cost of water exchange of 1,608,916 €/yr includes 792,821 €/yr, the total annual cost of the reclaimed water (Table 1) plus 810,700 €/yr, the extraction and conveyance cost of freshwater. No capital cost of the latter is considered as it is assumed that the existing infrastructure is sufficient to extract and distribute the released water to the city. The unitary cost of water exchange is around 0.22 €/m³, i.e. 1.6 M€/yr divided by approximately 7.3 Mm³/yr, the water volume exchanged.

**The freshwater release of approximately 7.3 Mm³/yr multiplied with the domestic water price of 1.11 €/m³ renders a lower estimate for the economic benefit of 8,103 M€/yr.

***The net benefit of water exchange is the sum of the value added in agriculture of 461,100 €/yr and the economic value of improved water availability for the city of 8,103,000 €/yr minus the total cost of water exchange of around 1,608,900 €/yr (column 1).
like in Catalonia, Spain (Agència Catalana de l’Aigua 2007). Ideally, water prices should cover also the environmental costs associated with the provision of municipal water services; however, they are often ignored. The European Water Framework Directive (WFD) commits the Member States to take into account the principle of cost recovery (WFD 2000). However, it should be taken into account that pricing is not the only financing instrument to achieve cost recovery. Apart from water tariffs, cost recovery can be ensured also by subsidies provided by governments or by transfers from international organisations. But in order to assess the economic efficiency of intersectoral water transfer projects, u should reflect the true value of water as far as possible.

Charging farmers with the full cost of water reclamation can discourage them from converting to irrigation with reclaimed water and participating in water exchange. Thus, cities involved in water reclamation programmes are often reluctant to charge farmers. On the other hand, farmers may contribute to the costs of water transfer if they expect significant income increases from reclaimed water application. Cost sharing may help poorer municipalities to finance the construction cost of wastewater treatment and reclamation plants. It is suggested, and sometimes practised, to charge the farmers with the current price of freshwater, so that its replacement with reclaimed water will pay, provided the price of the latter is lower. The revenue from water pricing could be used as a further financial resource for funding wastewater reuse projects (Abu-Madi et al. 2007).

To encourage farmers to join water exchange projects reclaimed water may be provided to farmers at a discount, for free or even by compensation (FAO 2007). When cities gain from water exchange they may refrain from charging farmers with the full cost of wastewater delivery. Ideally, the total economic net benefit resulting from intersectoral water transfer may be divided among the agricultural community and cities. To find an agreement, structured negotiations appear to be most appropriate. Water users such as industries, tourist companies and golf courses, who benefit from the release of freshwater, should also contribute to the costs of reclaimed water.

Public funds can be crucial in those cases where water reclamation and transfer projects would be economically feasible but not affordable for the municipalities. At the Llobregat River Delta, the water reclamation programme is financially supported from national and EU funds (Agència Catalana de l’Aigua 2007).

As several studies showed, the cost of wastewater reuse projects is often significantly lower than the cost of seawater desalination, in terms of energy implications and greenhouse gas emissions, and transmission of distant resources (Spulber and Sabbaghi 1998). For instance, at Llobregat Delta the average unitary cost of water exchange between agriculture and cities can be approximated to 0.34 €/m³, whereas, according to the literature, the unitary cost of seawater desalination ranges between 0.45 and more than 1.0 €/m³ depending on the technique applied (FAO 2006). However, if the volumes of freshwater that can be released are limited, sea and brackish water desalination will become inevitable to satisfy increasing water demands.

Authorities may require the use of reclaimed water as a condition for granting or renewal of freshwater abstraction rights (Asano et al. 2007). However, where it is needed to motivate farmers to join intersectoral water transfer, such policies will be probably counterproductive. There is a risk that farmers face losses in productivity and income, especially if the economic value added through reclaimed water use is relatively small.

Governmental interventions that aim to find agreements with farmers are advisable. The FAO suggested recently the establishment of transparent methods to negotiate allocation of water amongst competing uses (FAO 2007). The economic benefits to be expected from water exchanges must be demonstrated and the farmers should be involved from the very beginning of water reclamation programmes. Contracts can be based on temporary trade of water between rural and urban sectors without requiring the transfer of ownership of water abstraction rights or, alternatively, on purchasing permanent entitlements (Byrnes et al. 2008). If farmers request excessively high rewards for releasing freshwater, they must anticipate that no water trade would take place. Cities will undertake other measures, such as developing and conveying remote sources. If cities offer too small payments, farmers might not participate depending on the economic value added due to reclaimed water application in irrigation.

The range of freshwater price p to be paid to farmers may be specified by the following simple formula:

$$r x RW/FW - V/FW < p < u x FW + r x RW/FW - Q/FW$$

where

- r: reclaimed water rate,
- RW: reclaimed water volume per year,
- FW: freshwater volume per year,
- V: value added in agriculture (such as cost savings and increases in yields),
- u: unitary economic value of freshwater,
- Q: total cost of water exchange.
Then, it is to be considered that:

- The farmers face income increases if the revenue from water trade plus the cost savings and soared crop sales exceed the expenses from reclaimed water \( r \times RW \).
- The farmers’ revenue from selling freshwater entitlements to cities is \( p \times FW \).
- The price \( p \) should ensure that farmers obtain income increases.
- For cities, the price \( p \) for freshwater entitlements should ensure that the compensation payments \( p \times FW \) to farmers plus the total cost of water exchange \( Q \) do not exceed the sum of the economic benefit of the released freshwater \( u \times FW \) and the revenue \( r \times RW \) from charging farmers for providing reclaimed water.
- As long as the price \( p \) is within the range as indicated in Formula (2), wastewater reuse and intersectoral water transfer will be beneficial for both farmers and cities (win-win situation).
- As far as not covered by water pricing, the adverse and beneficial environmental and health impacts should be taken additionally into account.

**CONCLUSIONS**

As the illustrative example of Sant Feliu de Llobregat plant near Barcelona in Spain shows, water reclamation can lead to significant economic benefits in irrigated agriculture. Even though these benefits are lower than the cost of water reclamation, considerable economic benefits for the municipality can be expected from intersectoral water exchange. The reason for that is the high economic value of freshwater released for the urban water use in comparison with the total cost of the water exchange. However, because the water supply tariffs are often too low, there is a pervasive underestimation of the benefits if they are used to express the economic value of water.

Farmers face income increases due to the use of the nutrient content of reclaimed water, less water abstraction cost and additional sales revenues due to additional and more reliable water supply. Lowering groundwater tables, falling dry surface waters and impairment of ecosystems are usually the consequences of overexploitation and discharging effluents into the environment. Through application of treated wastewater in irrigated agriculture and augmenting the urban water supply by freshwater release such adverse impacts can be reduced. Cities can avoid expenditures for digging deeper wells, drinking water treatment and developing distant sources.

Cost recovery of municipal wastewater treatment and reclamation plants and distribution networks is often not guaranteed due to insufficient financial resources. Farmers who benefit from wastewater reuse can contribute to the costs. Charging farmers with the full cost of water reclamation may discourage them from joining water exchange projects. As the economic analysis of Sant Feliu de Llobregat case proves, the added values that can be obtained from such projects could allow even to compensate farmers, so that all parties will gain (win-win situation).

Particularly in developing countries with limited financial resources, the provision of funds from governments and debt financing may be needed to implement reuse and water exchange projects. Especially in regions with water scarcity, investments in such projects usually pay back and are profitable in the long term.

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