ELSEVIER

Desalination 187 (2006) 253–261

DESALINATION

www.elsevier.com/locate/desal

Feasibility studies for water reuse projects: an economical approach

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Received 3 January 2005; accepted 29 April 2005

Abstract

Usually the methodologies used to analyse the feasibility of water reuse projects are focused on the internal costs. The aim of this paper is to show a methodology to assess the feasibility of a water reuse project taking into account not just the internal impact, but also the external impact (environmental and social, for example) and the opportunity cost derived from the project. Internal benefit is obtained from the difference between internal income and internal costs. Internal income is obtained by multiplying the selling price of reclaimed water and the volume obtained. Internal costs are made up of the sum of investment costs, operating costs, financial costs and taxes. While some of these factors identified can be calculated directly in terms of money, biophysical and social aspects demand the definition of units of measurement. In order to homogenize results, an annual reference is proposed. A monetary value can be obtained from the calculation of each impact. However, there are a series of externalities for which no explicit market exists. In these cases economic valuation methods are used, based on hypothetical scenarios or patterns observed in related markets.

Keywords: Feasibility studies; Water reuse projects; Externalities; Internal impact

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Presented at the International Conference on Integrated Concepts on Water Recycling, Wollongong, NSW, Australia, 14–17 February 2005.

1. Introduction

Some methodologies have been used to analyse the feasibility of water reuse projects. In Table 1 some examples are given. Generally, the economic evaluation is based on a cost–benefit analysis, but is not very detailed. Only internal costs (investment, operating and maintenance costs) are taken into consideration. Many authors [5,20] defined economic analysis as a tool that enabled a water reuse project to be justified in monetary terms, providing total profits are greater than total costs. In this sense, it is important to take reclaimed water piping and distribution systems into account, as their cost are sufficiently high to question the economic feasibility of a project. In Pasqual [15] a general methodology to assess projects was proposed, which enables both internal and also social benefits to be determined for each case.

Following Seguí [19], some relevant subjects including feasibility studies from an economic point of view are presented.

1.1. Supply and demand of reclaimed water

The supply of reclaimed water is mainly determined by a plant's productive capacity. If there are no restrictions on wastewater generation (influent), the reclaimed water supply can be considered constant and guaranteed.

The demand for this water depends on the existence of potential customers, or in other words, those who need and accept the consumption of this type of water [1,20]. Demand potentiality depends on whether or not alternative water resources exist and, should this be the case, on their price. This leads to an analysis of water availability in terms of the quantity and quality the user requires in each geographical area.

1.2. The cost of reclaimed water reuse

Reuse costs include both the internal costs of producing and distributing the reclaimed water, as well as external costs of an environmental or social nature [11,16]. Only the first two are

Table 1
Methodologies for assessing the feasibility of water reuse projects, modified from Seguí [19]

Approach	Description	References	Main ideas
T. Asano et al.	Engineering perspective: applicable in developed countries	[1–5]	• Assess wastewater treatment needs • Ascertain the supply and demand of water • Study the market of reclaimed water • Carry out a technical and economic analysis of the alternatives • Design a plan of implementation, based on a financial plan
World Bank	Multi-discipline and inter-discipline perspective: applicable in developing countries	[9,10,13]	Necessary coordination among specialists, health experts, sociologists and economists
Standish-Lee	Asano approach is developed; lends more weight to social, legal and market aspects.	[20]	Places great emphasis on social and legal aspects
Seguí	Based on previous contributions	[19]	Global perspective including technical, social, economical, financial, environmental and legal aspects

regularly taken into consideration in water regeneration and reuse projects. The internal costs consist of:

- investment costs: land, civil works, machinery and equipment, facilities and connection works;
- financial costs, which result from financing the investment;
- operating and maintenance costs, divided into fixed and variable costs. The former are incurred regardless of the volume of water reclaimed, whereas the latter are directly related to output volume. Asano [2] presented the investment and operation costs of several water treatment systems in the US.

1.3. Price of reclaimed water

Some authors (see [6,14]) believe that the reclaimed water rates of many companies are based on a percentage of drinking water rates. While this strategy might help to encourage the usage of this type of water, there is general agreement that a water regeneration project should aspire to recover its overall costs, always including distribution systems. In other words, the price of the water offered should at least be based on costs. This price should also include the value of the water itself, its environmental effects and its own opportunity cost.

1.4. Financial analysis

Investment costs account for 45–75% of the total cost of a water reuse project [2]. Both obtaining financing as well as its cost in terms of interest are crucial for the project to be carried out. Although these projects have traditionally been state-financed, it is known that more and more privately funded initiatives are arising [7]. Furthermore, public sector participation can take many forms, ranging from investment subsidies to long-term loans or from interest rebates to risk guarantees.

A series of financial approaches has been described that can be applied to water reuse projects in different countries [18,19]. As far as public funding is concerned, three models can be distinguished: the first is the recipient returning part of the cost of the investment over its useful life, in other words, over a period of 25–50 years. The second, known as the "German Model", involves private financing that, once the project is executed, is paid for by the State. The third option, the so-called "shadow tolling", means that the private sector finances both the project's construction and running costs in exchange for a state concession over a specific period of time. With regard to the so-called mixed financing, it is worth mentioning the role played by state-run companies, which enable decision-making to be less centralised and also allow income to be earned by means of selling their services. In this case some resources are obtained which are not included in the calculation of the public deficit.

2. Proposal of a methodology for studying the feasibility of a water reuse project

The basic objective of all reuse projects is to maximise total benefits, which, in other words, is the difference between income and costs. This result shows whether or not the project is feasible. When calculating the total benefit, it is worth including internal benefit, benefits from externalities and opportunity cost [19]. Another way to write the function to be maximised is:

$$Max\, B_T = B_I + B_E - OC$$

where B_T = total benefit (total income−total costs), B_I = internal benefit (internal income−internal costs), B_E = external benefit (positive externalities−negative externalities) and OC = opportunity cost.

2.1. Internal benefit

The internal benefit is obtained from the difference between internal income and internal costs. Internal income is obtained by multiplying the selling price of reclaimed water and the volume obtained. Internal costs are made up of the sum of investment costs (physical infrastructure), operating costs (labour, energy, chemical products and fungible materials), financial costs and taxes.

It has been reported [17] that a cost estimation for this type of project should include projections of capital costs, annual operating and maintenance costs and life-cycle costs. (Life-cycle costs enable the economic feasibility of various alternative projects to be compared over a specific period of time.) This author calculates the overall cost of a project by taking into account the cost of construction, equipment and operating and maintenance costs. The usual unit costs for a series of materials used in calculating capital costs for an output capacity of between 4,000 and 40,000 m^3/d are presented in the Tables 2 and 3. Preparing the land and electricity costs are considered to represent 10% and 15% of total costs, respectively. Annual operating and maintenance costs include personnel costs (depending on the size and complexity of the facilities), consumption of energy and chemical products and maintenance costs, which are estimated as a percentage of equipment costs (e.g., maintaining pipes and storage tanks is estimated to be 2% of capital costs). It is important to underline the fact that maintenance costs represent the majority of costs in smaller plants, as an example of diseconomy of scale.

By calculating a project's potential costs and income, it is possible to appropriately assess its feasibility. Moreover, it must be remembered that these costs and income will vary over the useful life of the project. This methodology understands income as any benefit in well-being and cost as any loss of well-being or utility.

Table 2
Unit costs used in a reclamation system

Item	Unit cost, €
Grading, m^3	5
Structural excavations/ backfill, m^3	10
Structural concrete, m^3:	
Foundations	419
Walls	471
Slabs on grade	366
Elevated slabs	524
Grating, m^2	344
Handrail, m	131
Building cost, m^2	1292
Asphalt concrete paving, m^2	17
Piping (diameter, in.), m:	
8	92
10	105
12	118
18	157
24	210
30	262
36	315
42	367
48	420
Fencing, m	26

Source: Adapted from [8,17].

Mancini et al. [12] tried also to quantify the capital and operating costs of a water reuse project. The costs originated by the different treatments were divided into two groups: investment costs, including the land acquisition, civil works and electromechanical equipment; and operating costs, including staff, energy, sludge treatment and disposal, maintenance and chemical products (for example, chlorine or disinfectants, metal salts, polyelectrolytes).

In order to analyse the operating costs, the following criteria are described:

- Staff: The manpower requirement depends on the design of the plant, the complexity of the treatment or the automation level. The per-

Table 3
Pump station and storage tank costs used in a reclamation system

Delivery system component		Capital cost, €
Pump stations:		
4,000 m^3/d	H = 6–15 m	80,000
	H = 15–90 m	160,000
	H >90 m	320,000
20,000 m^3/d	H = 6–15 m	200,000
	H = 15–90 m	420,000
	H >90 m	880,000
40,000 m^3/d	H = 6–15 m	300,000
	H = 15–90 m	680,000
	H >90 m	1,400,000
Capacity of reclaimed water storage tanks, m^3		
2,000		600,000
3,800		760,000
7,500		1,000,000
15,000		1,600,000

Source: Adapted from [8,17].

sonnel costs associated with each plant size are calculated on the basis of necessary working hours assuming a labour cost of 20.66 €/h. Table 4 shows the results. A reduction of these costs per EI is observed when the plant size is increased.

- Energy: Habitually represents the most important part of operating costs. It is very variable depending of the type of the treatment plant, mainly in reference to sludge treatment. In Table 4 the energy costs appear in relation to the size of the plant assuming a cost of 0.07 €/kWh.
- Sludge disposal: This is a function of the quantity of sludge generated, which also depends of the costs of transport and disposal. In Table 4 the average quantities of sludge generated by plant size and their management costs assuming a unit cost of transport and disposal of 0.21 €/kg are shown.
- Maintenance: These costs are expressed as a percentage of the initial investment. Concretely, 0.5% of the initial investment is considered as maintenance of the civil works while 3% is assumed as maintenance of the electromechanical equipment. It is also considered that 80% of the equipment needs to be substituted every 10 years. These costs are reflected in Table 4.

Information on costs described previously [12] was used to develop a cost curve as a function of plant size. The investment costs that include land acquisition, civil works and electromechanical equipment have been amortized at a rate of 5%. Furthermore, it a life span of 30 years was assumed for the civil works and the substitution of the mechanical equipment every 10 years. As an example and, assuming a discharge of 300 L/d per EI, the cost curves for the different treatment alternatives are shown in Table 5.

Given the lack of a market for reclaimed water, it is difficult to obtain a price. In order to overcome this problem, the cost per m^3 should supposedly be equal to the minimum selling price. In this way, covering costs is guaranteed. Following Seguí [19], current net value (CNV) criteria are used to obtain this price. The minimum selling price is that which makes the CNV equal zero. After having established the quality objective for reclaimed water, the next step is to find the most suitable technology to achieve it. Clearly, when there are several technological alternatives, the one that offers the lowest cost per m^3 will be chosen. The following scheme shows the steps to be taken:

$$CNV = -I_0 + \sum_{n=1}^{n} \frac{NB_n}{(1+i)^n}$$

$$NB_n = (AVWR \times MSPWR) - (IC_n + OMC_n + T_n + FC_n)$$

Table 4
Staff, sludge disposal and maintenance costs

	Plant capacity (EI)							
	<1,000	5,000	10,000	30,000	50,000	100,000	150,000	>200,000
Staff (h/y)	800	2,500	4,000	10,000	13,000	24,000	30,000	34,000
Annual cost (€/y)	16,526	51,645	82,633	206,582	268,557	495,798	619,748	702,381
Annual unit cost (€/EI-y)	16.53	10.33	8.26	6.89	5.37	4.96	4.13	3.51
Sludge production (kg/EI-y)	40	40	60	60	35	35	35	30
Annual unit cost (€/E.I.-y)	8.26	8.26	12.39	12.39	7.23	7.23	7.23	6.20
Maintenance costs for civil works (€/EI-y)	0.67	0.51	0.39	0.23	0.24	0.20	0.17	0.17
Maintenance costs for electro-mechanic equipment (€/EI-y)	2.17	1.81	1.55	1.12	1.43	1.29	1.28	1.24
Total maintenance costs (€/EI-y)	2.84	2.32	1.94	1.35	1.67	1.49	1.45	1.41

Source: [12].

Table 5
Cost curve as function of treatment plant size

Treatment alternatives	X <30,000 EI	X = 30,000 EI
Primary treatment	$Y = 0.317–9 \times 10^{-6} \times X$	$Y = 0.132–5 \times 10^{-7} \times X$
Secondary treatment	$Y = 0.474–7 \times 10^{-6} \times X$	$Y = 0.309–4 \times 10^{-7} \times X$
Filtration	$Y = 0.507–7 \times 10^{-6} \times X$	$Y = 0.342–4 \times 10^{-7} \times X$
Nitrification/denitrification + filtration	$Y = 0.559–8 \times 10^{-6} \times X$	$Y = 0.369–5 \times 10^{-7} \times X$
Nitrification/denitrifation + P removal + filtration	$Y = 0.602–8 \times 10^{-6} \times X$	$Y = 0.393–5 \times 10^{-7} \times X$
Coagulation–flocculation	$Y = 0.939–2 \times 10^{-5} \times X$	$Y = 0.471–5 \times 10^{-7} \times X$
Carbon adsorption	$Y = 1.132–1 \times 10^{-5} \times X$	$Y = 0.730–5 \times 10^{-7} \times X$
Reverse osmosis	$Y = 1.503–2 \times 10^{-5} \times X$	$Y = 0.907–5 \times 10^{-7} \times X$

Y indicates the unit costs in €/m^3; X indicates the number of EI.
Source: [12].

where CNV = the current net value, I_0 = initial investment, NB = net benefit, i = discount rate, n = year, IC = investment cost, OMC = operating and maintenance costs, T = taxes, FC = financial costs, AVWR = annual volume of water reclaimed and MSPWR = minimum selling price of water reclaimed.

This methodology provides the cost per m^3 but is not enough to determine the feasibility of a project. In order to achieve this, the total benefit (B_T) must be calculated, according to the equation shown previously. Therefore, internal benefit is given by:

$$B_I = \sum_{n=0}^{n} \left[\left(AVWR_n \times SPRW_n \right) - \left(IC_n + OMC_n + T_n + FC_n \right) \right]$$

where SPRW = selling price of reclaimed water.

The tax variable refers to tax payments derived from tax benefits obtained for the activity. Providing an internal benefit is always positive; the project will always be economically and financially viable from an internal point of view.

Once water has been reclaimed, it can be used for a large number of activities such as irrigating farms and gardens, refilling water-bearing resources, industrial process, etc. The quality this water demands depends on its final use and its potential exposure to people. One problem associated with water reuse projects is the lack of planning, which often makes its real price much higher than that estimated when it was being designed. When the wastewater treatment and reuse system has been built and is running, the quality of the water to be reused must be monitored continuously in accordance with the parameters that the law establishes for each usage.

2.2. External impact

Project impact is considered as any consequence (positive or negative, intentional or random) that can be calculated and that is derived from the project. Limiting the scope of the research is fundamental to be able to analyse the impact of a project within that range. The identification and valuation of these impacts by group is shown in Table 6.

While any impact identified can be directly calculated in terms of monetary units, biophysical and social aspects demand the definition of units of measurement. In order to homogenise results, an annual reference is proposed. A monetary value can be obtained from the calculation of each impact. However, there are a series of external influences for which no explicit market exists. In these cases economic valuation methods are used, which are based on hypothetical scenarios or patterns observed in related markets.

According to the equation shown above, all projects need, apart from internal benefit, to calculate the value of positive and negative externalities derived from the water treatment and reuse project. External benefit can be given by:

$$B_E = \sum_{n=0}^{n} \left(PE_n - NE_n\right)$$

where B_E = external benefit, PE = positive externalities and NE = negative externalities. Externalities as a whole are made up of a positive and a negative impact derived from the project and are presented in Table 6.

2.3. Opportunity cost

The opportunity cost is defined as the value of goods in terms of a lost alternative use of those goods. Despite the fact that in the case of water treatment and reuse projects the land that the plant occupies is not normally of great value, it is still worth contemplating the possibility of an alternative use with certain profitability.

By substituting the previous equations in the general equation initially proposed, the following expression emerges:

$$\text{Max}B_T = \sum_{n=0}^{n} \left[\left(AVWR_n \times SPRW_n\right) - \left(IC_n + OMC_n + T_n + FC_n\right) + \left(PE_n - NE_n\right) - OC_n\right]$$

It is worth remembering that in this type of analysis, while having suitable methodology is important, so is the quantity and quality of the data used. The combination of both elements is what gives validity to the feasibility study.

2.4. Sensitivity analysis

To end the study, it was necessary to assess the feasibility of the project when faced with possible changes in a series of significant variables. The objective was to determine how sensitive the

Table 6
Identification and valuation of externalities

Groups	Externalities	
	Identification	Unit
Water infrastructure	Avoids constructing facilities to capture and store freshwater	€
	Avoids water purification costs	€
	Avoids constructing pipes and water distribution costs	€
Reuse of pollutants	Reuse of nitrogen in agriculture	kg of N
	Reuse of phosphorous in agriculture	kg of P
	Reuse of sludge in agriculture and gardening	kg
	Reuse of thermal energy	Watt
Uses of the resource	Increases the quantity of water available	m^3
	Guarantees supply in times when there is a shortage	% confidence
	Water quality adapted to different uses is obtained	kg waste
Public Health	Biological risks associated to wastewater reuse	People exposed
	Chemical risks associated to wastewater reuse	People exposed
Environment	Increase in the level of rivers	m^3
	Avoids overexploitation of water-bearing resources	Aquifer level, m
	Avoids water pollution	Waste eliminated, kg
	Allows wetland and river habitat to be recovered	Users
	Increase in pollution due to smell and noise	Number of people
	Decrease in the value of land nearby	€
Education	Raises social awareness of a new water culture	Number of people

Source: Adapted from [19] and own elaboration.

result of the project assessment is to changes in some of the parameters used in the analysis, such as the discount rate, financing conditions, energy costs or the price of reclaimed water itself. Once the changes of the total benefit were analysed for each of the scenarios proposed, the robustness, or true feasibility of the project under study can be evaluated.

Acknowledgements

This work was funded by the European Commission in the framework of the AQUAREC project on Integrated Concepts for Reuse of Upgraded Wastewater under contract number EVK1-CT-2002-00130 in the Fifth Framework Programme and the Spanish Government (REN2003-09675-CO4-04).

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