Chapter 4

Results and conclusions from case study analyses

This chapter illustrates how the economic methodology described in chapter 3 can be applied in the choice and appraisal of projects for the reuse of wastewater effluent in agriculture and other purposes. The case material used here is based on the actual situations in Spain and Mexico portrayed in chapter 2.

Although care has been taken in the choice and analysis of the data, the results presented here should not be regarded as a comprehensive and determinate feasibility study of the projects in question. The examples are intended to demonstrate a method of appraisal, the kind of data that needs to be collected, how they can be interpreted by policy makers, and how the projects can be made financially feasible. A full feasibility study would need to be part of the process of planning described more fully in chapter 5.

4.1 SPAIN: LLOBREGAT DELTA

4.1.1 Overall situation

The Llobregat River Delta covers c. 100 square kilometers of land situated in the North Eastern part of Spain adjacent to the major city of Barcelona. It is a valuable natural habitat, but also under relentless pressure from the city's urban and industrial growth. The river has become highly polluted and degraded, and the important groundwater aquifer, widely used by all sectors, is suffering seawater intrusion. The flow of the river is highly variable, and the main alternative source lies at some distance. In dry periods farmers compensate for reduced surface water with greater pumping of groundwater, and treated effluent is starting to be used on a small extent, mixed with groundwater. Effluent is also used for groundwater recharge and other environmental purposes.

Against this background, the regional water authority is considering bringing effluent reuse into its future water strategies. There is ample effluent available, treated to secondary and tertiary levels, and the existing WWTPs are being modified to reduce the salinity of the present effluent. There are plans to reuse the effluent in agriculture, for various environmental purposes, and in industry, which would exchange freshwater for metropolitan use and reduce the further depletion of the aquifer.

4.1.2 Specification of preferred options

Following preliminary screening, a preferred option has been selected for further appraisal at each of the two main WWTPs in the Delta, Sant Feliu de Llobregat (Sant Feliu) and El Prat de Llobregat (El Prat) (Box 4.1).

The reclaimed water from the Sant Feliu WWTP could be used on farms on the left side of the Llobregat River. The reclaimed water would be conveyed via the Infanta Canal to the farmlands and the freshwater released would be available to augment the Llobregat River and local aquifers.

For the El Prat WWTP, the concept is to pump effluent upstream to a regulatory pond from which water will flow into the Canal de la Dreta. Currently, freshwater with an average conductivity of 1.5 dS/m from the Llobregat River is conveyed via this channel to irrigate farm lands. The use of effluent in irrigation would require the desalination of the WWTP effluent by EDR and facilities to pump it to the Canal de la Dreta and a storage pond. The average salinity of the irrigation water would be reduced from 2.9 to 1.2 dS/m. The existing distribution network could be used to convey effluent to the fields.

BOX 4.1

Preferred options at Sant Feliu and El Prat WWTPs

Sant Feliu: project specification

Construction of a new tertiary treatment unit at the WWTP, involving increase in treated water volume & nutrient reduction;
Installation of a pipeline network to convey reclaimed water formunicipal, recreational and agricultural uses;
Extension of use of reclaimed water in farm irrigation via the Infanta Canal on the left side of the Llobregat River;
Release of freshwater by farmers currently extracted from Infanta Canal.

Expected project impacts

Replaces pumping of surface water (from Llobregat River);
Replaces pumping of groundwater by farmers (3 Mm^3/yr), saving pumping costs;
Increased water availability, quality and reliability;
Farmers cease rain-fed agriculture and irrigate the whole cultivated area (+ 14.5%) with increases in their net sales revenues;
Reduction of fertilizer use.

El Prat: project specification

Construction of EDR (electrodyalisis reversal) unit to reduce salinity of effluent at Sant Boi;
Pumping desalinated effluent to irrigation Canal de la Dreta;
Distributing the effluent to farmers;
Using the freshwater released by farmers for urban domestic water supply.

Expected project impacts

Surface and groundwater use for agriculture avoided;
Farmers save groundwater pumping costs;
Increase in water availability, quality & reliability;
Reduction of fertilizer use;
Avoided costs of groundwater extraction for domestic water use.

TABLE 4.1

Costs and benefits of projects

Euros (million)	**El Prat:** Irrigated area 801 ha Effluent vol. 13.0 Mm^3/yr	**Sant Feliu:** Irrigated area 275 ha Effluent vol. 7.3 Mm^3/yr
Capital cost of new treatment units:	(EDR unit) 14.00	(tertiary unit) 1.12
O&M cost of treatment p.a.	2.6	0.51
Cost of conveying effluent p.a.	0.12	0.20
Cost of conveying water released for urban use p.a.	1.43	0.81
Net new benefits to agriculture p.a.	0.35	0.46
Value of water exchanged for city use p.a.	14.43	8.12

Salinity is a crucial limiting factor for agricultural irrigation. Seawater intrusion into the aquifer limits its use by some farmers. However, farmers are more reluctant to use effluent from the El Prat WWTP because of its high salinity (average is 2 944 dS/cm), due partly to the presence of potash mines in the northern part of the watershed.

Cost-benefit analysis: results

The basic building blocks for the CBA are contained in Table 4.1 which indicates the capital and annual costs incurred by the proposed new facilities, and the aggregate benefits expected from the reuse of effluent and the redeployment of freshwater to the city.

For this exercise, no adjustment is made to the nominal market values of the cost and benefit items. For simplicity it is assumed that the whole capital cost is incurred at the end of year one, and that the recurrent costs and benefits arise, unchanged, in years 2-25 (extending the analysis beyond a 25 year period would make no substantial difference to the results).

For ***El Prat***, the steps are as follows (values in million Euros):

Net benefits (benefits less costs). Year 1: minus 14.00. Years 2-25: plus 10.63. Applying a 6% discount factor to this stream of net benefits gives a **Net Present Value** of 114.54. [1] The corresponding **Benefit-Cost Ratio** is obtained by comparing the Present Values of the benefit and cost streams separately, in this case 188.88 to 66.19, or 2.85 to 1.0.

For Sant Feliu the corresponding steps are:

Net benefits. Year 1 minus 1.12. Years 2-25 plus 7.06.

Net Present Value = 69.49

Benefit-Cost Ratio = 109.65 to 20.47, or 5.35 to 1.0.

If the values contained in Table 4.2 are plausible, both projects appear highly attractive in economic terms to the regional water authority. By far the largest benefit of both projects is the value of the extra freshwater made available for the city, whereas the net benefit to farmers, though positive, is much less. If a *sensitivity analysis* were to be done, it would show that the overall NPV would be highly sensitive to the size of urban water benefits that are assumed here. On the other hand, the *switching value* of urban water benefits (the % decline that would reduce the projects' NPV to zero) would also be very large, a sign of robustness in the projects.

Comments on the key variables follow.

- *O&M treatment cost.* 0.2 €/m³ for desalination by EDR. , 0.07 €/m³ for the tertiary treatment.
- *Costs of conveyance of effluent and fresh water.* Pumping costs of 0.11 €/m³. It is reasonable to assume that existing infrastructure would suffice to take the extra fresh water for the city. Water not used for the Canal is conveyed in the river down to the drinking water treatment plant, and the reclaimed water from the tertiary treatment unit crosses the river using a siphon to reach the Canal located nearby. Pumping costs would be very small.
- *Benefits to agriculture.* Assumes reliable supply of reclaimed water at Sant Feliu enables an increase in the irrigated area of 14.5%. The benefit is made up of increased sales revenue (in Euro million) 0.388, savings in the cost of groundwater pumping 0.06, and savings in fertilizer 0.01. At El Prat the benefits consist of savings in groundwater pumping costs 0.32 and savings in fertilizer 0.03. It is assumed there would be no produce restrictions due to the use of effluent. It is also assumed at this stage of the analysis that none of the costs of treatment or conveyance would fall on the farmers.
- *Value of water exchanged for city use.* This is valued at 1.11 €/m³, based on current tariffs in this region, which is a very conservative estimate of its full economic cost.
- *Choice of discount rate.* The rate used is 6%, as used by the regional consultants.

4.1.3 Implications of the CBA

The cost of water reclamation (extra treatment and conveyance) will not be offset by the value added in agriculture due to savings in fertilizer, groundwater pumping and the benefits from farming larger irrigated areas. This implies that neither of the preferred schemes makes economic sense as an agricultural cost-saving measure without considering the schemes in the broader regional context.

[1] The present value (PV) of 1.0 per annum over 25 years at 6% is 12.78. Multiplied by the actual annual net benefit this gives PV of 135.85. Since this only starts in year 2 a discount factor of 0.94 is applied to produce an NPV of 127.70 . Deducting the capital cost in year 1 (discounting by the first year rate at 6%) gives an NPV of 114.54.

However, taking a broader view of the projects in the context of growing urban demand for water, there are sizeable net benefits from releasing river water for urban use. Water shortages in the Barcelona region may have been factors in the relocation of several firms out of the area, and the drought of the last five years has severely constrained household and municipal use. In this perspective, the potential value of the extra freshwater for the city strongly justifies for the projects.

Apart from this, the infrastructure for conveying water from one place to another has been built, and it is relatively cheap to exchange the water since all the key sites are close together. Sufficient storage is also available since the river is well regulated for most of the time, except in a few occasions of heavy rains in the mountains.

Though both the projects appraised here appear economically attractive in drawing up a regional water strategy, they would need to be compared with other means of providing (including conserving) urban water to test whether the benefits they provide can be delivered *cost effectively*, in other words, more cheaply than the alternatives. This evidence is not available for the purpose of this report, hence no *Cost-effectiveness Analysis* is presented here.

FIGURE 4.1 a
Project infrastructure

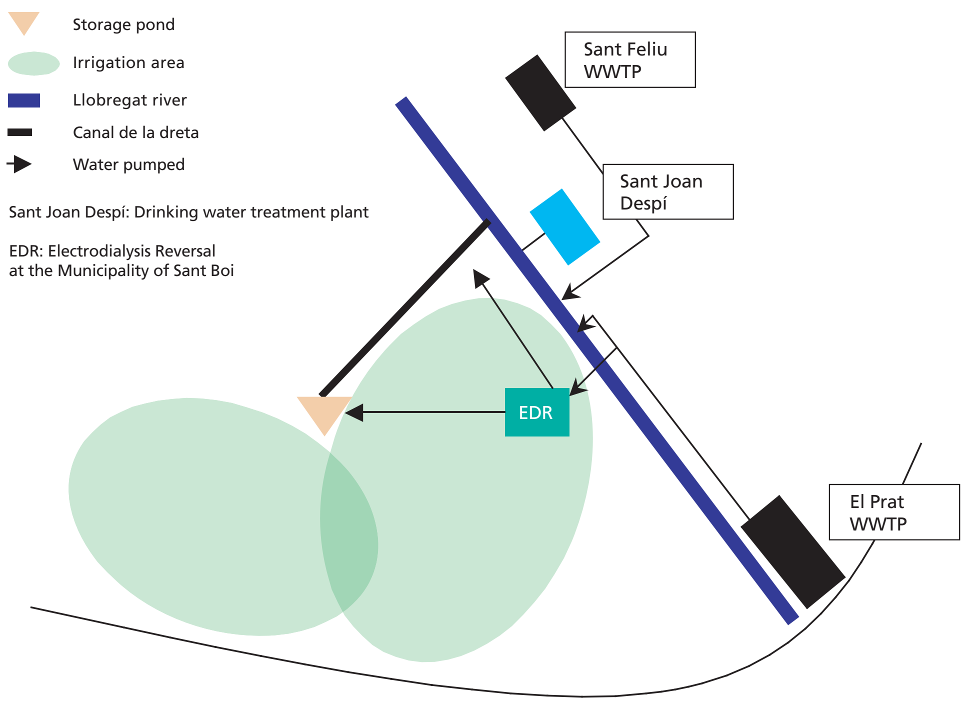
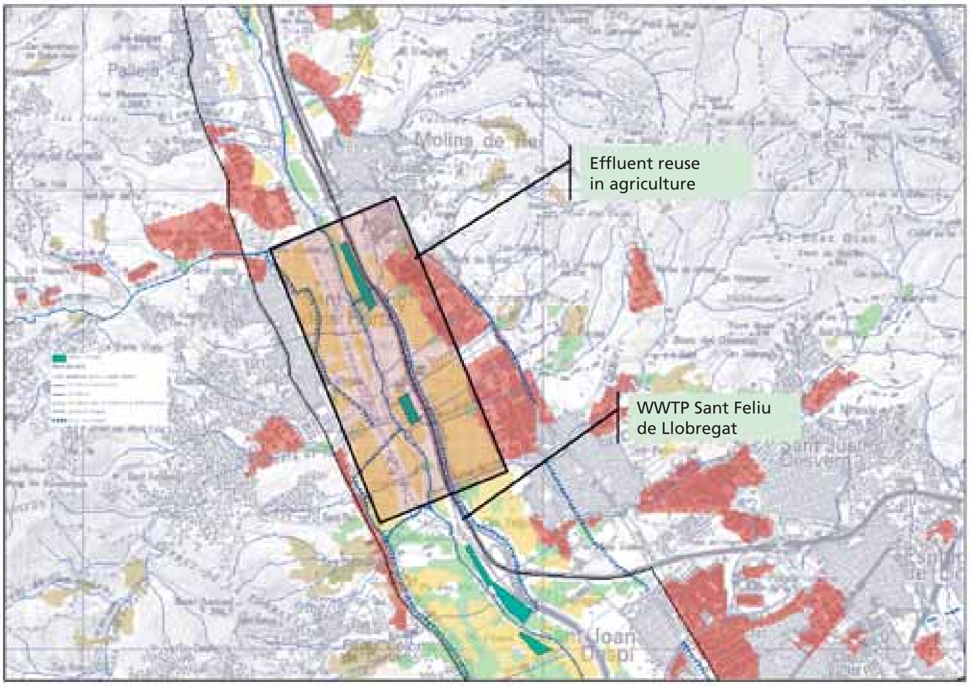


FIGURE 4.1 b
Map of WWTP and reclaimed water. Irrigated agriculture area



The crucial variable in the CBA is the amount of freshwater that would genuinely be released by farmers for exchange to the city. Farmers would need to be convinced of the value of the exchange for themselves – that the benefits from greater reliability of the water, the savings of groundwater pumping, and the nutrient in the effluent are sufficiently firm to offset the possible health hazard, impact on local amenity, and risk of produce restrictions. The analysis takes an *optimistic* view of this factor.

On the other hand, the analysis contains two sources of *underestimation* of the likely project benefits:

i. Underestimation of the value of urban water. This value is equated with the prevailing water tariff, which is less than its economic cost of supply. This is true even allowing for the fact that an environmental tax is incorporated in the water price, levied by the Catalonian Water Agency (ACA) in order to guarantee the long-term water supply of cities and to improve the present quality of both surface and groundwater. In practice, only 23% of the current cost of water and sanitation services is recovered from the tariff (Agència Catalania de l'Aigua 2007).

ii. The schemes have other benefits, not quantified in the analysis - improvement of river flow, wetland conservation, creation of a hydraulic barrier against seawater intrusion and potentially providing water for industrial use (see Table 2.4 in Chapter 2).

4.1.4 Financial feasibility

i) financial impact on key stakeholders

Farmers

In the Sant Feliu area, the project would have a relatively modest impact on farmers' costs through savings in pumping and fertilization, and the greater benefit would be the extra sales revenue expected from an expansion in the irrigated portion of land[2]. Farmers in the El Prat area would only enjoy the cost savings from pumping and fertilization. Up to the present farmers have resisted the use of reclaimed water due to its high salinity, compared with river water, but with the new desalination unit at the treatment works this factor would disappear.

Municipality

Given the tightly constrained demand for water at present, the City should be able to sell all the newly released amounts of freshwater at least at the prevailing water tariff. The city's water company is restricted in charging the full economic tariff, and may be unable to benefit fully from the extra sales revenue, or benefits to costs from economies of scale. Hence it is difficult to predict the final impact of the projects on municipal finances in this specific instance.

Nevertheless, the *potential* for fiscal gain is there. Revenues from the extra water sales would exceed the capital costs and incremental O&M cost of the exchange. If both WWTP projects and their associated works were implemented, on the evidence of Table 4.1 the city utility would make an *annual* financial gain of €16.88[3] million, in exchange for the initial capital outlays of €15.12 million. Any decision to raise tariffs in real terms would improve the project's financial appeal even more. In other circumstances, the city would also save Pollution Charges payable on wastewater released from the WWTPs, but in this instance the treated wastewater goes directly into the sea and no Pollution Charge arises.

A full dossier on this project would, of course, have to include a comparison of this scheme with the cost of other options for delivering the same volumes of fresh water, which is not available for this report.

ii) financial instruments and transfers

The analysis would support the view that most, if not all, of the cost of this project would have to be recovered from outside agriculture. On this evidence, there is little basis for charging farmers a cost-recovering level of tariffs for use of the effluent, which would have to be c. 0.40 €/m^3 for El Prat and 0.22 €/m^3 at Sant Feliu.[4] These are greatly in excess of anything considered realistic in Spanish agriculture at present. On the other hand, the levels of urban tariffs (1.1 €/m^3) are already considered to be well below the economic cost-recovering levels, and there may be scope to raise these, particularly in the context of demand management at times of scarcity. In the absence of compulsion or other kinds of administrative coercion, the voluntary participation of farmers in freshwater/effluent exchange may depend on subsidies, since the offer of free effluent may not be enough. Negotiations with farmers together with agricultural advisors may result in co-operative agreements with the commitments made by each of the parties laid down in contracts.

[2] The assumption in this analysis is that such an expansion in irrigated area would only be possible through the use of reclaimed water. Otherwise, these benefits could also be obtained in the without-project case.

[3] The sum of the annual value of fresh water exchanged for city use, minus the total of annual costs (excluding initial capital costs).

[4] Calculated as follows: El Prat: present value of cost stream over 25 years Euro 66.19, divided by annual volume of effluent 13 Mm^3 for 25 years discounted at 6% = 0.398 €/m^3. Sant Feliu: PV costs Eur 20.47 divided by volume of effluent over 25 years, discounted at 6% = 0.219 €/m^3.

The option of developing markets for the sale and purchase of water rights is a long term theoretical possibility which would substitute for a subsidy scheme. Farmers would then be able to sell their fresh water rights to the city, in exchange for cash and/or effluent. Such a scheme would depend on farmers having secure legal entitlement to a given amount of fresh water (from surface sources or aquifers), and the existence of a national legal framework for such exchanges.

iii) funding the project

In the Llobregat Delta, the investment cost of water development projects is financed in part from EU programmes and the Catalonian Water Agency. In 2009 the regional government of Catalunya announced a programme of wastewater reuse to be funded entirely by the public sector, though some projects would involve co-financing with municipalities or local water companies.[5] In the neighbouring region of Aragon the regional government has started implementing a major programme of wastewater treatment funded by a public-private partnership model.[6] In various other countries[7] effluent reuse projects have been funded under private Build-Operate-Transfer and similar types of concession. Such concessions require the creation of a project structure with a Special Project Vehicle whereby the concessionaire receives revenues from the public sponsor (off taker), since in many cases the recovery of costs directly from farmers is unlikely to be feasible.

4.2 TORDERA DELTA & COSTA BRAVA

4.2.1 Overall situation

The Delta of the River Tordera lies half in the Southern boundary of the Costa Brava (Girona Province coastline) and the other half in the North of Barcelona province, in North-Eastern Spain. It contains two WWTPs, at *Blanes* (Girona) and *Tordera* (Barcelona), both with tertiary treatment. Effluent from Blanes is used mainly for recharging the aquifer through river discharge and subsequent infiltration in a highly permeable river bed, though a few farmers also use it for irrigation. Reclaimed water from Tordera is currently being discharged into the Tordera River but, once its solar-powered pumps are operational, the effluent will also be used to recharge the aquifer. Farmers in the vicinity rely on groundwater since the Tordera River is completely dry during summer months when the water demand from crops is highest. However, several farmers are starting to use reclaimed water to supplement their normal sources.

In the Southern Costa Brava, the *Castell-Platja d'Aro WWTP*, started to supply effluent to farmers around its plant in 2003. Most of this effluent is treated to secondary levels, but around 20% is treated to tertiary levels and this is used for golf course watering and groundwater recharge, with the residue discharged into the sea. Plans are imminent for upgrading the tertiary treatment capacity of the WWTP, which would have a mixed impact on agriculture, reducing its nutrient content while broadening its applicability to other crops, and also making the effluent more usable by municipalities and golf courses. An important choice to be made is whether to produce effluent of a single quality, or of two qualities, aimed at different users.

This section outlines the analysis required for the economic justification for the projects at Blanes and Platja d'Aro. The former is brief, since data is lacking on certain key points, but the latter is more complete.

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5 *Global Water Intelligence (GWI)*, Aug 2009, p. 14.

6 OECD, *Strategic financial planning for water supply and sanitation,* 2009.

7 *GWI* "Reuse tracker" (a regular feature of the journal)

4.2.2. Project specification

At **Blanes** the proposal is to reuse the tertiary effluent from the WWTP (currently 3.15 Mm^3/yr, to be increased to 5.05 Mm^3/yr) for agriculture, which would replace all use of groundwater by farmers.

At **Platja d'Aro** the regional water authority ACA foresees an enlargement of the tertiary treatment capacity of the WWTP by 30% to a 20 000 m^3/day design capacity flow rate. Currently only 22% of the total treated water in the plant is reclaimed. The upgrade would respond to the potential demand from new users (*e.g.* the municipalities of Castell-Platja d'Aro and Santa Cristina d'Aro, farmers in Llagostera – a neighbouring municipality - and golf courses).

Following consideration of the option of differential effluent treatment standards for different users, it has been decided on grounds of cost to produce a single effluent quality. The project also includes new pumping stations, pipelines and water reservoirs. The total investment cost would be around 7.7 M€, 16% for the enlargement of tertiary treatment, 48% for the pipelines and 33% for storage facilities.

The extra reclaimed water would be allocated between uses as in Table 4.2.

4.2.3 Assessment of project impact

Blanes

Table 4.3 indicates the principal cost and benefit items that would constitute the CBA, with data filled where available. Certain key values that are not available for the purpose of this report are indicated.

The information provided in Table 4.3 does not permit an economic judgement on this proposal, but it does indicate where further data searches should concentrate. The cost of enlarging the existing tertiary wastewater capacity is unknown, though the cost of the distribution infrastructure seems substantial relative to the known benefits to farmers. It is assumed farmers will get no benefit from the fertilization properties of the effluent since most nutrients will have been removed. They will benefit from savings in the relatively heavy pumping costs (which are likely to grow in the future since pumping depths are large and increasing).

The two key potential benefits, which along with the incremental capital cost of treatment would largely determine the feasibility of the project, are unknown at present. The effluent would provide greater security of supply and economic benefit to farmers (for instance, enabling them to plant more valuable crops needing greater certainty of water[8]). The experience of the Mas Pijoan farm discussed below is relevant.

The other crucial benefit, the value of groundwater left in the aquifer, depends on regional policy – whether to keep the water in the ground, or to allow other users to exploit it. In the former case, the values would be environmental, in the latter case the value of the water to future users, whose identities are currently unknown.

TABLE 4.2
Proposed allocation of extra reclaimed water in Platja d'Aro area

	Requested reclaimed water Mm^3/yr
Agriculture (plots adjacent to WWTP, and farmers in Soilius & Llogostera)	1.263
Municipalities (Platja d'Aro & Santa Cristina d'Aro)	0.288
Golf and Pitch & Putt courses (6)	0.658
Improving water flow in Ridaura River for ecological purposes	1.0
Total	**3.209**

[8] though produce restrictions might apply to the use of effluent, compared with groundwater

Platja d'Aro

The enlarged tertiary treatment at the WWTP would reduce the nutrient content in the effluent by about 70%, which would diminish the potential savings in farmers' fertilizer costs. Thus, the main benefits to *agriculture* from the project would be the following:

i. The increase in crop production due to enhanced water availability. The use of reclaimed water will ensure less variable yields and sales revenues per ha as they are less reliant on uncertain water supplies.
ii. The avoided cost of groundwater pumping.
iii. A small reduction in fertilizer costs would still remain.

Benefits for *municipalities* would consist of the value of extra water available for domestic use. This would come from the release of 3.2 Mm^3/yr of groundwater currently extracted for agriculture. The benefits from use of the water for golf courses or other tourism purposes are not estimated, though are likely to be positive.

The project could benefit the *environment* through aquifer recharge: one possible estimate for this benefit is the savings in the cost of groundwater pumping because of the shallower aquifer level.

The balance sheet of costs and benefits is set out in Table 4.4.

TABLE 4.3
Blanes project: cost and benefit categories (€ M)

1	Capital cost of tertiary treatment	Not available [Incremental cost of raising tertiary output from 3.15 to 5.05 Mm^3/yr]
2	Capital cost of pipelines, pumps, etc. to convey effluent to fields	5.05
3	Annual O&M costs (mainly pumping) for conveyance of effluent to farms (0.02/m^3 x 5.05 Mm^3)	0.10
4	Savings in groundwater pumping costs (0.11 x 5.05 Mm^3)	0.55
5	Savings in fertilization	zero
6	Avoided losses in farm revenues due to water shortages in drought years	unquantified
7	Value of groundwater left in aquifer	unknown

Items 1 and 2 are initial one-off costs, other items are annual flows

TABLE 4.4
Costs and benefits of Platja d'Aro WWTP upgrade (Euro million)

1	Capital investment cost: total	7.70
	tertiary effluent treatment;	1.20
	pipelines;	3.68
	pumping;	0.25
	storage;	2.55
2	Incremental annual O&M costs of treatment (0.05 €/m^3), pumping, conveyance, etc (0.10 €/m^3)	Treatment: 0.16 Conveyance: 0.32 Total 0.48
3	Increased farm sales revenue (net):From future expansion from 41.6 to 291 ha	[0.874]
4	Savings in groundwater pumping	0.007
5	Savings in fertiliser cost	0.004
6	Value of groundwater released for urban and other potential use: 3.2 Mm^3 @ 1.1 €/m^3	[3.52]
7	Sales of effluent to municipalities 0.28 Mm^3 @ 1.1 €/m^3	0.30
8	Sales of effluent to golf & pitch & putt courses: 0.65 Mm^3 @ 1.1 €/m^3	0.71

The broad picture from Table 4.4 is that, for an investment of € 7.7 million and annual O&M costs of € 0.48 million, existing farmers will receive very modest savings in pumping and fertiliser costs (€ 0.011 million). Some of the effluent would be sold to municipalities and recreational establishments for €1.01/m^3. The costs and benefits mentioned so far are reasonably robust.

The reuse of effluent would relieve pressure on the groundwater aquifer of up to 3.2 Mm^3/yr if it is assumed that all the users stated in Table 4.2 would otherwise draw their water from the groundwater. This would create an environmental benefit, since the aquifer is diminishing and suffering from saline intrusion. If it is public policy to arrest the diminution of the aquifer, then this is purely an environmental benefit, which can be valued appropriately. If there is no such policy to stabilise the aquifer, the groundwater "saved" by the reuse of effluent would be available for other users. Since this benefit is uncertain, it is omitted from the Base Case CBA calculation below.

Another uncertain feature of the CBA arises from the possibility that part of the effluent from the upgraded WWTP would be available for a major expansion of agriculture in the Llagostera area, currently constrained by the availability of suitable water. This could be a major future benefit (which preliminary studies have estimated to be € 0.874 M/yr) but is somewhat speculative at present, and is also omitted from the Base Case CBA below.

Cost-benefit analysis - Base Case

As in the Llobregat case, no adjustment is made to the nominal values of the cost and benefit streams. It is assumed for simplicity that the whole capital cost is incurred at the end of year 1 and that the annual streams continue at a constant level for 25 years. The results are as follows (in Euro million):

i. Present Value of costs (1 + 2, discounted at 6%): 12.99
ii. Present Value of benefits (4, 5, 7, 8, at 6%): 12.26
iii. Net Present Value (ii minus i) minus 0.73
iv. Benefit-Cost Ratio (ii: i) 0.94 to 1.0

The result of this Base Case analysis is that there is a small negative NPV when only the "basic" benefits are reckoned. This may be considered a pessimistic rendering, for several reasons:

- The value of the groundwater "saved" is omitted due to its uncertainty. The main problem is a lack of the capacity of the aquifer to supply enough water. Several years ago, Platja d'Aro and other neighbouring municipalities started to be supplied by the El Pasteral dam.
- No account is taken of the potential value of the effluent to new irrigated land to be developed in Llagostera.
- The benefits for non-agricultural users (such as golf courses and other municipal purposes) are partly considered.
- There is no reckoning of the environmental benefits of reduced pollution of seawater, nor of the benefits from enhanced flow of the River Ridaura, which is practically dry for most of the year.

Clearly, either of the first two factors above would swing the NPV into a sizeable positive amount. Likewise, inclusion of a relatively small environmental value under the third category would make the project economically justifiable. The project is sensitive to the size of revenues from the sale of effluent, and highly sensitive to inclusion of the value of groundwater saved or released, and to its benefits for irrigation yet to be developed.

The preliminary analysis above indicates that further investigation could fruitfully focus on the potential use of the effluent by farmers in the Llagostera area, who hold the key to this project's feasibility.

Cost-effectiveness Analysis

If the project is only marginal at best, the *avoided cost* of the next best ("next worse") project is irrelevant since the project is not worth doing. However, if the omitted benefits above were reinstated, the project would become worthwhile. Then question arises, would there be more cost-effective ways of achieving its objectives?

While a comprehensive review of alternatives is not available, some estimation has been made of the cost of providing the water volume by desalination and, alternatively, the conveyance of water from the Ter River through a newly constructed pipeline. The reference costs for sea water desalination have been taken as 0.45-1.00 €/m^3. For comparison, the unit cost of the Platja d'Aro WWTP project based on Table 4.5 values is 0.33[9] €/m^3, which would give it a cost advantage, though the quality of effluent would differ in the two cases.

A simple estimation has also been made of the cost of bringing freshwater from the Ter River through the new pipeline. Based on capital costs of € 27 M and annual O&M of € 0.54 M the unit cost of this solution for a comparable volume (though of freshwater) would be 0.82 €/m^3 [10], more expensive than the Platja d'Aro WWTP but in the range of competitiveness with sea water desalination.

The significance of Mas Pijoan Farm

The account of the Mas Pijoan case in Chapter 2 is indicative of the gains that farmers can make from using reliable supplies of treated effluent, compared to pumping groundwater. The evolution of farm operations between 2003 and 2006, before and after use of the effluent, is shown in Table 4.5. In short, the farm was able to expand its irrigated area, reduce its reliance on groundwater and increase its crop yield by 40%. These results are being watched with interest by the farmers in the neighbouring area of Llagostera, where groundwater is extracted from depths ranging from 80-120 metres, even greater than in the Solius area used in the Base Case.

TABLE 4.5

Comparison between past and present situation at Mas Pijoan Farm

	Situation in 2003	Situation in 2006	Change compared to 2003 (%)
Total irrigated land (ha)	35	41.6	+18.9
Land irrigated with reclaimed water (ha)	0	25	-
Land irrigated with mixed water (ha)	0	7.6	-
Land irrigated with well water (ha)	35	9	-74.3
Well water used (m^3/yr)	175 000	71 240	-59.3
Reclaimed water used (m^3/yr)	0	136 760	-
Crop yield (kg/ha)	50 000	70 000	+40

[9] The NPV of the initial capital cost (€ 7.7M) and the annual operating costs (€ 0.48 M)of the new facility are discounted by 0.94 to obtain their PV at the beginning of year 2. This is divided by the volume of the extra water (3.2 M/yr) for 25 years beginning in year 2 discounted at 6%. (The present value (NPV) of 1.0 per annum over 25 years at 6% is 12.78. Since the flows of water and costs are assumed to only start in year 2 a discount factor of 0.94 is applied.)

[10] By the same process as that described in the above footnote

Financial feasibility

i) Financial impact on key stakeholders

In Blanes farmers would directly benefit from savings in pumping costs and from the greater reliability of effluent compared with existing sources. On the other hand, there may be produce restrictions. The immediate financial impact on the municipality is likely to be negative since there is no obvious possibility of "exchanging" the reused effluent for freshwater rights that can be sold elsewhere. The only current outlet for the effluent is agriculture which is unlikely to be able to pay for the whole capital cost of extra treatment, distribution and pumping. Any environmental benefits would need to be compensated by the regional or national authorities. In this case example, the aquifer has been declared "overexploited" which would allow the authorities to use some degree of compulsion. Although the formal trading of rights is illegal, some negotiation is possible.

The situation in the Platja d'Aro has similarities to that in Blanes but with two principal differences. Firstly, there are potential non-agricultural off-takers for the effluent in the shape of municipal and recreational users who can defray part of the cost through tariff revenues. Secondly, there is a promising agricultural demand for the effluent in Llagostera with the possibility of a contract with farmers developing new irrigable land. As in Blanes, the value of water left in the aquifer is difficult to determine without having regional authoritative policy on this issue.

ii). Financial instruments and transfers

In both areas, there are limited opportunities for exchanging reclaimed water for freshwater rights, hence most of the cost of the projects would have to be recovered either from farmers or from environmental custodians. The illustrative economic cost of the treated effluent in the Platja d'Aro scheme (0.31 €/m^3) is much higher than the cost of pumping groundwater (0.11 €/m^3) and the price of reclaimed water set by the *Consorci de Costa Brava* of 0.08 €/m^3. There is no present source of cross-subsidy from farmers – even in Platja d'Aro, where urban and recreational users could in principle afford the economic tariff. They only account for a minor part of consumption. The option of developing water markets is not much more promising since farmers have only rights over groundwater which is difficult to trade for both legal and cost reasons.

There remains a justification of subsidies to farmers on the grounds of environmental service providers, as compensation for maintaining the aquifer level, though the aquifer is no longer used as a source of water.

iii). Funding the projects

The initial investment costs of these projects could attract capital grants and soft loans from regional and central government and from EU schemes. In the Mas Pijoan scheme, 70% of the cost of connecting to the existing pipeline was provided by the European Agricultural Fund for Rural Development. It would also be reasonable to look to participating farmers for a contribution to the capital cost of distributing reclaimed water to their fields, where water from other sources is becoming scarce and unreliable. An agricultural water charge equivalent to the average cost of pumping groundwater (~ 0.11 €/m^3) would cover a minor part (in Platja d'Aro around one quarter) of the recurrent costs of supply.

Prospects of funding these projects from private concessions are not promising, except if the concessionaires are remunerated directly by municipalities through off-taker agreements for the effluent. Cost recovery from the users (mainly farmers) is unlikely, so long as they can pump groundwater at less than the tariff.

4.3. MEXICO

4.3.1.Mexico City & Tula Valley

Overall situation

Farmers in the Tula Valley irrigate their fields with free untreated wastewater from Mexico City, supplemented by other local water sources. The relationship between the City and Tula Valley is synergistic: the arrangement benefits both sides – providing the City with a downstream outlet for large volumes of untreated wastewater, and the farmers with ample nutrient-laden water to irrigate their crops. It would be possible to estimate the cumulative benefits to the City from the possibility of delaying its investment in advanced wastewater treatment until now, as well as the benefits to farmers of using wastewater in comparison with other possible water sources, of less fertility. Such an exercise would be interesting to countries and regions at an earlier stage of considering wastewater strategies, but in the present case it would be academic since decisions have been taken and alternatives for both parties seem few.

As a result of the City's on-going programme of investment in WWTPs, most of the wastewater will soon be treated to tertiary level. In theory this will widen the applicability of the reclaimed water for other crops, and further reduce any public health hazards, but will require farmers to apply fertilizer to offset the reduction in the nutrient content of the recycled water. Rough estimates done by the case study authors suggest that farm productivity could be 18% higher with the use of wastewater, compared with using freshwater.

The situation as described above is likely to continue: neither party has any strong reason to change it, nor the means to do so. There is little scope for an intersectoral exchange – of farmers' freshwater rights in return for continued supply of reclaimed water – such as was discussed above in the Spanish cases. A proposal has, for example, been made (Jimenez Cisneros, 2004a) for the City to take some of the aquifer water in the Tula Valley that has been recharged with the wastewater effluent and other sources. This would be part of an exchange for the continued supply of (treated) wastewater. However, there are physical and other obstacles to an exchange of water use rights between the farmers and the City – explained in chapter 2 that could limit exchanges of this nature, even if either party wished to do so – which is not obvious.

Cost-benefit and cost-effectiveness analysis only has traction where policymakers have choices, and these are severely limited in the Mexico City-Tula situation by the decision to implement the WWTP investment programme, by hydrological realities, by farmers' use rights, and the rights of users even further downstream.

4.3.2 Guanajuato City & La Purísima

Overall situation

This case has some similarities with the previous one. The farmers in La Purisima irrigation scheme draw water from a reservoir fed partly by fresh river water and partly from treated wastewater from the City's WWTP, which is upgrading its secondary treatment capacity. Their rights to water do not take account of the quality of the water concerned.

In this case farmers already use recycled water contained in the river feeding the reservoir, and upgrading the level of treatment would make little effective difference to the volume of water they received out of the reservoir. Farmers' main concern would be the impact on their operations of receiving a mixture of water with a much higher content of treated effluent from the new WWTP, which would reduce the previous benefits from fertilization. Farmers could, however, receive offsetting gains from the freedom to grow a wider range of crops. Rough estimates conducted by the case study authors suggest that farm productivity could be 10% higher compared with the (hypothetical) use of wholly freshwater.

As in the Tula Valley, there does not appear to be scope for an exchange of water use rights between farmers and the city, for reasons explained in chapter 2. Farmers would appear to be the passive recipients of any change in effluent quality decided by the city and – so long as they depend exclusively on the reservoir – they have no means of reducing their exposure to such changes.

4.3.3 Durango City & Guadalupe Victoria irrigation module

Overall situation

Consideration is being given to the scope for Durango city acquiring rights to the clear surface waters originally granted as a concession to irrigation farmers in the Guadalupe Victoria area adjacent to the city. This would be in exchange for providing reclaimed water to be used by the farmers.

Such an exchange of water use rights would have several benefits: the aquifer would cease to be overexploited; the municipality would get water of a good quality at a lower cost; energy would be saved in reduced pumping of the aquifer; and the irrigators would receive some biodegradable nutrient loads for their crops.

There is a precedent for the agricultural reuse of effluent. Between 2000 and 2006 the irrigators had an arrangement to use the city's treated wastewater to supplement their regular supply of reservoir water. This was mainly motivated by their need to secure supply in drought periods. In 2000 an inter-connector pipe was built from the aerated lagoons of the WWTP to the left margin main channel flowing from Guadalupe Victoria reservoir. Since 2006 effluent supplied under this arrangement has diminished, since the spillway crest of the reservoir has been raised, providing additional storage of 10 Mm^3 of water.

Project specification: the basis of a possible agreement

The situation has an arithmetical symmetry which makes an agreement between the city and the farmers appealing: the full Guadalupe Victoria irrigation module has a surface freshwater concession of 63 259 Mm^3/yr, while the city of Durango has a ground water assignment of 61 292 Mm^3/yr. The latter accounts for practically the whole of the aquifer's annual recharge. An arrangement for all municipal water to be supplied from the reservoir and all the reclaimed water would be used in irrigated agriculture would cover practically all the water required by both parties for the foreseeable future. This would avoid the current over-exploitation of the Guadiana Valley aquifer.

Such a long term agreement would require irrigators to formally cede their rights to surface water in exchange for treated urban wastewaters. More investment in infrastructure would also be required to make the outcome feasible. The second WWTP now being planned would increase the available volume of wastewater, and the existing inter-connecting pipeline would need to be enlarged and extended to serve the entire 9 399 ha command area of the Guadalupe Victoria irrigation module, and a regulation pond would also be required.

In the short term, a more limited arrangement might be envisaged, whereby farmers would relinquish their rights to 10 Mm^3/yr of surface streamflows stored at the Guadalupe Victoria reservoir, in return for receiving 10 Mm^3/yr of treated urban residual waters delivered to the Guadalupe Victoria irrigation module. The city would keep a small number of wells (10-15) for industrial use.

For illustrative purposes, a cost-benefit framework for the development of such an intersectoral agreement is sketched in (Table 4.6). In principle, the agreement could cover any level of water exchange, but for the purpose of exposition the full amount of the irrigation freshwater concession (63 Mm^3/yr) is taken as the Base Case.

Table 4.6 indicates that all the data necessary for a proper CBA are not yet available. The crucial items in any decision are likely to be:

- The value placed on keeping water in the aquifer and avoiding further groundwater depletion (this was estimated by the case study authors to be c. \$0.88/m^3). This is mainly an environmental benefit, which will affect local streams and wetlands, and therefore wildlife and amenity. But there would also be gains to users who continue to pump the aquifer (*e.g.* local industry), and the aquifer would also have monetary value as water storage as protection of future drought (insurance value).
- The city's savings in the cost of pumping groundwater from increasing depths. This has not been estimated, but is likely to be sizeable.

The assumption above is that the reuse agreement would enable the city to satisfy its municipal water need by replacing groundwater with surface water from the reservoir. This is, of course, a simplification of what is likely to happen, but insofar as it is valid, it indicates that the benefit of the agreement to the city would be as an *avoided cost* rather than creating any *new benefits*. The economic value of the water sold in the city would, *ex hypothesis,* be the same as before (though its financial value would probably be less, since the basis of charges has to be the actual cost of supply, which would be lower for surface water than groundwater). The *city* thus has to weigh the incremental cost of the project (enlarging the inter-connector, pumping effluent to farmers) against the benefits of savings in groundwater pumping and avoiding further aquifer depletion.

Farmers benefit from the nutrient value of the effluent, but may face produce restrictions due to their use of effluent rather than clear surface water.

Both parties, the city and farmers, would have to consider the *cost-effectiveness* of the arrangement compared with alternative ways of meeting their needs. Although the detailed alternatives are not available to this report, the options for the City might include further enlarging freshwater storage, transmitting water from more distant sources, and demand management including the reduction of losses in distribution. Alternatives for farmers to improve their own water security might be increasing water efficiency by changes to their irrigation techniques and the system for delivering water to their plots.

The *financial* impact on the city is likely to be positive, through savings in recurrent costs of obtaining water. For farmers the benefit seems more marginal, and – depending on their legal rights to the reservoir water – there may be a basis for compensation for the forfeit of such rights.

TABLE 4.6
A cost-benefit framework for an intersectoral agreement in Durango City
Values in millions of Mexican Pesos

1	Capital cost of wastewater treatment	It is assumed that the cost of the second WWTP is required anyway to conform with national environmental regulations, hence should not be attributed to the reuse project
2	Capital cost of the inter-connector pipeline from the WWTP(s) to the irrigation areas	Cost of original inter-connector (\$9.5M) is a sunk cost. Cost of enlarging this is ~ \$1M/km]
3	Net difference in annual O&M for conveying effluent from WWTPs to farmers, compared with farmers' original cost of conveying fresh water from reservoir to fields.	n.a.. [local convention is to assume this is 2% of capital cost of item 2 above. O&M cost of treatment should not be attributed to this project]
4	Farmers' avoided cost of fertilizer	17.17
5	Durango City: avoided cost of groundwater pumping	n.a.
6	Environmental benefits to aquifer	n.a. [Difficult to quantify, and dependent on public policies towards aquifer use]
7	Cost of produce restrictions: net loss of farm income	n.a.

n.a. = not available

4.4 ISSUES ARISING FROM THE USE OF THE ECONOMIC METHODOLOGY

The variety of case material presented from Spain and Mexico provides a good field testing for the approach presented in Chapter 3, and demonstrates that this is an appropriate framework of analysis for projects involving the reuse of effluent. In general, the framework presented, consisting of the three-fold approach – *Cost-Benefit Analysis*, *Cost-Effectiveness Analysis*, and finally *Financial Feasibility* – has proved its merits as a method of justifying the projects concerned.

The viewpoint adopted by the hypothetical CBA analyst in this report is that of the national or regional water or environmental authority. Such an agency takes an "IWRM" stance on water management, taking account of the interests of all relevant stakeholders. Although the two that are most prominent in this report are municipalities and farmers, there is an important third part at the table – the environment – which needs a champion and a custodian. Reflecting the needs of the environment, valuing its assets and services and ensuring that its financing needs are met, is a challenge to analysts in this area. The case studies confirm that effluent reuse is an area ripe for the application and refinement of the tools of environmental cost-benefit analysis.

The case material demonstrates that certain items of costs and benefits are more robust than others. On the cost side, the capital costs of treatment units, pumps and canals can be estimated with some confidence, and their operating costs (pumping, chemicals, labor, etc.) are also fairly evident. The technology of wastewater treatment (including desalination) is, however, evolving, and it is difficult to make firm assumptions about future unit costs. Turning to benefits, most of the case studies rely on the perceived benefits to farmers from the nutrient properties of effluent, savings in groundwater pumping, and the greater reliability of effluent compared with other sources in arid climates. While pumping costs are reasonably firm, the benefits of fertilization depend on local empirical evidence ("with and without project"), which is patchy and will need to be reinforced, for instance through agronomic trials. The benefits of reliability also need to be demonstrated more convincingly, possibly by closer study of farmers' response behavior (insurance, aversive actions, etc.).

From the viewpoint of urban water demand, the case studies reflect the widespread view that water supply tariffs are too low, hence there is a pervasive underestimation of the benefits created by developing new solutions to growing demand (*e.g.* Llobregat). However, some of the cases (*e.g.* Durango) illustrate the importance (stressed in chapter 3) of distinguishing genuinely new benefits, on the one hand, from the avoided costs of meeting existing demand in a different way.

In several cases the data were missing or incomplete, and a comprehensive CBA was not feasible. In these and all other cases, however, the use of sensitivity analysis (including *switching value* estimation) provides a good guide to the "value of information" approach – where scarce research time should be focused in cases where data is weak across the board. The following is a list of other items where information proved to be problematic:

- Market prices were typically used, without adjustment to reflect economic scarcity values or transfer payments;
- Calibration of the potential public health risk from using effluent, and information on the impact of produce restrictions;
- The downstream impact (on other users, the environment, etc.) of recycling water;
- The appropriate rate of discount for projects of this nature (justification of the rate employed, typically 6%);
- The difficulty in some cases of carrying out cost-effectiveness analysis because of the wide variety of alternative options available, and the need to place the project in the context of regional strategies (*e.g.* that of the regional Government of Catalunya);

- Environmental impacts, which are difficult to value at any time, crucially depend on government policies and regulations. The value of restoring groundwater levels is a recurring issue in the case studies, another is the impact of higher effluent quality on receptor water bodies. Where official regulations on these matters apply, a CEA approach is more appropriate for project decisions. None of the case studies appeared to involve protected species, which is a complicating issue in many water resource projects elsewhere. In several case studies, the result hinges on how environmental impacts are valued, which emphasize the importance of developing the methodologies and experience in this area[11].

4.5. POLICY IMPLICATIONS OF RESULTS OF CASE STUDIES

There are several ways of viewing the purpose of effluent reuse projects:

- *as a feasible and cost-effective means of meeting the growing demands of agriculture for water in regions of growing water scarcity and competition for its use.* This motive also applies in situations where demand is not necessarily rising, but where periodic water scarcity is a problem for farmers planning their annual crop patterns. The case studies contain evidence (*revealed preferences*) of farmers responding positively to the use of effluent in these situations, as a temporary expedient or long term solution. However, effluent reuse is one amongst a number of options at farm level to minimizing exposure to water risk. Moreover, the creation of expensive distribution and storage facilities, with a high recurrent cost, in order to furnish water for low value farm purposes, is not always warranted – unless there are benefits to other sectors (see below).
- *as an environmental solution to the growing volume of wastewater effluent and its potential for downstream pollution*. The Mexico City-Tula case is the clearest example of the mutual benefit for the City and farmers from disposing of urban sewage and effluent to agriculture – and allowing natural processes to carry out some of the purification *en route*. Reuse schemes allow the dispersion of effluent and its assimilation across a wide area, as compared to the *point source pollution* from WWTPs. The reuse of effluent nutrients in crop production, rather than their removal and effective destruction during advanced processes of wastewater treatment also has a strong appeal to many Greens. The case studies confirm these environmental benefits of using reclaimed water.
- *as a "win-win" project that is a solution to urban water demand, while also delivering the agricultural and environmental benefits stated above*. The Llobregat sites and Durango City are clear-cut examples of potential win-win propositions since in both cases it is physically and geographically feasible for farmers to exchange their current entitlements to freshwater for effluent, and for the cities to gain access to the freshwater rights that are thus "released". (Whether or not this actually happens depends on legal and other barriers being overcome, as well as successful negotiation over the financial arrangements between the parties to the deal. It must not be assumed that farmers will readily give up rights – as a general observation on the cases, the assent of farmers is presumed too readily, without further consideration of their operational situations. Most farmers prefer to have several water sources as insurance).

Much of this report, and all the case studies, are concerned with producing "win-win" outcomes of the third kind above. In two of the cases (Mexico City-Tula and Guanajuato) the scope for a win-win outcome is not fully apparent, since crucial

[11] Turner *et. al.* (2004), Hermans *et. al.*(2006)

elements of feasibility are either absent or yet to be determined. In other cases (Blanes, Platja d'Aro) the freshwater rights "released" by farmers are from groundwater – which could be a potential source of urban water, or may be better left in the aquifer for environmental reasons. The basis of a win-win exchange in such situations is tenuous.

Needless to say, a "win-win" outcome only happens when farmers really do relinquish their freshwater rights in favor of urban users. This currently only happens in a minority of cases (Box 4.2).

A CBA approach helps to set the parameters for agreements between the main stakeholders, which in this report are assumed to be farmers, cities and the natural environment. It helps to define the interests of the parties in moving towards, or resisting, agreements that change the *status quo.* Where the balance between costs and benefits for one party (*e.g.* farmers) is very fine, the existence of a large potential net benefit to another (*e.g.* city or environment) can provide "headroom" for agreement by indicating the economic or financial bounty available to lubricate a deal.

BOX 4.2

Global water Intellignece quote

"At the moment, reused water is mainly supplied to low-value applications such as agricultural irrigation, with pretty much no ceiling on demand. Around a third of all reused water is given away for free, and two-thirds is sold at an extremely low price, which means that although investment into facilities is relatively high, there is very little return. There is little more than environmental concern to motivate reuse projects, and reused water is failing to offer much-needed relief to the pressures of urban potable supply. "

Global Water Intelligence, October 2009, p. 6.

Chapter 5

A planning framework for wastewater reuse

The economic framework for wastewater reuse presented in chapters 3 and 4 should fit within a comprehensive planning framework. A sound and methodical planning approach will assist in identifying all the relevant factors necessary for the decision to proceed with a project. This final chapter presents such a planning framework, relating back to the key issues introduced in chapter 1 and fitting them into a comprehensive approach, which incorporates the economic and financial methodology expounded in this report.

The contents of this chapter are set out in Box 5.1

5.1 THE PROCESS OF PROJECT PLANNING

The typical stages of project planning are shown in Fig. 5.1. The process may be iterative. Reconnaissance level planning may occur initially for the analysis of project concepts based on limited data. If this preliminary analysis is favorable, the planning stages may be repeated with more detailed data gathering, definition of project alternatives, and analysis of each alternative.

The assumptions, data, and analyses should be documented in a *facilities planning report* to provide a basis for public review and for decision-makers to decide whether to proceed to implement the project. A suggested outline of such a report is shown in Table 5.1. This outline can also serve as a checklist of topics to evaluate during planning.

The interrelatedness of water supply, wastewater management and environmental protection lends greater importance to Integrated Water Resources Planning. Wastewater reclamation and reuse is a bridge

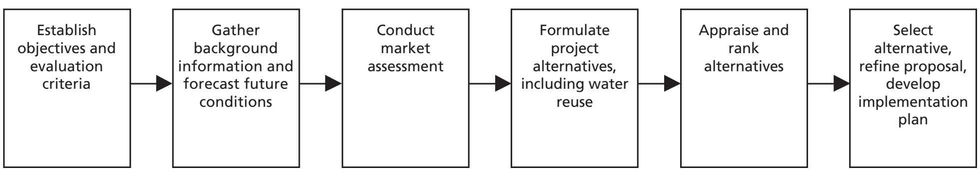
BOX 5.1

The planning framework

Project planning process	5.1
Identification of problem & project objectives	5.2
Definition of study area & background information	5.3
Market assessment & market assurances	5.4
Identification of project alternatives	5.5
Appraisal & ranking of project alternatives	5.6
Implementation	5.7
Specific technical issues:	5.8
Facilities & infrastructure	
Balancing supply and demand	
Wastewater quality	
Public health risks & safeguards	
On-farm issues	

FIGURE 5.1

Project planning process



Source: Adapted from Mills and Asano (1998) between water supply and wastewater management and is able to address a broader set of goals than is typical of single-purpose projects. Ideally, regional planning involving a broad spectrum of water supply and water quality goals would precede detailed planning for a wastewater reuse project. When such master planning has not taken place, it will be more important to address the larger water supply and wastewater management context in a facilities plan for water reuse.

The successful implementation of a project depends on its acceptance by the general public and the relevant body of public administration. Using reclaimed water as a water source raises concerns about public health, water availability, and costs. Farmers have concerns about their water rights, the availability and quality of reclaimed water, its effects on soils and crops, and its impact on farm operations and income. Water reuse often crosses jurisdictional boundaries of several agencies responsible for regulation, operation, and financing. Thus, participation of the public and stakeholders must be a part of the planning and decision-making (Asano et al., 2007; Wegner-Gwidt, 1998). Stakeholders that should be involved include:

TABLE 5.1
Outline of a wastewater reclamation and reuse facilities plan

1	Study area characteristics: geography, geology, climate, groundwater basins, surface waters, land use, and population growth
2	Water supply characteristics and facilities: agency jurisdictions, sources and qualities of supplies, description of major facilities and existing capacities, water use trends, future facilities needs, groundwater management and problems, present and future freshwater costs, subsidies, and customer prices
3	Wastewater characteristics and facilities: agency jurisdictions, description of major facilities, quantity and quality of treated effluent, seasonal and hourly flow and quality variations, future facilities needs, need for source control of constituents affecting reuse, and description of existing reuse (users, quantities, contractual and pricing agreements)
4	Treatment requirements for discharge and reuse and other restrictions: health- and water quality-related requirements, user-specific water quality requirements, and use-area controls
5	Reclaimed water market assessment: description of market analysis procedures, inventory of potential reclaimed water users and results of user survey
6	Project alternative analysis: planning and design assumptions; evaluation of the full array of alternatives to achieve twhe water supply, pollution control, or other project objectives; preliminary screening of alternatives based on feasibility criteria; selection of limited alternatives for more detailed review, including one or more reclamation alternatives and at least one base alternative that does not involve reclamation for comparison; for each alternative, presentation of capital and operation and maintenance costs, engineering feasibility, economic analyses, financial analyses, energy analysis, water quality effects, public and market acceptance, water rights effects, environmental and social effects; and comparison of alternatives and selection, including consideration of the following alternatives
	a. water reclamation alternatives: levels of treatment, treatment processes, pipeline route alternatives, alternative markets based on different levels of treatment and service areas, storage alternatives
	b. freshwater or other water supply alternatives to reclaimed water
	c. water pollution control alternatives to water reclamation
	d without- project alternative
7	Recommended plan: description of proposed facilities, preliminary design criteria, projected cost, list of potential users and commitments, quantity and variation of reclaimed water demand in relation to supply, reliability of supply and need for supplemental or backup water supply, implementation plan, and operational plan
8	Construction financing plan and revenue program: sources and timing of funds for design and construction; pricing policy of reclaimed water; cost allocation between water supply benefits and pollution control purpose; projection of future reclaimed water use, freshwater prices, reclamation project costs, unit costs, unit prices, total revenue, subsidies, sunk costs and indebtedness; and analysis of sensitivity to changed conditionsConstruction financing plan and revenue program: sources and timing of funds for design and construction; pricing policy of reclaimed water; cost allocation between water supply benefits and pollution control purpose; projection of future reclaimed water use, freshwater prices, reclamation project costs, unit costs, unit prices, total revenue, subsidies, sunk costs and indebtedness; and analysis of sensitivity to changed conditions

Source: Adapted from Mills and Asano (1998).

- End users of reclaimed water, such as farmers
- Water supply agencies
- Municipal wastewater treatment and management agencies
- Neighbours and passers-by
- Regional water and wastewater authorities
- Customers or consumers of agricultural goods
- Local associations
- Environmental organisations
- Water quality and public health regulatory authorities
- Economic development authorities
- Potential financial assistance organisations
- Agro-food industries
- Other people impacted directly or indirectly with reclaimed water use.

An important decision to be made at the start of planning is the time horizon appropriate for the planning period. There are four time horizons to consider in the planning and design of projects:

1. *Planning period* is the total period for which the need of the facility will be assessed and alternatives evaluated for their cost-effectiveness and long-term implementation.
2. *Design period* is the period over which a component of the facilities is expected to reach full capacity use.
3. *Useful life* is the estimated period during which a facility or component of a facility will be operated before replacement or abandonment.
4. *Financing period* is the period over which debts must be serviced and repaid, and the required return on the investment is achieved.

These four time periods should be kept distinct and applied appropriately in the various analyses of planning (Mills and Asano, 1998).

Many components of water supply and water reuse projects have useful lives of 50 years or more. Some major water developments, such as dams, may have capacities to meet water demands many years into the future. To document the full costs and future benefits of a project, it may be necessary to establish a long planning period, such as 50 years. However, it is difficult to predict economic conditions and future growth trends so far into the future.

Most water, wastewater and water reuse projects can be planned adequately with a time horizon of 20 years. The economic analysis can allow for facilities that have useful lives shorter or longer than 20 years (see chapter 3). In addition, because of the uncertainties in predicting the future, it is often not desirable to construct facilities with capacities to meet a demand period longer than 20 years. Phasing construction to meet future capacities in smaller increments is often the most cost-effective approach. A 20-year planning period can allow for a long-term framework or master plan to anticipate long-term trends and needs while at the same time analysing phased construction in the most cost-effective manner.

5.2 IDENTIFICATION OF PROBLEM & PROJECT OBJECTIVES

Planners should be clear what problems are to be addressed and which objectives are expected to be achieved. The reuse of water is not normally an objective in itself, rather it is a means to a broader and more fundamental social objective, such as:

- A reliable water supply
- Public health protection
- Environmental protection and restoration
- Regional or sectoral economic development
- Finally, for many developing countries, the use of treated or untreated wastewater in agriculture is crucial for ensuring the food supply (WHO-FAO, 2006).

Multi-objective planning in a context of integrated water resources planning (IWRM) can provide greater understanding of the relationships between water sources, demands, recycled water, and agricultural development needs. Through this understanding there is greater opportunity for formulating water reuse projects with a broader group of beneficiaries and thus gaining more public support.

Reliability may be a key issue, in the sense that supply is insufficient to meet existing demands or to prevent expected future shortages. This may be a particularly serious issue for agriculture, because of the shared use of water sources, the supply and demand of water in all sectors in a region should be considered. Agriculture may have adequate water supplies, but there may be opportunities to shift current freshwater use from one area to another within a region or from the agricultural sector to the urban sector by using reclaimed water. This exchange could create a more optimal use of all water resources in a region to meet current and future demands.

Water reuse may be a means of improving public health, at risk from poorly treated or improperly disposed of municipal or domestic wastewater. Reuse may drive an improvement in wastewater treatment, which would benefit the health of farmworkers and consumers of agricultural products currently grown with untreated or partially treated wastewater. However, the use of recycled water introduces a public health concern of its own that must be considered.

Discharging inadequately treated wastewater can cause environmental damage to aquatic resources. Conversely, water reuse may be a means of reducing wastewater discharges. Reclaimed water has also been used to restore wetlands or streams by replenishing flows that have disappeared due to development or to supply newly constructed wetlands to replace wetlands lost to urban and commercial developments.

For economically depressed areas, reclaimed water may provide a source of water to promote economic growth in a region or increase income of farmers. A sustainable water supply may allow farmers to be less vulnerable to weather conditions or to shift to more profitable crops.

The fundamental objectives described above should be considered primary objectives. It is also important to identify secondary objectives in establishing the criteria for evaluating project alternatives. Some examples of secondary objectives might be:

- Sustainability, such as, preventing soil sodicity;
- Public health protection, such as, preventing negative health impacts from use of reclaimed water;
- Crop productivity, such as, maintaining adequate irrigation water quality.

Care should be taken not to let secondary objectives divert attention from the ultimate goals of addressing fundamental social needs.

5.3 DEFINITION OF STUDY AREA AND BACKGROUND INFORMATION

An initial planning task is to establish the geographic scope of analysis. The study area should then be characterised for baseline (existing) and future conditions. This information becomes the factual framework upon which to formulate project alternatives, the sizing of facilities, and the project's costs and benefits.

The study area must be wide enough to include the water sources, demands and wastewater management needs that could be affected by a water reuse project. In some cases where water is imported from outside the region, the analysis will have to address the interrelationship between these sources and the region. The study area must also encompass all potential water reuse opportunities within a reasonable geographic area surrounding the wastewater sources. Where water resources are shared between areas or use sectors, the study area should include an analysis of water sources and needs for all shared areas to identify opportunities for shifting water sources from one area to another, or one sector to another, by using reclaimed water to replace fresh water.

For background information, the general characteristics of the study area should be provided, together with a description of water resources, wastewater management and related facilities. This is an exercise in data and information gathering to provide the basis for the remaining analyses. The types of information that generally must be documented are shown in Table 5.2.

TABLE 5.2
Study area characteristics and baseline information

Category	Information required
Demographics	Current and future population during planning period
	Current land use and future changes
Economic conditions	Major sources of employment
	Major sectors supporting community or regional economy
	Income levels in economic sectors
Climate & soils	Rainfall, seasonal variation
	Frequency and extent of droughts
	Temperature, seasonal variation
	Soil characteristics
Water sources	Surface water sources, existing and potential
	Groundwater sources, existing and potential, overdraft conditions
	Environmental damage from excessive surface water withdrawals
Water supply	Current and future water demands by sector and areas within region
	Currently developed water sources meeting current demands for each use sector
	Description of existing infrastructure of developed supplies, water conveyance, treatment, and distribution to consumers
	Capacities of existing facilities and estimated year that use will reach capacities
	Projection of future gaps between existing supplies or capacities and future demands
	Existing quality of various sources
Wastewater	Existing and projected quantities of wastewater generated and collected in urban areas
	Existing extent of sewered areas and future trends
	Description of existing wastewater collection, treatment, and disposal facilities
	Capacities of existing facilities and estimated year that actual use will reach capacities
	Existing or anticipated water pollution or public health problems associated with wastewater management or inadequate facilities
	Existing quality of wastewater, seasonal or daily variation
Institutions	Identification of relevant government and private sector institutions (water, wastewater, agricultural, financing)
	Public health and water quality regulatory authorities
	Roles and responsibilities of institutions
	Delineation of boundaries of agencies
Water reuse	Description and quantities of existing use of untreated or treated wastewater
	Potential quantity and quality of reclaimed water for future water reuse
	Reclaimed water market assessment (see Sec. 5.4)
Financing	Current sources of revenue in water and wastewater sectors
	Current and projected pricing of fresh water
	Potential sources of financial assistance for capital or operations costs
Regulatory constraints	Mandates to correct existing violations of public health or water quality laws and regulations due to water extraction or wastewater disposal
	Water quality and wastewater treatment requirements to reuse wastewater

5.4 MARKET ASSESSMENT & MARKET ASSURANCES

A particularly important criterion for assessing water reuse projects is the capability and willingness of water users to take reclaimed water in the quantities estimated, and the prices or costs that will be borne by the users. Early in the planning process a market assessment should be performed to determine the potential users of reclaimed water and the conditions that must be met to gain user acceptance. When a decision is made to proceed with implementation of a project, generally some form of market assurance will be needed to ensure users will participate in the project when it is constructed.

Market Assessment

After background information on the study area has been collected, a potential geographic area for the delivery of reclaimed water should be determined. Within this area, a comprehensive assessment of all potential types and areas of use for reclaimed water should be made. This is the *market assessment*. Even if the initial motivation of a study is to look for sources of water for the agricultural sector, the potential for use of reclaimed water in the urban and industrial sectors should not be ignored. Upon full analysis, the best and most economical use of reclaimed water may be in the urban sector, leaving more fresh water for the agricultural sector. Other options, such as desalination of seawater or interregional water transfer, should also be taken into consideration.

There are two aspects to the market assessment: 1) gathering of background data and information related to generic uses and sources of water and 2) gathering of data and information on specific potential customers or users of reclaimed water. The types of background information that is necessary are shown in Table 5.3 in a rough chronological order. Based on this information, individual users, including farmers or their representatives, can be interviewed to determine their existing sources, farming practices, water costs, needs, and expectations, as shown in Table 5.4.

Ultimately, a water reuse project will not be successful without the support of the actual and potential users of the reclaimed water. Farmers will compare the farming practices for using reclaimed water to current practices with respect to suitability for crops, yield, water costs, and the potential problems in marketability of crops due toperceptions of the public or agricultural produce distributors (WHO, 2006). The market assessment should identify all potential concerns of farmers so that they can be addressed at the planning stage. Because intermediate wholesale agricultural produce distributors may play a key role in whether crops grown with reclaimed water can be marketed, the market assessment should also include contacting the distributors to determine their concerns and attitudes.

Market Assurances

Water users are more reluctant to use reclaimed water than freshwater, for many reasons, some of which are shown in Table 5.5. Even potential users expressing a favourable attitude toward reclaimed water during a market assessment interview may reclaimed water when it becomes reality. It is often desirable to obtain some form of legally binding arrangement or contract to assure that farmers or others will actually take the reclaimed water once the project is completed. he success of such contracts depends on the economic incentives they contain for farmer (*e.g.* expected increase in income). Such a contract should include all relevant conditions, technical and financial, of the services to be provided in order to ensure transparency and full understanding of the terms of the agreement. Some governments or water purveyors have the legal authority to mandate the use of reclaimed water (Asano *et al.*, 2007)

TABLE 5.3
Steps in gathering background information for a reclaimed water market assessment

Step	Description
1	Create an inventory of potential users in the study area and locate them on a map. Group the users by types of use. Cooperation of retail water agencies can be very helpful in this task.
2	Determine public health-related requirements by consulting regulatory agencies. Such requirements will determine the levels of treatment for the various types of use and application requirements that will apply on the sites of use; *e.g.* backflow prevention devices to protect the potable water supply, irrigation methods that are acceptable, use-area controls to prevent ponding or runoff of reclaimed water, practices to protect workers or the public having contact with the water.
3	Determine water quality regulatory requirements to prevent nuisance or water quality problems, such as restrictions to protect groundwater quality.
4	Determine water quality needs of various types of use, such as industrial cooling or irrigation of various crops. Government farm advisors or agricultural experts familiar with local area may be helpful in this regard.
5	Identify the wholesale and retail water agencies serving the study area. Collect data from them on current and projected freshwater supply prices (rates) that would be applicable to the reclaimed water users. Also, collect data on the quality of freshwater being provided.
6	Identify the sources of the reclaimed water and estimate the probable quality of the reclaimed water after treatment to the level or levels under evaluation. Determine what types of use would be permitted at the various levels of treatment based on public health requirements and requirements suitable for various usages, such as industrial or agricultural uses.
7	Conduct a survey of the identified potential reclaimed water users to obtain detailed and more accurate data for evaluating each user's capability and willingness to use reclaimed water. The types of data that should be collected on each user are shown in Table 5.4. While most of these data must be obtained directly from the user, some of these data may be assessed from the background information obtained from other sources.
8	Inform potential users of applicable regulatory restrictions, probable quality of reclaimed water at various levels of treatment compared to freshwater sources, reliability of the reclaimed water supply, projected reclaimed water and freshwater rates. Determine on a preliminary basis the willingness of the potential user to accept reclaimed water.

Source: Adapted from Asano *et al.* (2007).

TABLE 5.4
Information required for a reclaimed water market survey of potential users

Item	Description
1	Specific potential uses, including types of crops irrigated, of reclaimed water
2	Location of user
3	Recent historical and future quantity needs (because of fluctuations in water demands, at least three years' of past use data should be collected)
4	Timing of needs (seasonal, daily, and hourly water demand variations)
5	Water quality needs
6	Methods of irrigation and related water pressure needs
7	Reliability needs - the availability and quality of reclaimed water, and susceptibility of user to interruptions in water supply or fluctuations in water quality
8	Needs of the user regarding the disposal of any residual reclaimed water after use
9	Identification of on-site treatment or plumbing retrofit facilities needed to accept reclaimed water
10	Internal capital investment and possible operation and maintenance costs for on-site facilities needed to accept reclaimed water
11	Monetary savings needed by users on reclaimed water to recover on-site costs or desired pay-back period and rate of return on on-site investments
12	Present source of water, present water retailer if the water is purchased, cost of present source of water
13	Date when user would be prepared to begin using reclaimed water
14	Future land use trends that could eliminate reclaimed water use, such as conversion of farm lands to urban development
15	For undeveloped future potential sites, the year in which water demand is expected to begin, current status and schedule of development
16	After informing user of potential project conditions, a preliminary indication of the willingness of user to accept reclaimed water

Source: Adapted from Mills and Asano (1998).

TABLE 5.5
Farmers' potential concerns about reclaimed water

•	Price of reclaimed water relative to freshwater costs
•	Inability to finance on-site conversion costs
•	Concerns over water quality and effects on crops and soil
•	Inability to prevent worker exposure to reclaimed water
•	Possibility of farm field worker objections
•	Lack of reliable reclaimed water supply
•	Water supply costs insignificant relative to inconvenience of reclaimed water
•	Liability to public health or third party claims
•	Restrictions on crop selection, marketability of crops, income
•	Problems selling crops to produce distributors or consumers

Source: Adapted from Mills and Asano (1998).

5.5. IDENTIFICATION OF PROJECT ALTERNATIVES

Based on the objectives of the project, the information available on existing infrastructure and the market assessment, a number of potential alternative water recycling and intersectoral water transfer projects usually become apparent. In the ideal situation, these reuse alternatives would be analysed simultaneously with other water supply and wastewater management options in an integrated water resources context. Even where this is not possible, water reuse must still be analysed in relation to other water supply and wastewater options that meet the same fundamental objectives (*e.g.* construction or upgrading of WWTPs, desalination of seawater, interbasin transfers).

To determine the net impact of a project, it is necessary to compare what the future would look like, respectively with, and without, the project (Asano et al., 2007; Gittinger, 1982; Mills and Asano, 1998). This would reveal the impacts, costs, and benefits of the alternative of doing nothing, or the *without project* alternative. The *without project* alternative depicts the situation that will arise from "business as usual" – the operation of existing infrastructure of water and wastewater facilities.

Since there are opportunities to shift water between areas or use sectors, it may be necessary to identify alternatives for serving individual areas or sectors, as a basis of comparison. While multi-regional or multi-sectoral comparison can greatly add to the complexity of analyses, it can identify multiple beneficiaries, thereby creating political and financial support for a water reuse project.

Examples of potential project alternatives that may be relevant to justification of a water reuse project are provided in Table 5.6. Note that even within a general project concept there may be alternative features to consider, such as alternative treatment technologies.

5.6 APPRAISAL AND RANKING OF PROJECT ALTERNATIVES

This report (chapter 1 and the current chapter) highlights a number of important criteria by which wastewater reuse projects should be judged. Although economic and financial criteria have been given a central place in the report (chapters 3 and 4) in a planning decision they take their place alongside other considerations. Box 5.2 illustrates what a list of criteria for project choice might include (Mills and Asano, 1998; WHO, 2006).

Not all of these criteria are of equal status. Depending on the local situation and public policy, some criteria will be paramount (*e.g.*. reduction of downstream effluent pollution, overcoming a growing scarcity of water for agriculture, minimising the cost of increasing freshwater supply to cities). Other criteria will be permissive (*e.g.* satisfactory public health safeguards, mitigation of environmental damage, legal feasibility). Certain criteria (*e.g.* existence of a satisfactory market demand for the effluent reuse) can be wrapped into others (such as the economic and financial feasibility, which would include sensitivity analysis of the impact of demand variations). Some criteria (economic, financial) can be monetised, some can be quantified in non-monetary terms, others are of a qualitative nature.

TABLE 5.6
Water reuse: examples of project alternatives

Functional category	Example of alternatives or variations
Freshwater supply (single purpose)	No project (existing infrastructure) Surface water storage (dams) Groundwater augmentation and storage (recharge, aquifer storage and recovery) Interbasin transfers Desalination (seawater or brackish water
Water demand management	Urban and agricultural water conservation
Wastewater management (single purpose)	No project (existing infrastructure) More WWTPs Alternative treatment technologies Stream discharge of treated wastewater Land application of treated wastewater with or without beneficial reuse
Water reuse (single or multiple purpose)	No project (existing infrastructure) Alternative uses of reclaimed water Alternative locations for use of reclaimed water Decentralised treatment locations to increase accessibility to more use locations (satellite treatment plants) Alternative treatment technologies Alternative levels of treatment (existing and new, primary, secondary, tertiary, advanced) Alternative routes for distribution pipelines or canals Inter-regional or intersectoral shifts in freshwater entitlements (water rights trading) One or multiple levels of treatment One or multiple wastewater treatment plants

BOX 5.2
Criteria for Project Choice

Economic justification
Financial feasibility
Public health impact
Public acceptability
Environmental impact
Technical feasibility
Market and demand
Legal and institutional feasibility
Etc.

One approach is to accept certain criteria as paramount, and to treat the planning exercise as maximising (or optimising) the primary criterion(a) subject to meeting the constraints imposed by other criteria. For example, the primary objective might be minimising the economic cost of obtaining extra freshwater for cities, subject to satisfactory safeguards for public health, environment, etc., and its feasibility on technical, legal and market demands.

Another approach is through *multi-criteria analysis* (MCA) which involves scaling, scoring and weighting of each criterion (Snell, 1997). This is a formal mathematical optimising method, which can be applied flexibly to accommodate the subjective or explicitly imposed weights of decision makers, regulators or politicians. This flexibility comes from maximizing first a single criterion subject to acceptable levels to the others and then varying the criterion and the weights. MCA may well prove to be a more acceptable and durable method of making planning decisions since it contains information about all the key considerations entailed in each situation, including non-monetary impacts.

MCA is likely to involve *trade-offs* – where a project performs well on one criterion, but poorly on another, compared to another project with the opposite scoring. The more criteria are included, the more difficult and complex this trading-off becomes. Aggregating the results of scoring on different criteria involves an implicit weighting ("all criteria are of equal importance") or priority setting based on arbitrary and subjective factors ("environmental issues are paramount"). However, the systematic variation in weights can produce a set of non-inferior solutions in which no objective can be improved without decreasing the others (the *Pareto optimal* result).

A simple process of multi-criteria analysis would involve the following elements:

For each of the project alternatives identified (section 5.5):

- i) list the criteria applicable to the project (Box 5.2);
- ii) for each criterion create a scale of judgement (*e.g.* good, satisfactory, poor, unacceptable or a scale of zero to 1) based on the factors appropriate for each (*e.g.* for the economic justification, the NPV or the BCA, for public health risks, acceptable or unacceptable according to the legally mandated standards in place);
- iii) score each of the project alternatives according to each of the criteria, *e.g.* tick for one of the boxes (good, poor, etc.). As a refinement, the projects could be scaled numerically from 0-5, 0-10, etc. where 0 = unacceptable, and 10 is excellent.
- iv) produce a score for each project, showing the ticks in each box, with the option of producing a single composite score from the scaling. The criteria may need to have different weights, following consultation with the main stakeholders.
- v) choose a preferred project based on the above scores. Alternatively, produce a short list by eliminating those with poorer ratings and apply an overriding criterion (*e.g.* economic BCR) to select the final preferred option.

5.7 PROJECT IMPLEMENTATION PLAN

The production of a project implementation plan should precede a final decision to proceed with a water reuse project. Many elements must be put in place for the project to succeed, not least the agreement by the many interested parties. Postponing the resolution of difficult issues until late in the design phase or even until after construction is completed can lead to false expectations and even project failure. All the key activities involved in implementation should be identified. A responsible entity should be identified and a performance schedule produced for each of the following activities:

- Facilities design
- Construction
- Wastewater treatment operation
- Reclaimed water conveyance and delivery to users (farmers or irrigation districts)
- Construction financing
- Revenue or tax collection for project operations and debt payment
- Technical assistance to farmers during project start-up and long-term problem resolution
- Analysis, monitoring and evaluation.

It is likely that more than one agency would need to be involved in all these activities, in which case contractual agreements will be needed between agencies to define their responsibilities and reimbursement for costs incurred. At the conclusion of planning there should be general agreement on the framework for responsibilities and willingness to participate in a project, even though contractual details may still have to be negotiated. Contracts or other legally binding arrangements usually will be needed with farmers, as discussed in Section 5.4. At the conclusion of planning there should be some form of written affirmation by farmers or their representatives and municipalities of willingness to enter into contracts at an early date. In the contracts, the commitments for each of the parties involved are to be specified (*e.g.* volumes and quality of treated wastewater and released freshwater, use of water-saving irrigation technologies, charges on water users, compensation payments, period of validity, etc.).

5.8 TECHNICAL ISSUES

Municipal wastewater consists of domestic, commercial, or industrial waste discharged into a sewage collection system. To this may be added stormwater run-off, unless this is collected separately. This run-off can be highly polluted. The wastewater passes through the following facilities on its way to being transformed into reclaimed water (effluent) and delivered to use sites:

- Sewer collection system
- Wastewater treatment plant (note that a reclaimed water unit could be outside the WWTP and managed separately)
- Reclaimed water distribution system
- On-site facilities at reuse sites.

Figure 5.2 contains a flow chart of the path of wastewater from source to point of use. Various costs are associated with each segment of wastewater management and reuse, as shown in Table 5.7. Reclaimed water may incur special costs that would not be required for freshwater use, for example, worker and public protection, and environmental protection, extra water for leaching soils, or protection of potable water systems, especially in urban areas. Some facilities are necessary for wastewater discharge, regardless of whether wastewater is reused. For the purpose of economic and financial analyses the differential, or incremental, costs of wastewater reuse, compared with "normal" wastewater treatment and disposal, should be identified and estimated.

FIGURE 5.2
Pathway of wastewater from source to points of use or discharge

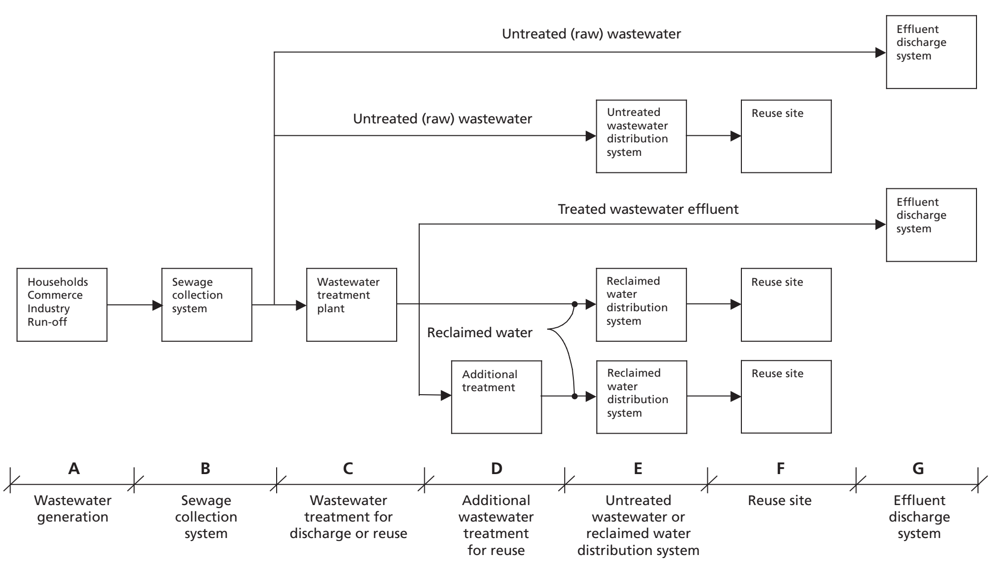


TABLE 5.7
Major cost elements of wastewater reuse systems

System segment		Major cost elements	
		Physical facilities and associated costs	Other costs
A	Wastewater generation	Pre-treatment (especially by industry) to prevent constituents toxic to humans or crops being discharged into sewers	Source control regulatory system
B	Sewage collection system	Construction, operation and maintenance costs for pipes, pump stations	
C	Wastewater treatment for discharge or reuse	Construction, operation and maintenance costs for treatment facilities	Regulatory system to set treatment or effluent quality standards and to monitor treated water quality, worker protection
D	Additional wastewater treatment for reuse	Construction, operation and maintenance costs for treatment facilities	Regulatory system to set treatment or effluent quality standards and to monitor treated water quality, worker protection
E	Untreated wastewater or reclaimed water distribution system	Construction, operation and maintenance costs for pipes, canals, water storage	
F	Reuse site	Construction, operation and maintenance costs for pipes, canals, meters or water measurement devices, valves, irrigation equipment; re-plumbing of existing sites to separate potable from nonpotable pipes	Additional water purchase to leach salts from soil, worker protection, negative effects on farm production and income, education of local residents, groundwater monitoring, regulatory surveillance
G	Effluent discharge system	Construction, operation and maintenance costs of pipes	Regulatory surveillance

At various points in the water cycle shown in Figure 5.2 the water/wastewater is stored and mixed with water from other sources. The characteristics of water and wastewater can change significantly when held for any period, especially when mixed, hence the importance of controls at the point of end use.

Certain of the specific cost items arising in a water reclamation and reuse system include:

- Supplemental fresh water to maintain supply reliability in the reclaimed water distribution system.
- Backflow prevention devices on potable water lines entering use sites to prevent potable water contaminated on the use site from flowing back into the community drinking water supply.

Some of the other technical issues requiring attention are discussed below (see also Asano, 1998; Asano et al., 2007; Lazarova and Bahri, 2005a; Pescod, 1992; WHO, 2006).

Balance of supply and demand

The reliability of reclaimed and recycled water is dependent on the abstraction and storage of the original freshwater that it is derived from. In certain circumstances, this may make it more reliable than farmers' alternative water sources. In any case, irrigation needs have different seasonal peaks and troughs than household demand. Raw wastewater has its own variable flow characteristics:

i) The quantity of wastewater in most communities varies widely, peaking in daytime and reaching a low during the night.
ii) Rainwater can leak into sewer systems, resulting in higher wastewater flows during storms or during rainfall seasons.
iii) Wastewater flows may have seasonal or other variations due to tourism, seasonal industries, or other conditions.

On the demand side, each water user has its own characteristics. Urban landscaping has its own regular needs, which are different from those of agricultural irrigation. Irrigation serves the transpiration needs of the crops, leaching to maintain soil quality, and in some cases a warming or cooling function for crops in extreme climates. The water demand from agriculture could change as it converts to reclaimed water, possibly resulting in increased water demand to increase crop yields, grow different crops or support more plantings during the growing season. Since reclaimed water may contain elements not present in freshwater, it may be necessary to increase applied water to leach out excess salts from the soil. Commercial and industrial customers can also vary their demand by time of day, days of the week, or season.

There is little or no control on the raw wastewater flows discharging from the sewer system. Whether treated or untreated, the wastewater must either be used directly, applied to land, discharged into a stream or other surface water, or stored until it can be used or safely discharged. Storage is usually required in reclaimed water distribution systems. Long-term or seasonal storage is often used where agricultural use takes place or where the discharge of wastewater is prohibited due to protection measures for surface waters. Short-term storage is most often used in urban settings where seasonal storage is not practical or there is insufficient demand to justify carrying wet weather flows into dry seasons for use.

Short-term storage can match reclaimed water to hourly water demands. For example, urban landscape irrigation is often done at night, when wastewater flows are at their lowest, to avoid human contact with reclaimed water in parks or school yards. Equilibrium storage is often incorporated into wastewater treatment plants to even out hourly flows, allowing downstream treatment processes to operate more efficiently at uniform flow rates. Design considerations and sizing techniques are addressed in several references (Asano et al., 2007; Mills and Asano, 1998).

Water quality

Regardless of its source, the quality of water is a critical concern to agriculture (Ayers and Westcot, 1985). The common uses of potable water in households and commercial and industrial premises contribute salinity and chemicals that are not removed in normal wastewater treatment. Reclaimed water may have higher concentration of some chemicals and additional constituents than are usually found in fresh water, but these can be removed before use (*e.g.* the RO desalination unit in the Llobregat cases in Chapter 2).

Water quality in relation to public health is addressed below and in chapter 1 (see also Asano et al., 2007; Lazarova and Bahri, 2005a; Pescod, 1992; Pettygrove and Aano, 1985). In the agricultural context, elements present in reclaimed water can have beneficial or negative effects. The main categories of water quality constituents and their effects are shown in Table 5.8.

Some of these negative impacts can be mitigated. Certain constituents can be reduced through source control, by preventing chemicals being discharged into sewers. Water softeners used in households replenished by sodium salts contribute to both salinity and sodicity and have been banned in some communities. Industrial sources of boron or other chemicals can be restricted. Another option is restriction on the delivery of reclaimed water during sensitive phases of plant growth, e.g. using good quality water in the initial growing period and worse quality water later on. This practice can even increase the quality of several fruits (Oron, 1987; Hamdy, 2004). The cropping pattern can be changed to favor more tolerant species or varieties. All these effects and mitigation measures have potential impacts on the overall costs and benefits and farm income resulting from use of reclaimed water.

TABLE 5.8
Reclaimed water quality and effects on agricultural use

Category	Example of constituents	Potential effects
Nutrients and trace elements	Nitrogen Phosphorus Potassium Calcium Magnesium Sulfate	**Positive:** Essential for plant growth Reduced need for fertilisers **Negative:** Phytotoxic in excessive concentrations Excessive foliar growth, delayed maturation, poor quality crop (due to excessive nitrogen during flowering/fruiting phase) Toxic to livestock in high concentrations in animal feed Biofilms in pipelines Algal growth in open storage or canals
Suspended solids	Particulates Algae in wastewater or subsequent growth in storage caused by reclaimed water nutrients	Clogging of irrigation infrastructures, particularly in sprinkler and drip irrigation emitters
Salinity	Total dissolved solids (Electrical conductivity)	Plant stress and growth reduction directly from irrigation water or salt accumulation in soil from irrigation water
Sodicity	Sodium (Sodium adsorption ratio)	Soil impermeability
Specific ion toxic elements	Sodium Chloride Boron	Phytotoxicity (leaf damage, dieback, reduced productivity)

Public health (see also chapter 1)

The main sources of pathogens in wastewater are households, hospitals and office buildings. Commercial and industrial uses of potable water can add harmful chemicals to wastewater. The degree of pathogen and chemical removal by wastewater treatment depends on the levels of treatment and technologies used. The risk to health depends on the infectivity of the pathogens, their concentrations in reclaimed water, and the extent of human contact. Acceptable levels of risk can be achieved through levels of wastewater treatment appropriate to the types of uses and the associated human contact as well as practicing multi-barrier risk management strategies in Good Agriculture Practices.

Table 5.9 gives examples of wastewater constituents of concern to public health. Through adequate treatment of wastewater, the proper handling of reclaimed water, and farming practices, the transmission of disease can be prevented or reduced. Table 5.10 shows the populations exposed to risk, and their means of exposure to pathogen or chemicals in reclaimed water.

In addition to their direct exposure to reclaimed water, people are also at risk from pathogens and chemicals passed through the food chain in crops or into groundwater and streams through percolation or farm runoff. The points of exposure (with reference to points in Fig. 5.2) and the groups exposed can be summarised as follows:

- Untreated or treated wastewater discharge to surface waters (downstream of point G): fishermen, swimmers, bathers, downstream users of drinking water
- Wastewater treatment (points C and D): workers
- Irrigation (point F): agricultural field workers, local residents or passers-by
- Crop handling (point F and later): workers, crop consumers
- Excess percolation of irrigation water (point F and later): consumers of groundwater
- Runoff from agricultural fields to streams and canals (point F and later): fishermen, swimmers, bathers, downstream users of drinking water, local residents
- Crop ingestion (after point F): crop consumers.

TABLE 5.9
Waterborne pathogens or chemicals of health concern present in wastewater

Contaminant category	Specific examples	Consequences
Excreta-related pathogens	Bacteria Helminths Protozoa Viruses	Human diseases (direct or indirect infection)
Skin irritants	Undetermined, but likely mixture of chemical and microbial agents	Contact dermatitis
Vector-borne pathogens	*Plasmodium* spp. *Wuchereria bancrofti*	Human diseases
Chemicals	Heavy metals Organic compounds Inorganic compounds	Acute or chronic human illness (direct contact or indirect through food)

Source: Adapted from World Health Organization, 2006.

The health risks that can be encountered are summarised in Table 5.10.
Wastewater treatment is the most fundamental barrier to the transmission of disease, but other precautions are also necessary. The methods of exposure control for the risk groups are as follows (Lazarova and Bahri, 2005b).

1. Wastewater treatment workers, agricultural field workers, and crop handlers:
   * Use adequate wastewater treatment, including disinfection
   * Use of protective clothing, such as boots and gloves
   * Maintenance of high levels of hygiene
   * Immunisation against or chemotherapeutic control of selected infections (if reclaimed water is not well disinfected).
2. Users of streams or canals (fishermen, swimmers, etc.):
   * Adequate wastewater treatment, including disinfection, before discharge
   * Restrictions on stream uses
   * Informing stream users, warning signs.
3. Crop consumers:
   * Adequate wastewater treatment, including disinfection, based on crop and level of exposure
   * Washing and cooking agricultural produce before consumption
   * High standards of food hygiene, which should be emphasised in the health education, appropriate to the type of wastewater treatment and consumer exposure
   * Restrictions on the types of crops grown with reclaimed water.
4. Local residents:
   * Using adequate wastewater treatment appropriate for the potential exposure
   * Informing them of the use of wastewater and the precautions to avoid fields or canals, warning signs
   * Not using sprinklers within 50-100m of houses or roads, depending on the level of wastewater treatment.
5. All groups:
   * Source control on sewer system to prevent toxic chemicals from entering wastewater.

There is a trade-off between the level of wastewater treatment and the degree of restrictions and precautions required for workers and consumers. It may be difficult to control the behaviour of workers, residents, or consumers through hygiene, education, or field practices. Farmers may resist the imposition of restrictions on the type of crops they can grow, such as food crops eaten without cooking.

Health risks from the use of wastewater in agriculture have been investigated in two separate areas of research: quantitative microbial risk analysis (QMRA) applied to irrigation and epidemiology (Mara et al., 2007). In the recent years, there has been a movement to apply the HACCP (Hazard Analysis and Critical Control Points) concept to wastewater reclamation and reuse (Westrell et al., 2003). The HACCP procedures were initially established for foodstuffs and aeronautical and pharmaceutical industries, where the final objective is to generate safe products.

Taking into consideration agricultural practices, hygiene, food processing, and the degree of human exposure, and in the light of the calculated risk for various pathogens, certain use practices and levels of wastewater treatment have been established by regulation (U.S.EPA and U.S.AID, 2004). The third edition of the WHO and FAO guidelines for the safe use of wastewater, excreta and greywater, published in 2006, is an extensive update of two previous editions, expanded to include new scientific evidence and contemporary approaches to risk management (Asano et al., 2007; WHO, 2006). Although it is technically feasible to obtain any required quality of water effluent from a particular type of wastewater, the treatment could be so expensive as to make reclamation non- feasible. In this case, the recommended practice is to use Best Available Technology (BAT) which involves use of the best adapted technology to every specific case, considering all the issues related to end-quality treatment, reclamation and reuse.

TABLE 5.10
Summary of health risks associated with the use of wastewater for irrigation

Group exposed	Health risks		
	Helminth infections	**Bacterial/virus infections**	**Protozoal infections**
Consumers	Significant risk of helminth infection for both adults and children with untreated wastewater	Cholera, thyphoid and shigellosis outbreacks reported from use of untreated wastewater; seropositive responses for *Helicobacter pylori* (untreated; increase in non-specific diarrhoea when water quality exceeds 10^4 thermotolerant coliforms /100ml)	Evidence of parasitic protozoa found on wastewater-irrigated vegetable surfaces, but no direct evidence of disease transmission
Farm workers and their families	Significant risk of helmith infection for both adults and children in contact with untreated wastewater; increased risk of hookworm infection for workers who do not wear shoes; risk for helmith infection remains, especially for children, even when wastewater is treated to <1 helminth egg per litre; adults are not at increased risk at this helminth concentration	Increased risk of diarrhoeal disease in young children with wastewater contact if water quality exceeds 10^4 thermotolerant coliforms/100 ml; elevated risk of *Salmonella* infection in children exposed to untreated watewater; elevated seroresponse to norovirus in adults exposed to partially treated wastewater	Risk of *Giardia intestinalis* infection reported to be insignificant for contact with both untreated and treated wastewater; however, another sutdy in Pakistan has estimated a treefold increase in risk of *Giardia* infection for farmers using raw wastewater compared with irrigation with fresh water; increased risk of amoebiasis observed with contact with untreated wastewater
Nearby communities	Transmission of helminth infections not studied for sprinkler irrigation, but same as above for flood or furrow irrgation with heavy contact	Sprinkler irrigation with poor water quality (10^6-10^8 total coliforms/100ml) and high aerosol exposure associated with increased rates of infection; use of partially treated water (10^4-10^5 thermotolerant coliforms/100 ml or less) in sprinkler irrigation is not associated with increased viral infection rates	No data on transmission of protozoan infections during sprinkler irrigation with wastewater

Source: World Health Organisation - FAO Guidelines (2006)

Chapter 6
Conclusions

6.1 CONTEXT AND STARTING POINT

The use of recycled water (treated and untreated) in agriculture is widespread and increasing in regions with water scarcity, growing urban populations and rising demand for irrigation water.

Many regions of the world are experiencing growing water stress, arising from a relentless growth of demand for water in the face of static, or diminishing, supply and periodic droughts. Water stress is aggravated by pollution caused by wastewater from expanding cities, much of it only partially treated, and from the contamination of aquifers from various sources. Such water pollution makes scarcity worse by reducing the amount of freshwater that is safe to use without proper treatment.

Climate change is adding to these pressures: it is estimated that global warming of 2 degrees Celsius could lead to a situation where 1 to 2 billion more people may no longer have enough water to meet their consumption, hygiene and food needs. The evidence of recent prolonged droughts, and the impact on social and economic life of severe seasonal water shortages, shows the high economic, social and political costs of water shortages.

Recycling water is a proven option for bringing supply and demand into a better balance. It is not the only option, but in many cases it is an acceptable and cost effective solution, as the growing number of reuse schemes in different parts of the world testify[1]. A recent comprehensive survey found over 3,300 water reclamation facilities worldwide and is growing.

Water recycling and Integrated Water Resources Management

Water recycling fits the IWRM paradigm – "…a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."[2] Recycling avoids putting further pressure on freshwater where it is becoming scarce, and reduces wastewater pollution for downstream users and the natural environment.

The reuse of wastewater is a means of recycling not only water but also nutrients, which would otherwise be wasted[3] during the process of treatment and disposal. "Closing the nutrient loop" entails the return of nutrients, principally nitrogen and phosphate, to the soil where they can benefit plant growth, rather than releasing them into rivers, estuaries, wetlands or coastal waters where they cause harm (variously, eutrophication, algal blooms, fish kills, hypoxia, etc.). The heavy environmental, and eventually economic, cost of such nutrient pollution is a growing concern.

1 E.g. "Queensland's Traveston Dam proposal has been rejected by the Australian federal government, meaning the state will have to implement alternative water resourcing strategies, including desalination and reuse." *Global Water Intelligence,* Nov 2009.

2 Global Water Partnership, *Integrated Water Resources Management* TAC Background Papers No 4, 2000, p. 22

3 or separated, for instance into sludge.

6.2 SYNERGIES AND WIN-WIN OUTCOMES

Agriculture is the principal focus of this report. Agriculture is the predominant global user of reclaimed water, and its use for this purpose has been reported in around 50 countries, on 10% of all irrigated land. However, it is necessary to place water recycling in a broader context.

Reuse of water can be the source of *win-win* outcomes, in which several different aims can be achieved, and several stakeholders can benefit simultaneously. For the purpose of exposition, this report has divided stakeholders into three parties – urban authorities (*cities*), farmers, and the environment (represented by *environmental custodians*). However, the use of recycled water also appeals to industry, power stations and recreational establishments, and a number of cities are considering using reclaimed water for various municipal purposes, often as an alternative to desalination. The report has implications for each of these potential stakeholders.

Agriculture

The use of untreated or partially treated wastewater is already widespread in urban and peri-urban agriculture, which is an important source of fresh vegetables in many poor cities (Bahri, 2009). The systems for providing this water are often low cost and improvised, treatment costs are absent or minimal, and because of proximity the cost of conveyance and pumping are relatively small. These factors, together with the relatively high value of the produce, make this practice economic. In the course of economic development, and as environmental standards rise, wastewater will increasingly be treated, but in the meantime for many countries the agricultural use of untreated or partially treated wastewater will remain. In these situations a realistic policy response will involve a combination of measures to safeguard public health (see below).

In other situations, and more generally, reuse may be a feasible response to the demands of agriculture in regions of growing water scarcity and competition for its use. There is evidence in the case studies of farmers responding positively to the use of recycled water, either as a sole source, mixed with water from other sources, or used indirectly from recharged aquifers. Reuse has been used both as a temporary expedient in years of drought, and as a long term solution.

Reuse is one amongst a number of options at farm level for improving long term water security and minimizing exposure to seasonal water risk. Where it entails the creation of an expensive distribution network and storage facilities[4], with a high recurrent cost for pumping, in order to furnish water for low value farm purposes, recycling may not be warranted unless there are benefits to other sectors. Where sizeable new infrastructure is required, recycling schemes may not be justifiable purely from their agricultural benefits. Although farmers may be net beneficiaries from using treated wastewater, compared with their previous or alternative sources of water, this depends very much on local circumstances, and in any event their net benefits may not offset the full costs of the scheme. This underlines the importance of viewing reuse as an element in IWRM, with reference to costs and benefits for water management more generally.

Cities

Cities are interested in recycling mainly from two points of view - as a solution for wastewater treatment and disposal, and as a potential source of water for household and other municipal use.

Rapid urbanisation has focused attention on recycling as a potential environmentally sustainable *solution for wastewater treatment and disposal.* The context for this is the growing volume of wastewater, the heavy costs of advanced treatment, and the

4 As well as extra specific treatment where necessary, such as the removal of excessive salts.

downstream pollution caused by untreated and partially treated effluent. There are great differences between cities in their levels of development and available options, which affect their choices of wastewater disposal. It is estimated that in sub-Saharan Africa, less than 1% of wastewater is treated (Keraita *et. al.* 2009). Yet in 3 out of 4 cities in developing countries wastewater is used for irrigation without any effective treatment. In many West African cities, more than 90% of vegetables consumed are grown within the cities, which implies that a high proportion are grown using untreated urban wastewater.

Reuse is an everyday reality for many such locations, and the efforts of national and international authorities have concentrated on promoting the "multiple barrier" approach to risk management, including technically, economically and socially appropriate non-treatment options for health protection, based on WHO, FAO and UNEP Guidelines (Keraita *et. al.* 2009). Where climate and space permits, various low-cost treatment methods (e.g. waste stabilisation lagoons) can also be used as an additional safeguard. Strong arguments have been made for making national policies on wastewater treatment more realistic and pragmatic, in short for: "...a paradigm shift where water reuse defines the required degree of treatment, where technical solutions have to match capacities, and where urban source treatment will be implemented along a multiple-barrier approach combining treatment and different health protection measures"(Bahri, 2009, p. 52).

For countries at an intermediate level of development, the use of *land disposal* for untreated wastewater has been widely resorted to. The Mexico City-Tula case is typical of mutual benefits that have accrued, in this case over a century or more, for the City and farmers from disposing of untreated urban wastewater to agriculture, allowing natural processes to carry out some of the purification *en route*. Recycling allows the dispersion of effluent and its assimilation across a wide area, as compared to the *point source pollution* from WWTPs. The reuse of wastewater nutrients in crop production (as well as *carbon sequestration* potential in soil organic matter), rather than their removal and separation during advanced processes of wastewater treatment, is appealing on grounds of efficiency and environmental sustainability.

The second important motive for recycling is as part of the *solution for urban water consumption*. In the course of their economic development, cities increase their fiscal resources and raise their environmental standards so that, over time, a growing proportion of their wastewaters is treated, to progressively higher standards. This wastewater can be recycled for various urban and industrial uses, such as watering public gardens, industrial cooling and other processes, replenishing aquifers, and – where systems were installed that allowed this – toilet flushing. Using recycled water for these purposes avoids the fresh abstraction of river water or groundwater, where these are scarce. The ultimate development of recycling is direct reuse for all household purposes, including drinking (as in Windhoek, Namibia), though this is still rare (Bahri, 2009). There is an active and rapidly growing market for wastewater reuse projects, much of it aimed at urban and industrial use (GWI, 2009).

One form of "win-win" agreement examined in this report is the surrender of farmers' freshwater entitlements to cities, in return for assured supplies of reclaimed water. This would enable cities to gain access to freshwater at a lower cost than otherwise, to use for any purpose including drinking water. For them to take part voluntarily in such an agreement, farmers would receive water which should be at least as reliable as their alternative sources, and which would contain nutrients for the growth of their crops. Depending on location, there may also be environmental benefits from such a deal.

The case studies illustrate situations with both the presence and absence of conditions for making such an intersectoral exchange feasible. The Llobregat sites in Spain and Durango City in Mexico are examples where physical and geographical conditions appear to be positive, and where legal and economic factors could dictate the outcome. In the other cases there are obvious barriers to an intersectoral agreement of this kind.

6.3 THE FEASIBILITY OF WATER REUSE

The feasibility of reuse projects hinges on a number of key factors. The physical and geographical features of the area should be conducive to the transfer of water between the parties concerned. Where an exchange of water rights is entailed, rights must be legally clear and *alienable*[5]. Any extra costs of treatment, plus that of installing the necessary infrastructure, should be affordable in relation to expected benefits. Farmers should be supportive, which depends on the net impact on their incomes, the status of their rights to freshwater, and what their alternatives are. Environmental impacts should be acceptable.

It is important that public health authorities are satisfied that the projects pose no undue risks, after reasonable precautions have been taken. National and international regulations and guidelines such as those promulgated by the WHO and FAO are available to guide the use of reclaimed wastewater in agriculture. Depending on circumstances, the options for health protection include the level of wastewater treatment, crop restriction, adaptation of irrigation technique and application time, and the control of human exposure.

Chapters 3 and 4 of this report dwell on the financial feasibility of recycling schemes as a necessary complement to the economic analysis. The vantage point of the economic methodology described in this report is the national interest[6]: if a project has sufficient net benefits in national socio-economic terms, it is considered to be justified. However, this is a necessary but not a sufficient condition for it to be implemented, since all the key stakeholders involved in the project need to be persuaded that they will be net beneficiaries. An essential part of building the case for recycling is to analyse the balance between its financial costs and benefits *specific to each party*.

Consequently the feasibility study should contain an analysis of the project's impact on the financial status of key stakeholders, including central and municipal government, regional water boards, utilities, farmers, and other interested parties. This should identify the main gainers and losers, with estimates of their gain or loss. It should also contain an estimation of the financial implications of the project for public capital and recurrent budgets. This part of the analysis provides a basis for understanding the incentives of crucial stakeholders, including farmers, to support, or resist, the project.

Where benefits and costs are out of balance, or not sufficiently decisive, for key parties, proposals will be necessary for financial instruments and transfers that would create conditions to make the project acceptable, and to provide suitable incentives for its major participants. This may entail both penalties (e.g. water charges, pollution taxes or other financial levies) or positive inducements (e.g. subsidies and innovative financial mechanisms such as paying farmers for environmental services[7]).The financial architecture of the project resulting from this analysis will influence the funding of the project, e.g. whether national or international subsidies should be sought, how far it can be self-financing, or whether commercial finance or private equity is feasible.[8]

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5 capable of being exchanged, e.g. bought and sold, between different parties, in accordance with local legal systems

6 Which for many, though not all, purposes will coincide with that of the region or river basin.

7 As described in FAO (2007).

8 A growing number of reuse projects are funded from commercial sources, including public-private partnerships (BOTs), though these tend to be for industrial and urban non-potable uses.

6.4 PUBLIC AWARENESS

Recycling depends on public acceptance, which in turn relies on awareness and understanding of the issues involved. In different contexts and cultures "wastewater" has connotations and resonances which have to be addressed. Public health and consumer concerns need to be dealt with transparently, using guidelines and procedures outlined in this report. Groups and whole communities affected by water recycling scheme have to be engaged in the decision-making and planning process, as outlined in Chapter 5.

Water issues are rising in the agenda of public actions, especially in the context of adaptation to climate change. Questions about the sustainability of current trends in urbanisation, water quality, environmental stress, and the needs of future food production – to name some driving issues – are leading to radical rethinking of water supply, use and disposal systems.9 The costs of water scarcity and water stress, on the one hand, and the expense and limitations of traditional responses to it, on the other, are key drivers of the new level of interest in recycling. From being an unfashionable and unspoken residual element of the water cycle, wastewater is emerging as a key link in IWRM.

[9] E.g. in the TECHNEAU programme of the SAFIR Project of the European Commission Research DG.

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The economics of wastewater use in agriculture

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