

The wealth of waste

The economics of wastewater use in agriculture



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35

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Summary

REUSE AS A RESPONSE TO WATER SCARCITY

The use of reclaimed water in agriculture is an option that is increasingly being investigated and taken up in regions with water scarcity, growing urban populations and growing demand for irrigation water. This report presents an economic framework for the assessment of the use of reclaimed water in agriculture, as part of a comprehensive planning process in water resource allocation strategies to provide for a more economically efficient and sustainable water utilization. Many regions of the world are experiencing growing water stress. This arises from a relentless growth of demand for water in the face of static, or diminishing, supply and periodic droughts due to climatic factors. Water stress is also caused by pollution from increasing amounts of 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. Water scarcity in all its aspects has serious economic, social and even political costs.

At times of serious scarcity, national authorities are inclined to divert water from farmers to cities since water has a higher economic value in urban and industrial use than for most agricultural purposes. In these circumstances, the use of reclaimed water in agriculture enables freshwater to be exchanged for more economically and socially valuable purposes, whilst providing farmers with reliable and nutrient-rich water. This exchange also has potential environmental benefits, reducing the pollution of wastewater downstream and allowing the assimilation of its nutrients into plants. Recycling water can potentially offer a “triple dividend” - to urban users, farmers and the environment.

Reclaimed water use can help to mitigate the damaging effects of local water scarcity. It is not the only option for bringing supply and demand into a better balance – and this report shows how different options can be analysed for comparison – but in many cases it is a cost effective solution, as the growing number of reuse schemes in different parts of the world testify. A recent comprehensive survey found over 3,300 water reclamation facilities worldwide. Agriculture is the predominant user of reclaimed water, and its use for this purpose has been reported in around 50 countries, on 10% of all irrigated land.

BENEFITS OF REUSE

The feasibility of reuse will depend on local circumstances, which will affect the balance of costs and benefits. The major benefit in most cases is likely to be the value of the fresh water exchanged for high-value urban or industrial use. This would lessen the cost for municipal authorities of seeking their supplies through more expensive means. In addition, reuse prevents untreated wastewater discharge to coastal and groundwater systems with ecosystem and tourism benefits.

Depending on the local situation, there could also be benefits to farmers if they can avoid some of the costs of pumping groundwater, while the nutrient present in the wastewater could save some of the expense of fertilizer. There could also be benefits to the local environment from reduced flows of untreated wastewater – though the interruption in the downstream water cycle could have other, less beneficial, effects.

The costs and benefits of reuse projects

The costs of the reuse option could include the installation or upgrade of wastewater treatment plants (WWTPs) to produce effluent of the desired standard, any addition or modification to the infrastructure for water and reclaimed water distribution, the extra recurrent costs of treatment, and the cost of any produce restrictions imposed by the use of reclaimed water in irrigation. Where climatic and geographical features are suitable, low-cost treatment of wastewater may be an option through the use of stabilisation ponds, constructed wetlands, etc. The net cost of treatment may also be reduced through the reuse of biogas for energy and power in the intensive treatment processes, or potentially through the sale of carbon offsets.

ECONOMIC JUSTIFICATION

The economic appraisal of the project should be from a regional basin viewpoint, comparing its economic costs and benefits. Judging by the evidence of our case studies, it is unlikely that schemes could be economically justified with reference only to agriculture. 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 are unlikely to offset the full costs of the scheme. On the other hand, the benefits to urban and industrial users could be relatively sizeable, and in most cases would be the principal justification for the project. The net impact of the project on the local and downstream environment will also be very site-specific, and there are likely to be both benefits and costs.

FINANCIAL FEASIBILITY

Once the basic economic justification of the project is established, the next step is to examine its financial feasibility. The distribution of the costs and benefits of the project between different stakeholders is crucial to its feasibility. Its impact on the finances of the various stakeholders – national government, regional water authority, farmers, municipal utility and/or other major players – should be assessed. Financial gainers and payers should be identified to gauge the incentives, or conversely the penalties, to be applied and the type of funding that would be appropriate. Water charges, taxes, subsidies, soft loans, environmental service payments, and other instruments could all form part of the financing proposals.

A PLANNING FRAMEWORK

The economic framework for wastewater reuse presented in chapters 3 and 4 is intended to 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. Chapter 5 presents such a planning framework, its key elements being: identification of problem and project objectives; definition of study area and background information; market assessment and market assurances; identification of project alternatives; appraisal and ranking of project alternatives; and implementation. Among the major specific technical issues to be addressed are: facilities and infrastructure, balancing supply and demand, wastewater quality, and public health risks and safeguards.

FACTORS ESSENTIAL FOR THE SUCCESS OF REUSE PROJECTS

The feasibility of reuse projects hinges on several key factors. The physical and geographical features of the area should be conducive to an exchange of water rights between the parties concerned. The extra costs (of treatment and infrastructure) should be affordable in relation to benefits. Farmers should be supportive, which depends on

the net impact on their incomes, the status of their rights to freshwater, and what are their alternatives. Public health authorities should be satisfied that the projects pose no undue risks, after reasonable precautions have been taken. Finally, the environmental impact should be acceptable: the same impact may be acceptable or not in different circumstances, and different authorities will place a different weight on specific impacts in forming an overall judgement.¹

A REALITY CHECK – CASE STUDIES FROM SPAIN AND MEXICO

On a global scale, only a small proportion of treated wastewater is currently used for agriculture, but the practice is growing in many countries, and in some regions a high proportion of reclaimed water is used in irrigation. The variety of case material presented from Spain and Mexico provides a good field testing for the approach presented in Chapter 3 on *Methodologies of Cost-Benefit and Cost-Effective Analyses*. Chapter 4 on case study results demonstrates that the methodology presented for appraising wastewater reuse projects is viable. Although the *Cost-Benefit Analysis* analytical framework is well able to incorporate the interests of municipalities and farmers, there is an important third party 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 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 high confidence, and their operating costs (pumping, chemicals, labour, etc.) are also fairly evident. The technology of wastewater treatment and its future level of unit costs are liable to change, and future options should not be prematurely foreclosed.

Most of the case studies stress the perceived benefits to farmers from the nutrient properties of effluent, plus savings in groundwater pumping and the greater reliability of effluent compared with other sources of water in arid and semi-arid climates. While pumping costs are reasonably firm, the benefits of fertilization depend on local empirical evidence (“with and without project”). The value of *reliable* wastewater also needs to be demonstrated more convincingly, e.g., by a closer study of farmers’ response behaviour where water supply is erratic or scarce.

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. However, some of the cases 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.

The analysis of the case studies has implications for policy towards the use of reclaimed water, depending on what its principal objectives are:

- *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

¹ Local environmental policy (pollution taxes, payments for environmental services, incentives for the recovery of heat from biogas, etc.) could tilt the balance in favour of reuse schemes.

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.

- *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 “win-win” outcomes occur 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 their rights to freshwater, without further consideration of their operational situations. Most farmers prefer to have several water sources as insurance against drought. A cost-benefit 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 the deal.

The overall message the report seeks to convey is that the recycling of urban wastewater is a key link in Integrated Water Resource Management (IWRM) that can fulfill several different, but interrelated objectives. These are expressed as *win-win* propositions, delivering simultaneous benefits to farmers, cities and natural environmental systems, part of the solutions to the urgent global problems of food, clean water, the safe disposal of wastes and the protection of vital aquatic ecosystems. The traditional “linear society” is not a sustainable solution and the “circular society” has to become the new standard.

The annex to the report contains an extensive bibliography, testimony to the large and growing interest amongst the professional and policy communities in this important topic.

List of Acronyms

ACA	Catalonian Water Agency
BAT	Best Available Technology
BCR	Benefit-Cost Ratio
BOD	Biological Oxygen Demand
BOT	Build Operate Transfer
CBA	Cost-Benefit Analysis
CEA	Cost-Effective Analysis
CRF	Capital Recovery Factor
DALY	Disability Adjusted Life Years
DBOT	Design Build Operate Transfer
EA	Economic Appraisal
EDR	Electrodialysis Reversal
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FYRR	First Year Rate of Return
HACCP	Hazard Analysis and Critical Control Points
IRR	Internal Rate of Return
IWRM	Integrated Water Resources Management
MCA	Multi-Criteria Analysis
NDMA	N -nitroso-dimethylamine
NPV	Net Present Value
OC	Opportunity Cost
PES	Payment for Environmental Services
QALY	Quality Adjusted Life Years
QMRA	Quantitative Microbial Risk Analysis
SEEAW	System of Environmental-Economic Accounting for Water
STP	Social Time Presence
WFD	Water Framework Directive
WHO	World Health Organization
WTP	Willingness to Pay
WWTP	Wastewater Treatment Plant

Chapter 1

Introduction to wastewater reuse

1.1 BACKGROUND, CONTEXT AND KEY ISSUES

The reuse of treated wastewater in agriculture is an option that is increasingly being investigated and taken up in regions with water scarcity, growing urban populations and growing demand for irrigation water. Many regions of the world are experiencing growing water stress. This arises from a relentless growth of demand for water in the face of static, or diminishing, supply and periodic droughts. Climate change is adding to these pressures: it is estimated that a 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.

Water stress is also caused by pollution from the growth of wastewater and run-off from expanding cities, much of it only partially treated, from the release of agricultural fertilizer, and from the contamination of aquifers from various sources. This pollution causes eutrophication of surface water, one result of which is the formation of algal blooms, such water pollution makes scarcity worse by reducing the amount of freshwater that is safe to use by humans. The same factors are causing hypoxia (oxygen depletion) in estuaries and coastal waters, causing harm to fisheries and other aquatic life and negatively impacting ecosystem integrity. This is concern both to the environment and to local economies dependent on tourism and fisheries.

Water scarcity has heavy economic, social and political costs. The drought in Kenya in 1998-2000 is estimated to have reduced GDP by 16% over this period, falling with particular severity on industrial output, hydropower, agriculture and livestock. The cost of mitigating water crises is currently entailing huge sums in regions as diverse as California, Northern China and Australia.

At times of serious scarcity, national authorities are inclined to divert water from farmers to cities since water has a higher economic value in urban and industrial uses than for most agricultural purposes. In these circumstances, the reuse of treated wastewater for agriculture enables freshwater to be exchanged for more economically and socially valuable purposes, whilst providing farmers with reliable and nutrient-rich water. This exchange also has potential environmental benefits, reducing the release of wastewater effluent downstream, and allowing the assimilation of its nutrients into the soil.

Wastewater reuse projects can therefore offer a potential double or even triple “dividend” - to urban users, farmers and the environment. In typical situations of growing water stress the use of reclaimed water must be considered as an available option. In such cases the “without project” scenario will incur costs that will grow over time, and alternative solutions have serious costs of their own. To reject the reuse option could be costly in such situations.

1.2 PURPOSE OF THE REPORT

Agriculture accounts for around 70% of global water use, mainly in the growth of crops for food and raw materials and for processing agricultural products. When rainfall is insufficient to sustain crops, irrigation is necessary and adds to the cost of agricultural operations.

The lack of natural water resources from aquifers, rivers, and lakes has led to the growing recycling of domestic and municipal wastewater (both treated and untreated) for irrigation. Recycling water¹ for this purpose raises issues of water quality, the health of the general public and farm workers, public acceptability, the marketability of crops, and how such projects can be financed, amongst other matters. Some of these issues also arise with the use of freshwater, while others apply with special emphasis, or specifically, to the use of recycled water. There is a large literature on water resource economics, dealing with the role of water in economic development and the evaluation of alternatives to serve various water needs. The development of the agriculture sector has been the most important and initial phase in the economic development and well-being of many countries, and agriculture remains as a key to food security and growth in much of the world.

Although guidance is available on the economics of water resources in agriculture (Gittinger, 1982; Turner et al., 2004), there is an unfulfilled need for guidance on the specific issues arising in the use of recycled water. This report is an attempt to fill this gap. Recycling includes both untreated and treated wastewater. While the economic concepts discussed in this report are applicable to untreated (raw) and treated (reclaimed) wastewater and to many types of reuse, the main focus of this report is on the use of reclaimed water from community sewerage systems for irrigated agriculture.

This report addresses the economic and financial issues and the methodology and procedures involved in the analysis of water recycling projects. The issue is dealt with in the wider context of water resources and covers human health, water quality, acceptability, institutional constraints, and other factors, all of which have economic implications and affect the feasibility of reuse schemes.

The current chapter provides a contextual background. Chapter 2 introduces the case material, drawn from regions of Spain and Mexico. Chapter 3 contains the methodology proposed for the economic analysis of projects, together with the procedure for determining its financial feasibility. Chapter 4 applies this methodology to the analysis of the case studies. Finally, chapter 5 proposes a broader planning framework into which the economic and financial analyses can fit. Chapter 6 draws some conclusions from the report that are relevant to policy makers and professionals working on this topic.

1.3 THE GLOBAL CONTEXT

Earth contains an estimated 1 351 million cubic km of water. Only 0.003 percent of this is classified as fresh water resources, that is, water that can be a source for drinking, hygiene, agriculture, and industry. Most fresh water is remote from civilization or too difficult to capture for use. The Food and Agriculture Organization of the United Nations (FAO) estimates that only about 9 000 to 14 000 km³ are economically available for human use each year (FAOWATER, 2008).

The world's population is growing at a rate of about 1.2 percent per annum and is expected to grow by two billion by 2030. Providing adequate water for all these people will be a major challenge. Water is essential not only for direct human consumption and household purposes, but also for producing the food and manufactured goods necessary for life and improved standards of living. The common needs for water fall into the following categories:

- drinking water
- agriculture

¹ In this report, wastewater treated to a level allowing for its beneficial reuse (normally tertiary) is referred to as *reclaimed water*. Otherwise, it is referred to as *wastewater*, which includes both raw sewage and wastewater treated to lesser levels. *Recycled water* includes both reclaimed water and wastewater in the above senses. See the Glossary for these and other definitions.

- personal hygiene and public sanitation
- domestic uses (food preparation, cleaning, outdoor uses)
- commerce and services
- industry
- recreation and tourism
- commercial fisheries, and
- environmental and ecological maintenance, conservation and protection.

Many countries struggle to meet current water needs for basic sustenance and sanitation. The problem is compounded by increasing standards of living which increase the per capita use of water.

Converting from rainfed to irrigated agriculture can increase yields of most crops by 100 to 400 percent and can permit the growth of different crops with higher income value. Humid-climate species can be grown in arid areas. Shifting away from rainfed agriculture often means that water must be available at unnatural times and locations, requiring infrastructure energy and labour. Even relying on groundwater directly beneath farms is becoming a problem as water tables fall. Because irrigation leaves salts behind in the soil, the rate of water application may have to be increased over time to counter salinization, though in many places rainfall can achieve this function. Compared to the daily drinking water requirement of 2 to 4 litres per person, producing a day's food requirement takes 2 000 to 5 000 litres of water per head. As a result, agriculture is by far the largest user of water, accounting for almost 70 percent of all withdrawals - up to 95 percent in developing countries - and demand is increasing (FAOWATER, 2008).

Improvements in lifestyle and the use of labour-saving devices also demand more water. Some examples are:

- community sewerage systems and toilets using water for the conveyance and disposal of human waste;
- household appliances such as dishwashers and garbage grinders;
- domestic hot water devices increasing the use of water for bathing;
- gardening and residential landscaping;
- leisure activities such as golf courses and aquatic parks;
- urban greenery for local amenity;
- increased consumption of manufactured goods;
- dietary changes involving higher consumption of foodstuffs with greater water requirements and;
- tourism and recreation increase with incomes, and many of these activities are water-intensive.

Meeting these water demands has often come with great environmental cost. In a well-known example, the Aral Sea has lost 85 percent of its inflow due to irrigated cotton production on its main feeder rivers. The fall in level by 16 metres between 1981 and 1990 has led to the disappearance of 20 of its 24 species of fish, the loss of almost the entire fish catch, and the creation of toxic dust-salt from the dry seabed, killing crops on nearby farmland (FAOWATER, 2008). This tragic episode illustrates the claim of the natural environment as a legitimate user of water.

Scarcity, stress and competition

Climate change is likely to aggravate the scarcity of water that is being driven by other basic forces. On one authoritative view, global warming of 2 °C would lead to a situation where “between 100 million and 400 million more people could be at risk of hunger, and 1 to 2 billion more people may no longer have enough water to meet their consumption, hygiene and food needs” (World Bank, 2009).

The heavy economic cost of water scarcity is illustrated by estimates of the impact on Kenya's GDP of the *La Niña* drought of 1998-2000. Overall, this reduced GDP by 16% over this period, the reductions falling with particular severity on industrial production (58%), hydropower (26%), agriculture (10%) and livestock output (6%) (World Bank, 2004).

There are many other partial estimations of the high costs of water scarcity (Orr, 2009):

- The cost of water crisis management in California is estimated to be US\$1.6 billion annually by 2020.
- The emergency overhaul of Australia's water supply regime, triggered by the 2007 drought but resulting from a longer period of imbalance between supply and demand, is expected to cost US\$ 10 billion.
- In China the scheme to channel billions of cubic meters of water from the Yangtze River to farmers along the dwindling Yellow River involves massive outlays, not yet fully estimated.
- Libya's Man-Made River project to pump 730 million m³ annually from below the Sahara Desert to coastal water users costs US\$ 25 billion each year.

The natural environment, a silent water stakeholder, is bearing much of the water stress, which will rebound at some stage on the supply of water for human needs. In the Australian Murray-Darling basin, 30% of the normal river flow is needed for environmental purposes, yet irrigated farming takes 80% of the available water. Recently, practically no water from the Murray-Darling River has reached the sea. In China 25% of the flow of the Yellow River is needed to maintain the environment, yet less than 10% is actually available after human withdrawal. In 1997 the River was dry up to 600 km inland for 226 days (World Economic Forum, 2009).

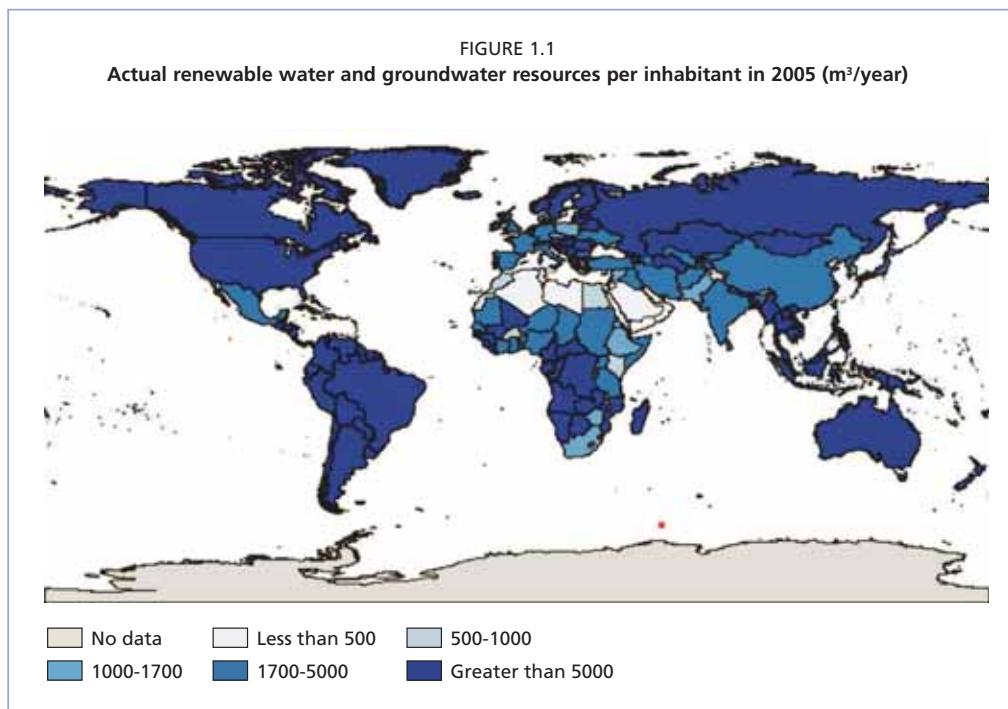
Several indicators have been developed to measure the relative scarcity of water (Kumar and Singh, 2005; Falkenmark and Widstrand, 1992). A summary of two common indices is shown in Table 1.1. The Water Scarcity Index, based on per capita availability of renewable fresh surface water and groundwater, represents the potential usable water per person without regard for existing water infrastructure or economic usage. The Water Intensity Use Index expresses the amount of surface water and groundwater withdrawals as a percentage of internal actual renewable water resources available for a region. The distribution of these indices by country is illustrated in Figures 1.1 and 1.2. As of 1995, about 41 percent of the world's population, or 2 300 million people, lived in river basins under water stress (that is, having a Water Scarcity Index below 1 700 m³/capita-year) (EarthTrends, 2001).

TABLE 1.1
Threshold values used to characterise water stress within a region

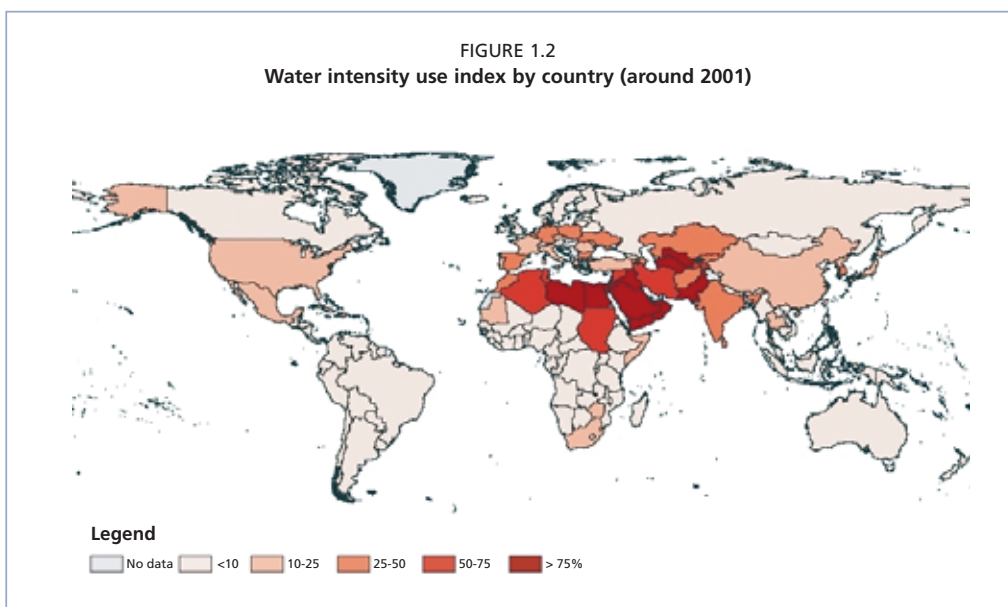
Characteristic	Threshold	Situation
Water Scarcity Index, m³/ capita-yr		
Water stress	<1 700	The region begins to experience water stress and the economy or human health may be harmed
Chronic water scarcity	<1 000	The region experiences frequent water supply problems, both short and long-term
Absolute water stress	<500	The region completes its water supply by desalting seawater, over-exploiting aquifers or performing unplanned water reuse
Minimum survival level	<100	Water supply for domestic and commercial uses is compromised, since the total availability is not enough to fulfil demand for all uses (municipal, agricultural and industrial)
Water Intensity Use Index		
Water stress	>20%	The region is experiencing severe water supply problems that are addressed by reusing wastewater (planned or not), over-exploiting aquifers (by 2-30 times), or desalinating seawater

Source: Adapted from Jiménez and Asano (2008b)

Even within countries with apparently abundant water, there are regions of scarcity or regions without the infrastructure to gain access to the available water resources. Areas of water withdrawals approaching or exceeding sustainable limits, for example, 75 percent or more of renewable water resources, are described as areas of *physical water scarcity*. On the other hand, *economic water scarcity* can occur where water resources are abundant, but deficiencies in human, institutional, or financial capital limit the access to it.



Source: Food and Agricultural Organization of the United Nations (2008)



Source: Food and Agricultural Organization of the United Nations (2008)

As water demands approach the limits of available resources, or the capacity of existing systems for water supply, competition between water sectors can arise. Urban areas with a sizeable industrial base often have greater economic capacity or political power to fund the infrastructure to develop new water supplies or reallocate existing supplies from agricultural to urban areas. In the competition for water, human needs often prevail over aquatic needs to sustain ecosystems and fisheries. Some of the factors or impacts related to water use sectors are summarised in Table 1.2.

Competition for water resources is often at the expense of agriculture and the traditional economies dependent on it. Water traditionally has been considered a common public good. Without government controls however, this public good can be abused and access to water lost to sectors with political and economic power. Upstream users can both diminish and pollute the water reaching downstream users.

In addition to social inequities, civil and even physical conflict can result from the competition for water. Where there is no established legal framework, or where this is violated, conflicts can result within regions or even between nations when one entity extracts water to the detriment of another (Trondalen, 2004; McCann, 2005; Tamas, 2003). Some legal systems establish priorities in the rights to use water, often giving domestic and urban use a higher priority than industrial or agricultural use. Thus, it

TABLE 1.2
Competition for conventional water resources in agricultural areas

Location	User sector	Potential competitive factors and impacts
Areas with arid or semiarid climate conditions	Agriculture	Optimal temperatures for crops but irrigation necessary to sustain agriculture; over-extraction or illegal extraction of water, especially for high-revenue agriculture
	Industry	Economic advantage over agriculture to purchase needed water, may pollute water resources
	Urban/domestic	Bad water quality and scarcity of water, especially in the lowest part of basins
Industrial areas	Agriculture	Tends to be marginal because industrial jobs are better paid and agriculture is often a secondary occupation, though with exceptions, such as where the agrofood industry is important
	Industry	Has economic or political priority in obtaining water it needs
	Urban/domestic	Usually in exponential growth as jobs congregate around industry; has economic or political leverage in getting water, increased pressure on existing water resources
Coastline	Agriculture in hot climates	Vulnerable, unless protected; uncompetitive for jobs and water
	Leisure activities/tourism in hot climates	Increasing uses of water for people and activities (e.g., golf or water parks)
	Industry	Growth in areas of good transportation infrastructure (harbours, motorways, railways)
Small islands in arid and semiarid climates (e.g., Mediterranean)	Agriculture	Uncompetitive against tourism for jobs or water
	Leisure activities/tourism	High revenue activity, economically dominant for jobs, water and land
River basins	Ecosystems	Damaged without regulatory protection due to reduced flows from human activities
	Urban	Economic and political advantage to obtain needed water (even overexploiting water in a non-sustainable way)
	Agriculture/livestock	Source of water pollution
	Industry	Water demands are usually not consumptive, temperature pollution from discharges by power generation facilities; source of persistent organic chemicals
Groundwater dominant regions	All sectors	Frequently groundwater overdraft, seawater intrusion and contamination
	Agriculture	Soil permeability reduced
	Urban	Reduced natural recharge due to impermeable surfaces

Source: Author's compilation

may be legal for one sector to deprive another sector of its traditional water supply. It is common, for example, for municipal and agricultural uses to be at the expense of the conservation and preservation of natural systems (streams, wetlands, groundwater and associated ecosystems).

The relationship between available water resources and their utilization can be established using the water scarcity index (Smakhtin et al., 2004; Kumar and Singh, 2005). When this index signals potential water scarcity, the country concerned would need to take measures to alleviate the situation, involving either or both of demand management and supply augmentation. The resources to be developed could be conventional (surface or groundwater) or non-conventional. Increasingly, the development of new conventional resources is not feasible on grounds of cost, or faces opposition from conservationists or others who prefer the *status quo*. On the other hand, some non-conventional resources are also questionable on grounds of sustainability problems (e.g. desalination in terms of brine disposal and high energy costs). Problems such as these increase the relative attractiveness of reclaimed water, though this has problems of its own. Environmentalists are concerned that reuse in the upper part of basins can reduce the availability of water for ecosystems further downstream. There are also public health risks from the use of reclaimed water, and its prolonged use could impact soil salinity depending on treatment level, though it may also enhance soil fertility and organic matter content. However, there are ways of mitigating any harmful impact on agriculture, e.g. using good quality water in the initial growing period and poorer quality water later - this practice can even increase the quality of certain fruits (Oron, 1987; Hamdy, 2004).

Communities reliant on direct precipitation and natural surface water supplies are at the mercy of the availability of these supplies over time and space. They are also susceptible to flooding and drought. Groundwater is less affected by short term weather conditions but is vulnerable to long-term overdraft, resulting in increased pumping costs, salinization from seawater intrusion and long residence time in contact with minerals, and subsidence.

The growth of urbanization and irrigated agriculture weakens the bond between naturally available water supplies and the timing and geography of demands. This has necessitated an infrastructure of canals or pipes to transport water and dams to capture river flows for later release when the demands occur. In developing countries the costs of such infrastructure can be prohibitive. In developed countries, the most cost-effective locations of dams and other schemes of water development have already been taken. Further water development not only is more costly but also competes with the needs for environmental protection of water quality, fisheries, and wetlands. In some cases, limitations have been placed on historic extractions of ground and surface waters to prevent further environmental damage or to restore the sustainable yield of groundwater.

As the development of conventional surface and ground water resources become increasingly expensive and difficult, the use of nonconventional resources or demand management are receiving increasing attention. One such source, seawater desalination, remains a relatively expensive option for irrigated agriculture despite progress in membrane technology. Achieving more efficient water use amongst urban and agricultural users through the various forms of *demand management* has great potential and remains one of the lowest cost alternatives to align supply and demand. The use of better technology to reduce leaks in urban water distribution networks and localized irrigation can also improve the Water Intensity Use Index.

To characterise reclaimed water use as “nonconventional” is not to imply that wastewater is uncommon or unproven as an effective water supply source. Domestic wastewater has been used for centuries in agriculture, and the use of *treated* wastewater is at least a century old. Its nonconventional status reflects the fact that it is only in the

last 30 years that the use of reclaimed water has become prominent in water resources planning. With adequate treatment, wastewater is suitable for many urban, industrial and agricultural uses. Though still not approved in many countries, reclaimed water is used for drinking in some locations, such as Namibia (Lahnsteiner and Lempert, 2007).

1.4 THE CASE FOR REUSING WASTEWATER

Reusing wastewater is an important option for Integrated Water Resources Management (IWRM) which is concerned with managing all aspects of the water cycle, and with optimizing the use of water in all its aspects. The World Summit on Sustainable Development in 2002 called for all countries to develop IWRM and water efficiency plans. This approach includes the following elements, amongst others:

- assessment of water needs in collaboration with end users;
- examination of all the water sources available; and
- matching water supplies to needs based on the quantity, quality and reliability required for the various purposes and the costs of supply relative to the benefits in each case.

The reclamation of wastewater and its reuse in agriculture is gaining wider acceptance in many parts of the world. In many water-scarce countries, wastewater has become important in bridging the demand and supply of water in different uses. The drivers of wastewater reuse are somewhat different in developed and developing countries, but there are common problems of increasing population and food demand, water shortages, and concern about environmental pollution. All these forces make reclaimed water a potentially valuable resource.

Water reuse does, however, entail changes in the traditional frameworks for water allocation, funding structures, fixing of water-quality standards, regulatory frameworks, and institutional mandates. It involves good governance at all levels in order to develop a holistic approach and sets of consistent policies for water allocation meeting multiple user needs.

Economic values of water in different uses

Fundamental to reuse is the insight that water is an *economic good*, as recognised in the Dublin Statement on Water and Sustainable Development of 1992: “Water has an economic value in all its competing uses and should be recognised as an economic good.” A distinction needs to be made between the *value, cost and price* of water, which are often very different from each other. The economic *value* of water is particularly apparent in situations of water scarcity. Water has different economic values in its different uses. It has an economic *cost* of supply, which also varies in different situations and for different purposes. Water provided to a particular user, in a specific place, at a certain time has an economic benefit, but also entails an economic cost. The relationship between the specific benefit and the specific cost is the basis of the *economic* justification for supplying that user. Finally, the *price* of water is a financial or fiscal transaction between the provider and the user, which is often closely controlled by public authorities, and often bears little relation either to its value in specific uses, nor its cost of supply.

Allocating water purely on the basis of such economic principles is complicated, and difficult to apply in practice (Turner, 2004; Winpenny, 1997). However, the basic concept of comparing the costs and benefits of supplying water in specific locations and to specific categories of users is fundamental to wastewater reuse projects, and this requires some estimation – however rough – of the benefits of the water to the potential users.

The methods of valuing water are eclectic, and depend on the sector concerned, the type of use, and the information available.

- *Household* consumption is commonly valued using Willingness To Pay (WTP) evidence from direct surveys using structured questionnaires or various kinds of “choice experiments”. This “stated value” approach can be supplemented and cross-checked by “revealed preference” evidence, such as inferring users’ preferences from their changes in consumption following a tariff change or by estimating what they are actually spending at present.
- *Irrigation* water use can be valued in either of two different ways. The marginal productivity of water (the extra value of output that can be obtained from additional applications of water) can be estimated from changes in yields during crop-water trials. Alternatively, the more common approach (the “net-back” method) is to derive the value of water as the residual from farm budget data, after all other costs have been allowed for. This latter method makes the crude assumption that all the residual, or unexplained, farm surplus is due to water, rather than to other factors.
- Industrial water use valuation poses a greater problem. For most industrial (and commercial) enterprises, water is a tiny part of their total costs. It would therefore be misleading to use the “residual method” as in irrigation, and attribute the whole residual surplus to water. Much industrial bulk water is self-supplied from wells and rivers. Many firms recycle water by treating and reusing waste flows. One valuation device is to regard the cost of recycling as the upper limit on industrial willingness-to-pay, since above this level firms would rationally recycle rather than buy in. A crude short-cut to industrial water valuation is to estimate ratios of gross output or value-added to the volume of water involved in different processes. Whilst these ratios can signal the water-intensity of different industrial sectors, they do not indicate the real productivity of water.

The above uses all involve the abstraction of water.

- Water also has *in-stream values* for waste assimilation and dilution, flushing sediment, the functioning of ecological systems, navigation, and various kinds of recreation (fishing, water sports, sight-seeing, rambling, etc.). There are various valuation options. Often, these natural functions of water (assimilation, dilution, flushing) can be compared with the extra cost of alternatives (dredging, treatment). The value of water for navigation can be imputed from its cost advantage over the next cheapest transport mode (e.g. railways). The value of water for recreation and ecological purposes (the maintenance of low flow regimes and wetlands) is generally estimated by WTP or travel cost² surveys. It is increasingly common to use the benefit transfer approach to derive empirical values for these environmental effects – as the term suggests, evidence is transferred from situations where it is available to locations and projects which seem to be broadly comparable³.
- *Hydropower* water usage is normally valued according to the cost advantage of hydro over thermal and other alternative ways of generating electricity. In this, as in other cases, it is important to compare like with like, and to be clear about the basis of the estimate⁴.

² The travel cost valuation method infers the valuation that visitors place on a free amenity from the amount of time and expense they incur in getting to the site.

³ A database exists of such studies (www.evri.ca), and a number of results are reviewed in van Beukering *et al.* (1998) and Turner *et al.* 2004.

⁴ If a *short term* approach is taken, capacity is assumed to be fixed for both alternatives to be compared. In the *long term*, new investment can be made in either. Marginal and average costs will also differ, for both alternatives.

TABLE 1.3
Values of water use in the USA, by sector
 1994 US\$ acre/foot of water

Sector/Use	Average	Minimum	Maximum
In situ			
Waste disposal	3	0	12
Recreational/habitat	48	0	2 642
Navigation	146	0	483
Hydropower	25	1	113
Withdrawal			
Irrigation	75	0	1 228
Industrial	282	28	802
Thermal power	34	9	63
Domestic	194	37	573

Source: quoted in Turner et. al. 2004

There have been several comprehensive studies of the economic values of water in different uses, and a number of more selective exercises. One of the earliest was done for the US National Water Commission in 1972, a subsequent one in 1986 at Resources for the Future, and another, also for the Resources for the Future, in 1997. These all use data from the USA, but more selective studies from other regions broadly endorse their results. Table 1.3 indicates the results of a comparative study.

The sectors of most concern for the current report are agriculture, households, irrigation and the various facets of the environment. The evidence presented here is that the value of water for *agricultural irrigation* of many low-value crops (typically food grains and animal fodder) is very low. By the same token, water values can be high for high-value crops (e.g. fruit, vegetables, flowers) where the water is reliable, likewise for supplementary irrigation taken as insurance against drought. These results are supported by the actual prices paid for water where water markets exist. In short, the value attached to irrigation water depends heavily on how reliable it is and on the type of crop being produced. Values tend to be higher for privately-owned groundwater than for publicly supplied surface water schemes.

Household values are relatively high, but this is not a homogeneous category. Water used for truly essential needs such as drinking, cooking and basic hygiene is only a minor part of typical daily use, the rest being used for “lifestyle” or productive purposes. In affluent regions with a warm climate a high proportion of water is used for outdoor purposes such as garden watering and swimming pools. Households tend to place a higher value on indoor than outdoor uses, though this would not apply where water is used for productive purposes. In some societies, much of the water provided for households is used for growing crops and feeding livestock (in other words, it is supplied for *multiple use* purposes).

In practice the valuation of water for household use is commonly taken to be equivalent to the average tariff, which usually underestimates its economic cost of supply, and ignores the *consumer surplus*⁵ involved. This is typically the approach used in the case studies presented in this report.

The value of water in its *environmental uses* is not adequately represented in the studies described above – which relate mainly to *use values*, particularly recreation. In fact, recreational values show great variation, depending on the visitation rate, location of the site, quality of water, and type of recreation (with fishing and shooting

⁵ The difference between what consumers would be *willing-to-pay*, and what they actually have to pay.

licences attracting high fees in some countries). The various methods of valuing the *non-use* environmental benefits of water are described in Chapter 3⁶. In some cases the environmental value of water is expressed through cities and regions purchasing the rights to water sufficient to meet their environmental needs.

The above discussion of economic values has been in the context of sectors, projects or specific uses. However, exercises are also underway to estimate the value of water at a macroeconomic level. One such is the System of Environmental-Economic Accounting for Water (SEEA_W) being developed by the UN Statistics Division (UN, 2008).

SEEA_W provides a conceptual framework for organising hydrological and economic information in a coherent and consistent manner. It is an elaboration of the handbook *Integrated Environmental and Economic Accounting 2003* of the United Nations, which describes the interaction between the economy and the environment. Both this document and the SEEA_W use the basic framework of the 1993 System of National Accounts, which is the international standard. When fully developed, SEEA_W would permit a consistent analysis of the contribution of water to the economy and the impact of the economy on water resources. Because it covers all important environmental-economic interactions, it is ideal for capturing cross-sectional issues such as IWRM as well as a range of other relevant features

The contribution of natural resources such as cropland, forests, pastureland and minerals to economic output is already reflected in national accounts, and estimates have been made of the value of such assets as natural capital⁷. These assets yield a future stream of income/benefits and constitute an important form of wealth for well-endowed countries. Conversely, where they are depleted (through exploitation, deforestation, overgrazing causing desertification, etc.) this represents a loss of capital and wealth, which will reduce future income from these sources. Water is part of natural capital: used sustainably (up to its renewable limit) it provides a recurring bounty to national income, but if its aquifers or surface storage is over-exploited, or if its reserves are contaminated, this is tantamount to capital depletion which will reduce future national income.

1.5 WASTEWATER REUSE IN PRACTICE

The global extent of wastewater reuse

Currently, there are over 3 300 water reclamation facilities worldwide with varying degrees of treatment and for various applications: agricultural irrigation, urban landscaping and recreational uses, industrial cooling and processing, and indirect potable water production such as groundwater recharge (Aquarec, 2006). Most of these were in Japan (over 1 800) and the USA (over 800), but Australia and the EU had 450 and 230 projects, respectively. The Mediterranean and Middle East had around 100 sites, Latin America 50 and Sub-Saharan Africa 20. These numbers are growing rapidly⁸.

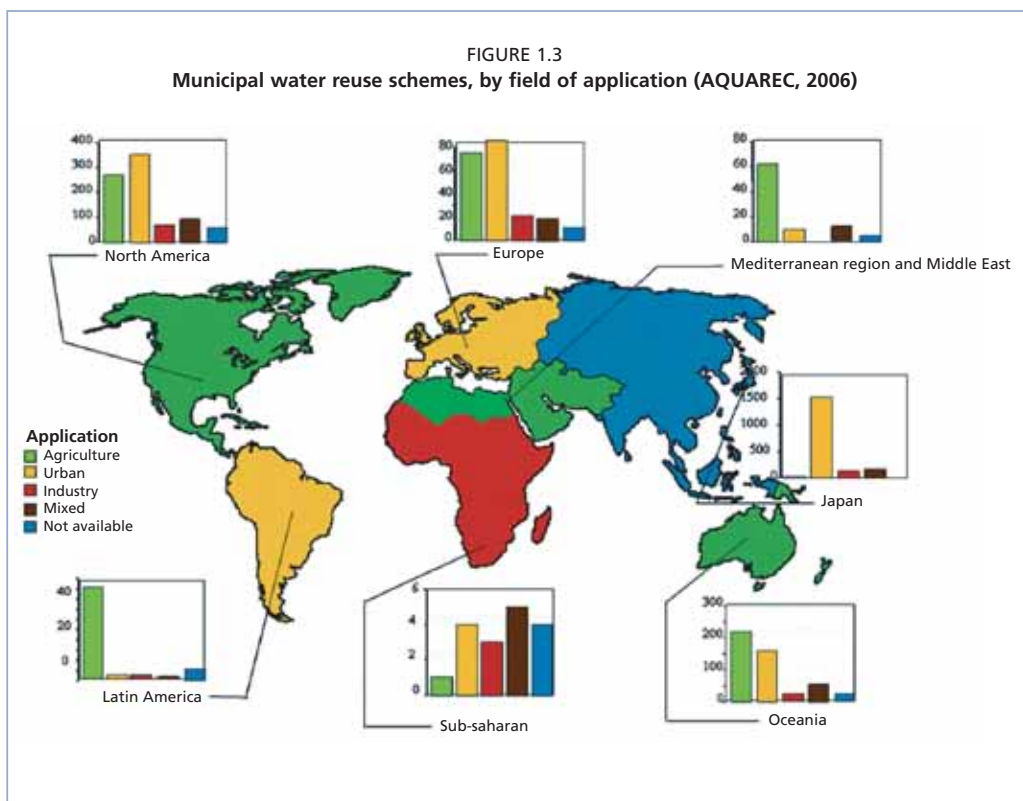
Figure 1.3 shows the number of municipal water reuse schemes across different regions of the world according to field of reuse application. Applications are arranged in four main categories: agriculture, urban, industrial and mixed (multipurpose).

It is estimated that, within the next 50 years, more than 40% of the world's population will live in countries facing water stress or water scarcity. Growing competition between the agricultural and urban uses of high-quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase the

⁶ And more fully in Turner (2004).

⁷ This particular exercise from the World Bank did not include water as one of the types of natural capital.

⁸ The monthly journal *Global Water Intelligence* contains a regular Reuse Tracker with data on all new reuse projects.

**BOX 1.1****Integrated wastewater treatment and reuse in Tunisia**

Tunisia has a high coverage of sanitation, with 96% in urban areas, 65% in rural areas and 87% overall. Industries also have to comply with national standards for the discharge of wastewater into sewers, and are given subsidies for pre-treatment processes. 78% of wastewater collected is treated, mainly to secondary biological standards.

30-43% of treated wastewater is used for agricultural and landscape irrigation. Reclaimed water is used on 8 100 ha to irrigate industrial and fodder crops, cereals, vineyards, citrus and other fruit trees. Regulations allow the use of secondary-treated effluent on all crops except vegetables, whether eaten raw or cooked. Golf courses are also irrigated with treated effluent.

Tunisia launched its national water reuse programme in the 1980s. Treatment and reuse needs are combined and considered at the planning stage. Some pilot projects have been launched or are under study for industrial use and groundwater recharge, irrigation of forests and highways and wetlands development. The annual volume of reclaimed water is expected to reach 290 Mm³ in 2020, when it will be equivalent to 18% of groundwater resources and could be used to counter seawater intrusion in coastal aquifers.

pressure on this ever scarcer resource. Wastewater may be a more reliable year-round source of water than other sources available to farmers, though this is dependent on the primary sources of urban water also being reliable. The value of recycled water has long been recognized by farmers not only as a water resource, but also for the nutrients it contains for plant growth and soil conditioning properties. Currently, the total land irrigated with raw or partially diluted wastewater is estimated at 20 million hectares in fifty countries, which is approximately 10% of total irrigated land (FAO Wastewater Database). Recycling and reuse of wastewater can relieve pressure on water resources due to abstraction from surface water or aquifers, provided that its impact on downstream flows is manageable (Box 1.1).

In Europe, most of the reuse schemes are located in the coastal areas and islands of the semi-arid Mediterranean regions and in highly urbanized areas. Water scarcity is a common constraint in the Mediterranean region with varying precipitation, sometimes below 300 mm to 500 mm per year in southern parts of Spain, Italy, Greece, Malta and Israel. At times, water resources may fall below the chronic water scarcity level of 1 000 m³ per inhabitant per year. Long distances between water sources and users also create serious regional and local water shortages, and water scarcity may worsen with the influx of peak summer tourists to the Mediterranean coasts and demographic growth, as well as drought and potential climate change-related impacts.

A limited number of European countries have guidelines or regulations on wastewater reclamation and reuse. Article 12 of the European Wastewater Directive 91/271/CEE states: “treated wastewater shall be reused whenever appropriate.” The term ‘appropriate’ still lacks legal definition, and the EU countries themselves have to develop their own national regulations. Nevertheless, water reuse is an option for implementation in the European Water Framework Directive (WFD) that emphasizes

BOX 1.2

Potential impact of EU Water Framework Directive on wastewater reuse

- * Requirement for municipal water conservation plans, emphasizing reuse.
- * Pressure for development of financial incentives for local governments, developers, and property owners to adopt water conservation and reuse measures and implement public education programs. Incentives can include tax incentives, tax credits, grants and low interest loans. If there is an absence of subsidies, incentives to improve environmental performance by forcing users to innovate or reduce water use might be considered.
- * Requirement that, by 2010 water pricing policies be introduced that provide incentives to efficient water uses, aiming to achieve a good ecological status of the water bodies.
- * As part of river basin development plans, need to identify the least expensive water supply alternatives that provide the highest level of water sustainability at the river catchment level.
- * In pricing conventional and alternative water supplies, need to ensure that the user bears the costs of providing and using water, reflecting its true costs. This implies a stricter application of two major principles: the *polluter-pays principle* and the *full cost-recovery principle*, which means that: “the recovery of the costs of water services including environmental and resource costs associated with damage or negative impact on the environment should be taken into account” when applying the polluter pays principle. This implies that tariffs related to conventional and alternative water sources will have to be reviewed and adjusted. The financial, social and environmental burdens of effluent disposal to the environment should be considered in the economic analysis; thus the true value of reclaimed water would be reflected net of externalities.

Source: Aquarec (2006)

TABLE 1.4
Agricultural crops grown with untreated and treated municipal wastewater

Types	Examples of crops
Field crops	Barley, corn (maize, <i>Zea mays</i>), oats, wheat
Fibre and seed crops	Cotton, flower and vegetable seeds
Vegetable crops that can be consumed raw	Broccoli, cabbage, cauliflower, celery, chilli pepper, green tomato (tomatillo), lettuce, pepper, tomato
Vegetable crops that will be processed before consumption	Artichoke, asparagus, beans, onion, peanut, potato, spinach, squash, sugar beet, sunflower
Fodder and forage crops	Alfalfa, barley, clover, cowpea, hay, maize, pasture
Orchards and vineyards	Fruit trees, apple, avocado, citrus, lemon, peach, pistachio, plum, olive, date palms, grapevines
Nurseries	Flowers
Commercial woodlands	Conifers, eucalyptus, poplar, other trees

Sources: Asano *et al.* (2007), Jiménez and Asano (2008), Lazarova and Bahri (2005), Pescod (1992), California State Water Resources Control Board (1990).

the need to integrate health, environmental standards, service provision and financial regulation for the water cycle, in order to achieve overall efficiency and protection of the water cycle (Okun, 2002). The WFD encourages the integration of water reuse options in an integrated water supply and disposal system, in various ways (Box 1.2).

Reclaimed water for agricultural use

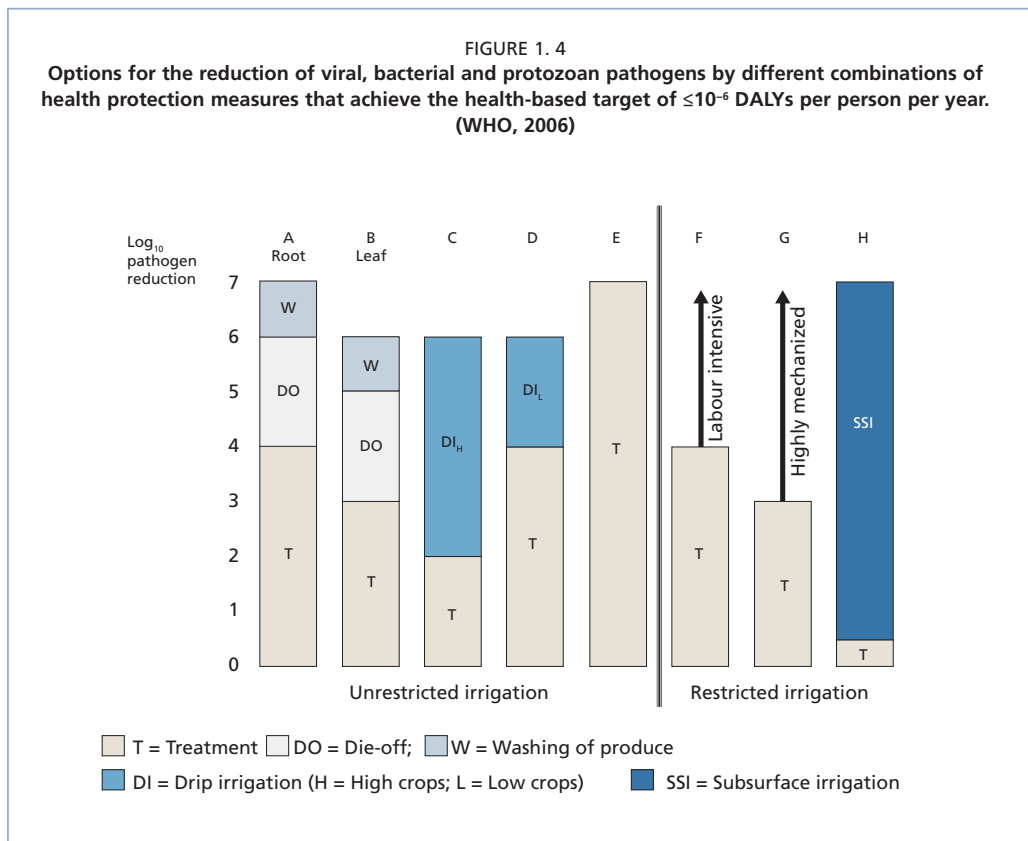
There is evidence of the reuse of wastewater in agriculture since ancient Greek and Roman civilisations (Angelakis and Durham, 2008). Because agriculture uses nearly 70 percent of water withdrawals, it is to be expected that in times and regions of water scarcity farmers would turn to domestic or urban wastewater as a water source. While recycled water is a relatively small component of water supply overall, in some countries it has a prominent role, especially for agriculture - as in Kuwait where reused water accounts for up to 35 percent of total water extraction. In agriculture, the UN has estimated that at least 20 million ha in 50 countries are irrigated with raw or partially diluted wastewater, around 10 percent of total irrigated land. About 525 000 ha are irrigated with reclaimed water. Despite progress in the control of water pollution from municipal wastewater, irrigation with untreated wastewater still prevails (Jiménez and Asano, 2008a; Jiménez and Asano, 2008b; Lazarova and Bahri, 2008; Bahri, 2009).

Agriculture is the predominant user of reclaimed water, as it is of freshwater. The use of reclaimed water for agricultural irrigation has been reported in at least 44 countries with a total use of over 15 Mm³/d (Jiménez and Asano, 2008b). The wide array of crops grown with untreated and treated wastewater is shown in Table 1.4 (this table is not comprehensive, but it illustrates the most common crops). Many more varieties of crops could be grown with reclaimed water under appropriate conditions (Asano *et al.*, 2007; Lazarova and Bahri, 2005; Mujeriego, 1990; Pescod, 1992; Pettygrove and Asano, 1985).

1.6 PUBLIC HEALTH CONCERNS & GUIDELINES

Concern about the risks to public health from the greater use of recycled water is a serious obstacle to the greater spread of this practice.

Many countries base their rules and regulations on this matter on a combination of the California guidelines - the first publications on this topic - and WHO recommendations. For many years, the California standards were the only legally valid reference for reclamation and reuse with the goal of zero risk and with expensive compliance requirements. For example, they stipulate that unrestricted reuse of wastewater requires, after secondary treatment, additionally advanced treatment with a coagulation/filtration step followed by chlorination/de-chlorination to strive for a 0 Fecal Coliform/100 mL limit (Aquarec, 2006) to produce an effluent that is virtually pathogen-free. This technology, referred to as the Title 22 benchmark, is considered



the yardstick for unrestricted irrigation, against which all other systems are evaluated because of its long history of successful practice. In Europe, more than half of the tertiary treatment technology is derived from this concept even though full Title 22 treatment is applied only in a few instances (Koo-Oshima, 2009).

In 2006 WHO guidelines for safe use of wastewater apply risk management approaches under the Stockholm Framework and recommend defining realistic health-based targets and assessing and managing risks. The guidelines refer to the level of wastewater treatment, crop restriction, wastewater application methods and human exposure control. The health based targets used by WHO apply a reference level of acceptable risk [e.g. 10^{-6} Disability Adjusted Life Years (DALYs)]. The DALY is a quantitative indicator of 'burden of disease' that reflects the total amount of healthy life lost; that is, the quality of life reduced due to a disability, or the lifetime lost due to premature mortality. Depending on circumstances, various health protection measures - barriers - are possible, including waste treatment, crop restriction, adaptation of irrigation technique and application time, and control of human exposure.

Partial treatment to a less demanding standard may be sufficient if combined with other risk reduction measures to achieve the $\leq 10^{-6}$ risk (or 1 in 100 000). Figure 1.4 shows the options for risk reduction from pathogens (*i.e.*, viruses, bacteria, protozoa, helminths) in recycled water used for irrigation (WHO, 2006). A major observed risk is from helminths in developing countries where sewage is used with no or minimal treatment. Epidemiological studies from Mexico have reported that children of farmers who live near fields irrigated with untreated wastewater have a higher prevalence of round worm infections than the general population (Peasey et al., 2000). In these studies, infection rates are inversely correlated with the level of sewage treatment.

TABLE 1.5
Water quality categories for different final uses of reclaimed wastewater defined by the Aquarec project (Salgot et al., 2006)

Microbial category	Chemical category	Specific final use
I	1	Residential uses (gardening, toilet flushing, home air conditioning systems, car washing)
	-1	Aquifer recharge by direct injection
II	1	Bathing water
III	1	Urban uses and facilities: irrigation of open access landscape areas (parks, golf courses, sport fields ...); street cleaning, fire-fighting, ornamental impoundments and decorative fountain; greenhouse crops irrigation-Irrigation of raw-consumed food crops. Fruit trees sprinkler irrigated: unrestricted irrigation.
	1	Irrigation of pasture for milking or meat animals: Irrigation of industrial crops for canning industry and crops not raw-consumed. Irrigation of fruit trees except by sprinkling; irrigation of industrial crops, nurseries, folder, cereals and oleaginous seeds.
IV	2	Impoundments, water bodies and streams for recreational use in which the public's contact with the water is permitted (except bathing)
	1	Irrigation of forested areas, landscape areas and restricted access areas; forestry
V	2	Impoundments, water bodies and streams for recreational use in which the public' contact with the water is permitted (except bathing)
	3	Aquifer recharge by localised percolation through the soil
VI	2	Surface water quality, impoundments, water bodies and streams for recreational use, in which the public's contact with the water is not permitted
VII	4	Industrial cooling except for the food industry

Source: Direct aquifer recharge should be drinking water quality, potable water should not be produced from reclaimed wastewater without advanced tertiary treatment like reverse osmosis or percolation through the soil (i.e. indirect aquifer recharge).

Instead of focusing only on the quality of wastewater at its point of use, the WHO-FAO guidelines recommend defining realistic health-based targets and assessing and managing risks along the continuum – from wastewater generation to consumption of produce cultivated with wastewater – to achieve these targets. This allows a regulatory and monitoring system in line with the socio-economic realities of the country or locality.

For the EU, the Aquarec project proposes seven quality categories for different types of reuses (Table 1.5) with microbial and chemical limits for each category (Salgot et al., 2006).

In addition to microbial contaminants in wastewater, chemical contaminants can also be expected from: inorganic salts, nutrients, heavy metals in organic matter, detergents, trace pollutants, pesticides, chlorination by-products such as N-nitroso-dimethylamine (NDMA), chloroform, and endocrine disrupting chemicals and pharmaceuticals. Highly saline irrigation water can severely degrade soils as well as high boron concentrations (>0.4 mg/L) with toxic effects on plants.

Health protection measures

A variety of health protection measures can be used to reduce health risks to consumers, workers and their families and local communities, some of which have already been mentioned. Hazards associated with the consumption of wastewater-irrigated products include excreta-related pathogens and some toxic chemicals. The risk from infectious pathogens is significantly reduced if foods are eaten after thorough cooking. Cooking has little or no impact on the concentrations of toxic chemicals that might be present. The following health protection measures (barriers) have an impact on product consumers:

TABLE 1.6
Examples of Crops Irrigated with Treated Wastewater

Types	Examples of crops	Treatment requirements
Field Crops	Barley, corn, oats	Secondary, disinfection
Fiber and seed crops	Cotton flax	Secondary, disinfection
Vegetable crops that can be consumed raw	Avocado, cabbage, lettuce, strawberry	Secondary, filtration, disinfection
Vegetable crops processed before consumption	Artichoke, sugar beet, sugarcane	Secondary, disinfection
Fodder crops	Alfafa, barley, cowpea	Secondary, disinfection
Orchards and vineyards	Apricot, orange, peach, plum, grapevines	Secondary, disinfection
Nurseries	Flowers	Secondary, disinfection
Commercial woodlands	Timber, poplar	Secondary, disinfection

Adapted from Lazarova and Bahri (eds.) 2005

- wastewater treatment,
- crop restriction,
- wastewater application techniques that minimize contamination (e.g. drip irrigation),
- withholding periods to allow pathogen die-off after the last wastewater application,
- hygienic practices at food markets and during food preparation.
- health and hygiene promotion,
- produce washing, disinfection and cooking,
- chemotherapy, immunization and Oral Rehydration Therapy.

The highest quality recycled water is achieved by dual membrane (micro-filtration and reverse osmosis) tertiary treatment processes (Aquarec, 2006). This is, however, expensive, and is best suited for high value cash crops or aquifer recharge. A pragmatic approach is to make wastewater treatment “fit-for-purpose”, depending on its intended use and the degree of human contact entailed (e.g. whether the produce is eaten raw, peeled, cooked, used for fodder, industry - cotton, biofuels, or whether the water is used for fruit trees, etc.) Various crops can be irrigated with reclaimed water (Table 1.6) and guidance is available on all agronomic aspects of irrigation using reclaimed water.⁹

The FAO and WHO have developed a “Code of Hygienic Practice for Fresh Fruits and Vegetables.”¹⁰ This takes a *food chain* approach, assessing risks *from farm to fork*, taking account of all aspects of crops from primary production to consumption. Risks can occur at the primary production stage in the farm environment (through soil, wildlife, proximity to urban or industrial development, waterways, susceptibility to run-off, etc.), in the source of irrigation wastewater, or through manure, soil amendments, pesticides and even the seeds or plants themselves. Risk assessment should also consider the exposure of workers (growers, pickers) and issues arising in transport from the field to the packing/processing houses and the post-harvest handling of fresh produce.

Potential sources of contamination and hazards in the food chain include pathogenic bacteria (*Salmonella*, enterohaemorrhagic *Escherichia coli*, *Campylobacter*, *Listeria*, *Shigella*, *Yersinia*), parasites (*Cryptosporidium*, *Cyclospora*, *helminths*) and

⁹ FAO publishes various reports such as Water Quality for Agriculture as well as studies on the salt tolerance of various crops under the Irrigation and Drainage Report Series. They are available from the website: http://www.fao.org/nr/water/infores_pubs_quality.html.

¹⁰ Expert Group of the Codex Alimentarius Committee on Food Hygiene for Fresh Produce.

viruses (hepatitis A, noroviruses). Recently, problems have emerged with pathogens in fresh produce. Leafy greens pose the greatest concern in respect of microbiological hazards. Leafy greens are grown and exported in large volume and have been linked with multiple outbreaks involving many cases of illness in at least three regions of the world. These crops are grown and processed in diverse and complex ways ranging from in-field packing to pre-cutting and bagging which can amplify foodborne pathogens. International standards such as Codex Alimentarius (WHO, 1993) play a critical role in protecting the health of consumers and facilitating international trade.

1.7 WASTEWATER QUALITY: THE BASIC TREATMENT PROCESSES

Municipal sewage treatment involves the main processes (WELL, undated) illustrated below but extensive definitions are not provided here as they can be found in specific engineering texts. In addition, it is beyond the scope of this report to include discussions on lagoons and extensive treatment systems.

- *Preliminary*: screening and grit removal to remove coarse solid and other large materials often found in raw wastewater. It includes coarse screening and grit removal.
- *Primary*: sedimentation – simple settlement of solid material in a primary settling tank. Solid particles settle at the bottom, and oils and greases rise to the top. This material is removed as sludge, for separate treatment.
- *Secondary*: the further removal of common pollutants, usually by biological processes to remove dissolved organic material. Wastewater from primary treatment flows into an aeration tank, to which micro-organisms are added to consume the remaining organic matter. Following aeration, the mixture is clarified. The residue is removed as sludge, for separate treatment and disposal.
- *Tertiary*: involves the removal of specific pollutants, e.g. nitrogen or phosphorus, or specific industrial pollutants. The effluent may then be disinfected to kill harmful micro-organisms by chlorination or ultraviolet disinfection. The residual chlorine is then removed.
- *Processing of solids and sludge*: solids from the primary and secondary processes are sent to a digester which produces by-products including methane and water. The final residue is sent to landfills or incinerators, or used in agriculture for fertilizer or soil beneficiation¹¹.

Although untreated sewage is quite widely used in agriculture in many locations, the more typical situation involves the reuse of effluent treated to at least secondary levels. As noted in section 1.6 this can meet public health concerns, with appropriate use limitations and safeguards. Effluent treated to secondary levels still contains nutrients of value to farmers, whereas tertiary treatment removes nitrogen and phosphorus which are crucial ingredients for fertilization.

In certain localities (e.g. the Llobregat Delta taken as one of the case studies in Chapter 2) the wastewater effluent has an excessively high salt content, which needs to be removed to make it usable by farmers. In this specific case, an Electrodialysis Reversal (EDR) unit is being installed to provide additional treatment for the effluent being sent to farms.

The choice of the degree of wastewater treatment is normally made for reasons of environment, amenity and public health. However, where extra treatment is being considered as part of a reuse project it is desirable to minimize costs by employing technologies that can offer long-term reliable operation, low operating costs, minimize the use of chemicals and be as compact as possible (Sorgini, 2007). Where space permits, the additional facilities can be built inside the existing WWTP premises.

¹¹ Disposal of sludge at sea is another option, though this is now banned in EU countries, and elsewhere.

1.8 ENVIRONMENTAL, INFRASTRUCTURAL AND LEGAL ISSUES

Environmental

The potential impact of using recycled water on human health was considered in section 1.6. Wastewater contains potential pathogens for plants, animals and humans transmitted through the food-web or the environment: nitrates, *Giardia* and *Cryptosporidium*, endocrine disruptors, other persistent organics, etc., have been matters of recent concern.

Different types and degrees of wastewater treatment can affect the presence of contaminants in the effluent released for recycling. Where this contains heavy metals or other harmful substances there is a risk of their long term build-up in soil. In some cases the contaminant may be present in the source water (as in the Spanish case studies, where salinity is a problem being dealt with through a reverse-osmosis desalination unit).

Discharging inadequately treated wastewater could cause eutrophication of surface waters – hence the environmental directives of the EU and other countries requirement treatment to tertiary levels in specified cases. In these circumstances, farmers confer an environmental *benefit* by using recycled water where nutrients such as phosphorous and nitrogen are absorbed by the crop rather than discharged into other water bodies.

Water reuse may be a means of reducing wastewater discharges. Reclaimed water has also been used to restore wetlands or streams or groundwater aquifers by replenishing flows and water table levels. Reclaimed water may provide a source of water to promote growth in water scarce regions or to increase income of resource-poor urban and peri-urban farmers.

TABLE 1.7
Factors affecting the choice of irrigation method and special measures required for reclaimed water applications

Irrigation Method	Factors affecting choice	Special measures for irrigation with reclaimed water
Flood irrigation	Lowest cost Exact levelling not required Low water use efficiency Low level of health protection	Thorough protection of field workers, crop handlers, and consumers (eg. protective equipment)
Furrow irrigation	Low cost Levelling may be needed Low water use efficiency Medium level of health protection	Protection of field workers, possibly of crop handlers and consumers (eg. protective equipment)
Sprinkler irrigation	Medium to high cost Medium water use efficiency Levelling not required Low level of health protection (due to aerosols)	Minimum distance 50-100 m from houses and roads Water quality restrictions (pathogen removal) Anaerobic wastes should not be used due to odour nuisance Use if mini-sprinklers
Subsurface and drip irrigation	High cost High water use efficiency Higher yields Highest level of health protection	No protection measures required Water quality restrictions (filtration) to prevent emitters from clogging

Source: Lazarova and Bahri (2005, 2008).

Infrastructure and conveyance

In some situations (most of the case studies in chapter 2), treated wastewater of the required quality is available in sufficient quantities, or decisions have been taken to upgrade existing WWTPs to produce such effluent. However, in other cases some upgrading of WWTPs will be required and there may even be a need to add specific processes (e.g. desalination) to render the wastewater suitable for farm use.

Local geography is important for the feasibility of recycling schemes. The source of reclaimed water needs to be in reasonable proximity to the intended users, in order to minimise the need for new conveyors and the cost of pumping. If existing conveyors could be used, this would obviously be advantageous. Equally, if not more, importantly, the economics of reuse schemes normally rely on an exchange of fresh water entitlements between farmers and cities: this must be physically and geographically feasible. The freshwater entitlement must be accessible to the city at a reasonable cost, with minimal new conveyance infrastructure and pumping, compared with the alternatives. The case studies in chapter 2 include cases where the transfer is highly feasible in these terms, as well as those where its feasibility is not obvious.

TABLE 1.8
Classification of cultivation practices as a function of the health risk for agricultural workers

Low risk of infection	High risk of infection
Mechanized cultural practices	High dust areas
Mechanized harvesting practices	Hand cultivation
Crop dried prior to harvesting	Hand harvest of food crops
Long dry periods between irrigations	Moving sprinkler equipment
	Direct contact with irrigation water

Source: Lazarova and Bahri (2005)

TABLE 1.9
Levels of risk associated with different types of crops irrigated with reclaimed water

Lowest risk to consumer, but field worker protection still needed	Medium risk to consumer and handler	Highest risk to consumer, field worker, and handler
Agricultural irrigation		
Industrial crops not for human consumption (e.g., cotton, sisal)	Pasture, green fodder crops	Any crops eaten uncooked and grown in close contact with wastewater effluent (e.g., fresh vegetables such as lettuce or carrots, spray-irrigated fruits)
Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar beets)	Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that sprinkler irrigation must not be used (e.g., tree crops, vineyards)	Spray irrigation regardless of type of crop within 100 m of residential areas or places of public access
Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens	Crops for human consumption normally eaten only after cooking (e.g., potatoes, eggplant, beets)	
Fodder crops and other animal feed crops that are sun-dried and harvested before consumption by animals	Crops for human consumption, the peel of which is not eaten (e.g., melons, citrus fruits, bananas, nuts, groundnuts)	
	Any crop not identified as high risk if sprinkler irrigation is used	
Landscape irrigation		
Landscape irrigation in fenced areas without public access (e.g., nurseries, forests, green belts)	Golf courses with automated irrigation scheduling	Golf courses with manual irrigation Landscape irrigation with public access (e.g., parks, school playgrounds, lawns)

Source: Lazarova and Bahri (2005)

Irrigation infrastructure and methods

The second aspect is the feasibility of reuse from the viewpoint of irrigation infrastructure. Certain methods of irrigation may reduce the exposure of crops to pathogens, whereas others are not suitable. Sprinklers, for instance, are not advisable for lettuce irrigation, due to the capacity of the crop to hold water between its leaves and thus improve the survival of pathogens. Other crops need specific irrigation methods, *e.g.*, forage grass is usually irrigated with sprinklers and is difficult to do so with drippers unless the soil is heavy.

Some of the general problems of using reclaimed water for irrigation are the likelihood of algal and rooted macrophyte growth in open channels, the formation of biofilms in pipelines, and the re-growth of pathogens along the reclamation and reuse systems. Some of these effects can be mitigated by using chemicals or other means that change the composition of reclaimed water.

Irrigation practices and devices (*e.g.* drip or porous pipes) which limit contact with humans, sensitive parts of the environment, or parts of plants, are less risky to health than those (*e.g.* sprinklers, aerosols) which broadcast reclaimed water in a diffused manner. Some of the factors to consider in the choice of irrigation method, from the viewpoint of the impact on workers and consumers, are illustrated in Tables 1.7, 1.8 and 1.9.

Legal framework & water rights

Wastewater reuse commonly involves a transfer of entitlements to freshwater between farmers and municipalities (or other water users). In principle, both parties should be able to benefit from such an exchange of rights where conditions are favorable. However, unless compulsion is ruled out, a voluntary exchange depends on the farmers having secure and alienable rights to the water that they can transfer – either in water markets or in return for compensation. They must possess such legal rights, and their national legal system must permit the transfer or sale of these rights to others. Many legal systems do not provide these assurances. Consequently, municipalities, which stand to gain (or save) financially, and which could fund reuse projects, may not get sufficient reassurance of their rights to the freshwater “exchanged” for the recycled effluent. Where the water problems of a city or region are sufficiently grave, some compulsion might be required to achieve a solution. Even then, however, questions of rights and compensation are likely to arise.

Formal or informal legal rights may also attach to the use of wastewater (treated or not) by farmers or other groups, who may claim compensation if this is diverted for use elsewhere (Bahri, 2009).