Promoting the Use of Reclaimed Water in the Mediterranean: Planned Water Reuse in the Mediterranean

Rafael Mujeriego, PhD
Professor of Environmental Engineering
Universidad Politécnica de Cataluña
Barcelona, Spain

Sponsored by

WHO/EURO Project Office
Mediterranean Action Plan
World Health Organization
Regional Office for Europe

March 2006

TABLE OF CONTENTS

1. INTRODUCTION

Freshwater has been a precious natural resource in the Mediterranean Basin since ancient times. Urban, agricultural, commercial and industrial activities flourished around abundant freshwater sources, frequently made readily available through ambitious canals, aqueducts and storage basins. The Mediterranean basin has numerous and eloquent examples of Roman constructions, some still in service. Subsequent civilizations further developed the efficient use of water for urban use, and especially for ornamental uses and agricultural irrigation. The beautiful Moorish gardens in Alhambra, Spain, and the Water Courts in Valencia, Spain, are vivid and practical examples of those traditions.

The privileged climatic conditions prevailing in the Mediterranean basin, particularly in its southern rim, have made irrigated agriculture a highly attractive economic activity since early times. The expansion of the European Union and the increased levels of commercial exchange among EU member states and among those and other neighboring states have greatly contributed to expand and modernize irrigated agriculture. The new objectives of this agricultural activity are to produce higher quality crops, while fostering higher crop yields.

However, the expansion of irrigated agriculture and landscape irrigation, either for ornamental purposes or playgrounds, has resulted in an increasing conflict between irrigation areas and equally expanding urban areas that have priority rights for water use, according to traditional legislation in most countries of the region.

Urban growth has resulted in increasing demands for water supply and water sanitation, which have resulted in new sources of larger flows of treated effluent from wastewater treatment facilities. Those treated effluents, adequately purified, could serve as a new source of water supply for numerous beneficial uses that do not require potable water quality. The concept and the practical experience of planned water reuse around the Mediterranean region offer a real alternative to those uses. Instead of domestic and other uses competing for the same water flows, planned water reuse offers an alternative for using the same water flow in several subsequent uses: urban users first, after potable water treatment, and then other users, after wastewater treatment and water reclamation.

Water reclamation and planned water reuse have an extensive and successful record in the Mediterranean region and other semi-arid zones of the world as California and Florida. They are water management practices approved and supported by public health and environmental agencies in both developed and developing countries. However, there are still numerous cases of distrust, if not overt rejection, concerning the use of reclaimed water, which need to be further evaluated and resolved, before planned water reuse can be fully accepted in a given geographical area for a given beneficial use.

2. OBJECTIVES

The objective of this report is to describe and assess currently applied water reuse strategies to determine its potential for promoting the use of reclaimed water for different beneficial uses in the Mediterranean region.

The specific objectives of this report are:

1. To describe the challenges currently faced by water resources management in the Mediterranean region.

2. To highlight the benefits and the requirements of using reclaimed water.

3. To review the public perception issues raised by planned water reuse.

4. To describe potential sources of treated water, and the techniques available to produce reclaimed water of suitable quality for different beneficial uses.

5. To identify the potential beneficial uses of reclaimed water in the region.

6. To review international public health recommendations and guidelines for reclaimed water quality and reclaimed water use.

7. To review proposed quality criteria and standards for agricultural and landscape irrigation with reclaimed water.

8. To review agronomic quality criteria and economic management strategies for planned water reuse in agricultural irrigation in coastal areas.

9. To describe the role of water reclamation and reuse in integrated management of water resources, and alternative options for action.

10. To present several case studies of successful use of reclaimed water in the Mediterranean region.

11. To propose convincing arguments, new incentives and novel approaches to consolidate and further advance planned water reuse projects in the Mediterranean region.

3. WATER RESOURCES MANAGEMENT IN THE MEDITERRANEAN

Water resources management in the Mediterranean region is currently confronted with several challenges:

1. A significant population increase, both on permanent populations and in seasonal visitors. Coastal areas have become an attraction point for a considerable number of nationals, an increasing number of international residents (temporary residents), and a large number of tourists, particularly during the summer. That population growth has resulted in mounting pressures on water supply and water sanitation. Larger flows for urban water supply often mean reduced flows for agricultural irrigation. However, the larger flows of treated wastewater available during summer months offers a new water supply source for uses that don't require potable water quality, such as landscape and agricultural irrigation, environmental enhancement, and industrial uses.

2. The consideration of the environment as an essential component of the water resources management framework. The educational effort undertaken by national and international institutions and agencies over the last decades has resulted in a real and increasing public concern for the aquatic environment, particularly continental surface waters and coastal waters. An increasing number of laws and regulations have been passed to protect the aquatic environment. The net result has been a new water allocation system that assigns increasing portions of surface water and groundwater to environmental preservation and enhancement.

3. The need to achieve further advancements in water sanitation, particularly in coastal areas. An increasing number of wastewater treatment plants has been planned and constructed, which has resulted in the production of increasing flows of treated effluent. Those treated flows can be considered for numerous beneficial uses, other than just disposal and dilution into coastal waters.

4. The difficulties of all sorts, political, social, technical and even economical, to generate significant flows of new water resources using traditional management strategies. Those controversial options include dam construction and basin transfers, and particularly large scale desalination facilities. Two of the main concerns raised by those options are their large capital investments and their specific energy requirements.

5. The recurring drought episodes that have affected some Mediterranean areas over the last decades. Although drought episodes have created considerable tensions among water users, they have helped in promoting new and more efficient water management strategies for water storage, water conservation and water use, and to a search for new or non conventional water sources.

4. BENEFITS AND REQUIREMENTS OF USING RECLAIMED WATER

4.1. BENEFITS

The water balance in a given geographical area can be derived as the difference between the annual water contributions, resulting from rainfall and flow contributions from rivers, aquifers and watershed transfers, and the annual water losses, o irrecoverable losses, through atmospheric evaporation and discharges into the sea (Pettygrove and Asano, 1984, 1985; Mujeriego, 1990). Any water conservation action aimed to reduce those irrecoverable losses will improve the temporal and geographical availability of water for other beneficial uses that can take place during the year. In this context, water reclamation and planned water reuse can actually provide a net increment of the water resources available in a given area only if those water flows are currently lost from the system, through evapo-transpiration in inland areas or discharge into the sea from coastal areas.

Although planned water reuse in inland areas does not increase available water resources, it provides an opportunity for improving water resources management. By using the same water flow in successive uses, each with decreasing water quality requirements, instead of allocating that flow among simultaneous competing users, it is possible to expand water resources availability, both in inland and coastal areas.

Planned water reuse in general, and specifically for agricultural and landscape irrigation, has numerous potential benefits; the following can be highlighted:

1. A new water supply source, capable of contributing additional water resources, either as net resources or as alternative resources that can liberate water resources of high quality currently used. The water resources liberated can be assigned to beneficial uses with higher water quality requirements, such as public water supply.

2. A reduction of the treatment and disposal costs of treated effluents. Planned reuse of treated effluents will offer a real economic advantage when quality requirements for the beneficial use considered are less restrictive than those applicable to receiving waters, where treated effluents are currently disposed.

3. A decrease of the contaminant loads to natural water streams, particularly when planned water reuse is applied to agricultural, forest or landscape irrigation. Water reuse through irrigation provides an opportunity for low biodegradable organic substances to be biologically mineralized in the soil matrix, and offers a chance for the resulting inorganic components to be assimilated by vegetation.

4. A postponement, reduction or even complete suppression of the additional water treatment facilities necessary for drinking water supply, decreasing its negative effects on both natural water streams and water supply costs.

5. A potential energy savings derived from abandoning new projects that would be necessary to bring additional water flows from locations farther away than the water reclamation facility.

6. A reduction of the atmospheric emission rates of carbon dioxide, resulting from lower energy consumption rates.

7. A beneficial use of plant nutrients, mainly nitrogen and phosphorous species, when reclaimed water is used for agricultural and landscape irrigation.

8. Higher supply reliability. Treated water flows have a higher reliability than numerous surface water streams, particularly in semi-arid areas like those of the Mediterranean coast. Furthermore, the seasonal patterns of local and visiting populations in most Mediterranean coastal areas result in larger flows of treated water during the summer, when irrigation water demands are the highest.

In summary, planned water reuse for agricultural and landscape irrigation offers a supply reliability much higher than conventional water sources, ensuring availability of flows particularly during the summer season, allowing a beneficial use of plant nutrients (nitrogen and phosphorous), promoting a more efficient management of water resources, and providing an opportunity for surface and groundwater of pre-potable quality to be used for drinking water supplies.

4.2. REQUIREMENTS

One of the determining factors for the implementation and development of planned water reuse is the formal adoption of a set of quality criteria and standards applicable to reclaimed water intended for different beneficial uses. Among the numerous substances added to water during its domestic and urban use, the following can be mentioned: dissolved salts, plant nutrients, pathogenic microorganisms, toxic and bio-accumulative inorganic substances, and trace organics (Pettygrove and Asano, 1984).

To produce a reclaimed water of the highest possible quality, the commonly adopted criteria is to use treated effluents of urban origin, as a first alternative, leaving industrial effluents for unusual situations. For the same reason, treated effluents with the largest fraction of domestic wastewater are preferred. However, it must be noticed that treated effluents from specific types of industrial activities (e.g., food industry) may offer a water source of comparable quality to that from urban areas.

To ensure that undesirable contaminants reach the water reclamation facility, and disturb or even prevent the water reuse project, an efficient source control program has to be implemented. The program should include a pollutant discharge ordinance and a public education and outreach program, to ensure that no undesirable compounds are disposed into the sewage network system. Those requirements will preserve the integrity of the network itself, as well as the wastewater treatment process and the water reclamation process.

Transporting reclaimed water from the reclamation facility to the actual point of use is an essential requirement of any water reuse project. That normally involves the construction of a new or dual water distribution system, particularly when water reuse is implemented in areas that were not previously irrigated. For economic reasons, new distribution networks for reclaimed water are commonly implemented in a gradual manner, starting with user groups that have the largest total water demands and are closer to the reclamation plant, and expanding subsequently to reach new urban zones or users with lower reclaimed water demands.

Reclaimed water use requirements are an essential component of any environmental and public health protection strategy. In general, as restrictions on the use of reclaimed water decrease, due to higher potential exposure to persons, animals or edible products, reclaimed water quality limits increase. As a result, landscape sprinkler irrigation with reclaimed water in areas with no restriction to public access may require a secondary effluent, adequately filtered and disinfected, while agricultural reuse by subsurface drip irrigation may be conducted with an effluent mechanically treated, just to prevent clogging of water outlets.

Public health authorities give considerable attention to water use requirements, such as: 1) use of widely visible panels that indicate the nature and the intent of the water reuse project, 2) adoption of a normalized color for reclaimed water pipes (e.g., the pink color has been adopted in the USA for pipes and appurtenances used with reclaimed water), 3) use of back-flow prevention devices, 4) systematic inspections of reclaimed water connections, 5) requirement of particular irrigation schedules and sprinkler types, 6) prohibition to install water taps above the ground surface, to prevent inadvertently use for drinking purposes, and 7) use of pipe diameters and appurtenances sizes different from those normally used for drinking water supply.

Furthermore, the gradual increase of the number of water meters at reclaimed water connection points clearly illustrates the main objective of those dual distribution systems: to optimize the beneficial use of available water, instead of an alternative disposal method by agricultural and landscape irrigation.

The public signs currently used in states like California and Florida, in the USA, convey a very positive and familiar perception of water reuse, with indications such as "To conserve water, this irrigation system (or toilet flushing facilities) use reclaimed (or recycled) water"

4.3. RELIABILITY OF RECLAMATION PROCESSES

A characteristic requirement of reclaimed water projects is the need to ensure a considerable reliability of the treatment process, and an adequate management of the water reuse system. Considering that reclaimed water is frequently the only alternative water supply proposed for the beneficial use considered, without the protection that dilution with water of higher quality may offer, and considering that water reuse may commonly involve the possibility for direct exposure to water by persons, animals and plants, which can be affected in their health and development, water reclamation plants must have a high level of reliability.

Reliability of water reclamation processes has become a critical element of the design, and operation and maintenance of water reuse systems, well beyond the performance and efficiency of the processes themselves, which have to conform to the effluent quality limits required. Among the requirements commonly established to ensure the reliability of reclamation processes, it is worth to mention the need to apply continuous monitoring of certain quality parameters, the inclusion of alarms and automatic systems, the availability of spare parts, the adoption of duplicate equipments and processes, the inclusion of automatic operation of certain equipments in case of emergency, the availability of additional supplies of chemicals, particularly of disinfection agents, and the availability of electricity generators or a dual electric power supply.

To prevent the use of inadequately treated reclaimed water, which can result in an unacceptable level of environmental or public health risks, operation of water reclamation facilities may require the inclusion of some type of water storage ponds, where inadequately treated effluent can be temporarily diverted for subsequent treatment, o the provision of an alternative water discharge system.

In summary, water reclamation is currently considered a treatment process to produce a quality product. Production and marketing of this product have to be contemplated in a much larger framework than that of the traditional water pollution control projects, and with a new mentality during the design and operation of water reclamation processes. That mentality must be different from that commonly adopted during wastewater treatment processes, where the final result is commonly considered a liquid o solid residue. This new way of approaching water reclamation has contributed to make planned water reuse an essential element of integrated water resources management.

Planned water reuse, together with water storage in off-stream reservoirs and aquifers, water conservation, and water use efficiency are the new basic elements adopted to further advance integrated water resources management in semi-arid zones, such as those in Southern California (Mujeriego, 2004).

5. PLANNED WATER REUSE PERCEPTION

The following are some of the reasons most commonly offered by users and the public at large to disregard, distrust or reject the use of reclaimed water:

1. To loose traditional or consolidated water allocations rights. Even in spite of their variable quality (they frequently differ from the supposed pristine "river quality") and the supply restrictions that may be applied to them, due to increasing urban demands and severe drought episodes.

2. To adversely affect the quality and the productivity of the crops or the landscape areas irrigated with reclaimed water.

3. To promote soil contamination, and eventually adversely affect the crops cultivated on them, due to salinity, organic micropollutants, emergent pollutants and microorganisms that may be present in reclaimed water.

4. To require significant changes in growing or irrigation practices, due to the different physical, chemical and microbial quality of reclaimed water, as compared to those of surface water or groundwater conventionally used. Those changes are commonly associated to potential risks for users' safety and health.

5. To raise definite consumer rejection, or even to incur in a lack of regulatory compliance, due to either the origin of reclaimed water or to some of its specific characteristics, regardless of the real quality of reclaimed water.

6. To incur in some type of market restrictions, real or perceived, due to a lack of conformity to some type of generic regulatory specifications, or simply to commonly accepted and historical beliefs.

7. To preclude or jeopardy environmental and public health protection when reclaimed water is used for urban uses (toilet flushing, irrigation of private or public landscape areas), commercial uses, environmental uses or industrial uses.

The following sections include a detailed discussion on initiatives and projects, promoted by private and public agencies that illustrate the unfounded nature of those issues, and provide valuable reasons for considering planned water reuse as an essential component of integrated management of water resources.

6. SOURCES AND PROCESSES TO PRODUCE RECLAIMED WATER

6.1. RECLAIMED WATER SOURCES

Water reclamation builds upon treated wastewater flows. The quality of treated effluents is commonly determined by: 1) the scope of regulatory requirements applicable for public health and environmental protection, 2) the actual degree in which those regulations are enforced, and 3) the technical and economic resources available to implement those regulatory provisions.

Although water reuse can be implemented using wastewater effluents produced by simple treatment processes, water reuse is commonly considered when biologically or highly treated effluents become available. As sanitation and environmental protection programs advance, wastewater treatment requirements increase, resulting in treated effluents of higher quality. Reclamation processes are commonly introduced to fill the quality gap that it may exist between the effluent limits required for environmental protection and those required for public health protection or more specific environmental protection.

Wastewater treatment processes may be designed using either natural systems or more conventional systems that require considerable inputs of technology and energy. A combination of conventional and natural treatment systems is becoming a common option, as a result of their synergies and their water purification potential, due to the "multiple barriers" system that it provides. Wastewater treatment requirements for European Union states are established in Directive 91/271 (OJEC, 1991) and provide for a good quality secondary effluent, which can be considered for planned reuse in numerous beneficial applications.

The microbiological quality of wastewater effluents is the most specific feature to take into account when considering their potential for planned water reuse. There are numerous natural and technical processes for disinfection of treated effluents before reuse. Although detailed discussion of disinfection processes is beyond the scope of this report, it must be noted that natural processes have the potential to reduce microbiological contaminants to considerable low levels, depending on treatment time and meteorological conditions (light and temperature mainly). Conventional and newly developed technical processes can inactivate practically all pathogens present in treated effluents. Natural and technical disinfection processes are commonly applied in combination to inactivate a larger spectrum of microorganisms than that affected by a single disinfection agent. The diverse inactivation rate and the selective inactivation of specific natural processes and conventional disinfectants explain the current interest for combining them under a "multiple barriers" system, to ensure higher operating reliability and expand the spectrum of microorganisms (parasites, bacteria, and viruses) that can be inactivated.

Water reclamation includes a combination of treatment processes capable to produce an effluent that satisfies the quality limits applicable to the intended beneficial use. Implementation of a water reclamation program requires two basic and complementary elements: 1) a set of quality criteria and standards for each beneficial use considered, and 2) a series of treatment processes that can achieve the water quality requirements for each beneficial use considered.

Planned water reuse involves all the necessary arrangements to convey reclaimed water to the intended use. Implementation of planned water reuse requires: 1) a conveyance system to bring reclaimed water from the reclamation facility to the intended reuse location, 2) a storage system to balance reclaimed water production with reclaimed water use over time; otherwise, operation of the reclamation plant will depend on water reuse patterns, and 3) a set of water use requirements that establish the precautions to be taken during distribution and use of reclaimed water.

6.2. WATER RECLAMATION PROCESSES

The treatment processes required to produce reclaimed water with a microbiological quality in conformity to the WHO Health Guidelines (1989, 2006) and the USEPA (2004) Guidelines for sprinkler irrigation of agricultural areas or landscape urban areas, with no access or public exposure limitations to the water, includes four main elements:

1. The implementation of a source control program that prevents disposal into de sewage network of those contaminants that may jeopardize o prevent the use of reclaimed water. Salinity is one of the most significant elements to be considered among the elements regularly discharged into sewerage systems, either through infiltration and inflow along coastal areas, and also through drainage from construction of coastal buildings and other public facilities as marinas and amusement parks. The increase in electrical conductivity resulting from such inputs can deteriorate the operation of wastewater treatment facilities, and may certainly render the resulting reclaimed water unsuitable for agricultural and landscape irrigation.

2. A wastewater treatment system capable of producing an effluent in conformity with applicable environmental protection regulations. The provisions of European Directive 91/271 will be applicable to Mediterranean EU member states, and will require most likely a secondary biological treatment capable of producing a treated effluent with less than 35 mg/L of suspended solids, and less than 25 mg/l of BOD_5. Limitations on nitrogen and phosphorous concentrations will vary depending on the biological sensitivity of receiving water, as officially designated. Treatment requirements are normally determined by local environmental protection agencies, and are funded through water resources management programs based on fees and taxes for water use. Conformity with effluent discharge limits is mandatory, and independent of any water reclamation initiative that may be considered for the treated effluent.

3. A tertiary treatment process designed to further remove suspended solids from secondary effluent, and to adequately disinfect the treated effluent. This process is actually the water reclamation process. The water reclamation process can adopt numerous alternatives, ranging from a combination of natural processes, including conventional waste stabilization ponds and sophisticated constructed wetland systems, to a conventional water treatment process. Any of those alternatives can be in turn implemented at centralized facilities, where reclaimed water is produced and subsequently distributed to users, or in decentralized facilities, in the proximity of the point of use.

4. A storage tank, pond or lake, where reclaimed water flows can be accumulated, to balance reclaimed water produced by the treatment facility with reclaimed water supplied for the beneficial use. The storage capacity will determine the ability of the system to balance water production and water use over a given period of time. Storage capacity may cover the daily needs of reclaimed water,

or provide room for collecting reclaimed water produced during the winter months, so it can be extensively used for irrigation during the summer season.

The size of the storage facility will be determined by the need to optimize the capacity of the water reclamation facility. If the mean capacity of the reclaimed water plant exceeds water needs at some point, it will have to be put out of service. In addition, provision will have to be made for the disposal of secondary treated effluent when the reclamation plant is not operating, or when the reclaimed water produced is not needed by users.

Extensive studies and experimentation conducted in numerous water reclamation plants in different parts of the world clearly indicate that a good biological secondary effluent (e.g., less than 10 mg/l de SS and BOD_5), filtered through a granular media bed, with an eventual addition of a few milligrams per liter of coagulant (e.g., aluminum or iron salts), and subsequently disinfected with chlorine, using from 30 minutes to 2 hours contact time, can achieve a total inactivation of microbial and viral pathogens and ensure a water quality equivalent to that of drinking water (Asano et al., 1990), even if it is intended for non potable uses. Other combinations of natural and conventional treatment processes, under the "multiple barriers" approach, have the potential for achieving similar quality effluents.

The level of automation reached by water reclamation plants varies widely, depending on the quality required for reclaimed water and the characteristics of the treatment processes adopted (e.g., natural or conventional processes). Water reclamation plants built in the northern rim of the Mediterranean, and particularly in European Union member sates, normally include a secondary wastewater treatment process, as an environmental protection requirement. Conformity to the limits specified by EU Directive 91/271 is normally based on continuous monitoring of the biological process, using 24-hr composite samples.

Subsequent water reclamation processes normally include a continuous turbidity monitoring of both the secondary effluent and the filtered effluent, an evaluation of the total residual concentration of disinfectant, and a periodic analysis of coliforms or *E. coli* concentrations in batch or composite samples of reclaimed water. Helminth egg analyses are conducted in accordance to WHO Health Guidelines (1989, 2006). Experimental results obtained in water reclamation facilities in Costa Brava (northeastern coast), Costa del Sol (southern coast), and Vitoria (north inland areas), in Spain indicate a systematic absence of helminth eggs when analyzing up to 10 liters of reclaimed water produced using biologically treated secondary effluents.

In general, water reclamation plants that receive treated municipal effluents, and whose reclaimed water is to be used for municipal beneficial uses (agricultural and landscape irrigation) and also industrial uses (cooling towers) are normally operated by the corresponding public agencies, either directly or through a service company. Those water reclamation facilities resemble drinking water treatment plants, as all the operating personnel is perfectly aware of the need to produce a quality product, in conformity to the limits contractually agreed upon, and to apply urgent corrective actions to any undue changes of the treatment process, as to prevent water of inadequate quality to be delivered to users.

In general, municipal agencies are responsible for distribution and management of reclaimed water, thus providing a new quality public service. Coordination and communication with both individual users and collective users (irrigations districts, planned communities, and golf courses) is direct and friendly, as to detect any potential incident and to dispel any concern that may arise concerning the use of reclaimed water. In addition, a management option that segregates the agency in charge of wastewater treatment and that in charge of water reclamation has provided a very successful and well accepted alternative in the integrated water reclamation and reuse project of Vitoria-Gasteiz (Del Río et al., 1996; Julio López, personal communication, 2005).

6.3. TECHNOLOGICAL ADVANCES

Among the technological aspects that will contribute to further advance planned water reuse, it may be pointed out the gradual implementation of water reclamation processes based on the simultaneous use of natural and conventional water treatment processes, in combination or addition to treatment processes based on synthetic membrane filtration, ranging from microfiltration up to reverse osmosis. Although current costs of some of those alternatives can hardly justify its generalized application, it is expected that the continuous progress made by membrane developers and equipment manufacturers will result within a very few years in new technical solutions, whose costs and energy requirements should be acceptable from the economic and environmental perspective (Mujeriego and Asano, 1999; Asano et al., 1991; Asano and Mills, 1990; WPCF, 1989).

The water reclamation and reuse sector offers considerable opportunities for technological innovations, mainly considering that reclaimed water has an economical value as a new or alternative water resource. The main criteria adopted to assess future technologies will be the operational reliability of individual components, and the ability of the overall treatment process to produce reclaimed water that satisfies the quality criteria specifically adopted.

Natural treatment processes, such as maturation ponds or constructed wetlands, and tertiary or advanced treatment processes can be used as supplements to the conventional wastewater treatment processes, to diminish the concentration of dissolved or suspended contaminants, plant nutrients, specific metals and other components of concern. The choice of advanced treatment processes currently available include: granular media filtration, carbon adsorption, membrane processes, and disinfection with ozone, chlorine species, and ultraviolet light.

Application of those and future treatment technologies offer new options for water resources management, such as: 1) the use of raw materials of higher quality, 2) the use of cleaner technologies, 3) the adoption of technologies with higher water efficiency, and 4) the adoption of advanced treatment technologies that promote recovery of materials and energy, in addition to water reclamation and reuse (Mujeriego and Asano, 1999).

The progress in planned water reuse is not exclusively dependent on technological advances. Integrated management of the whole process, ranging from project planning and public hearings up to facilities operation and maintenance, plays a critical role in ensuring the success of a planned water reuse project.

In this context, it is worthwhile to mention the background information included in a research project conducted by the Water Environment Research Foundation in the late 1990, on Management Practices for Water Reuse in Non Potable Uses. The introductory section indicated that practical experience shows that agencies responsible for water reuse have to face institutional, legal, regulatory, cost estimation, marketing, financial and liability issues that generally are more significant in the final outcome of the project than the purely technical issues.

7. BENEFICIAL USES OF RECLAIMED WATER

Reclaimed water is currently used for numerous beneficial uses: 1) agricultural, forest and landscape irrigation, 2) urban uses (garden, fire hydrants, street cleansing, and car washing), 3) industrial uses (cooling, process water, railroad wagons washing), 4) ornamental and recreation uses, 5) environmental protection and enhancement (constructed wetlands), and 6) groundwater recharge. Agricultural and landscape irrigation are the beneficial uses most widely adopted, either for vegetable crops likely to be eaten uncooked, sports fields, public parks, or irrigation of cereal crops, industrial crops, fodder crops, pasture and trees. Irrigation systems include surface irrigation, sprinkler and micro-sprinkle irrigation, and localized irrigation.

Depending on the potential exposure to or ingestion by the public of reclaimed water, water reuse is classified in: 1) non potable reuse, and 2) potable reuse. This second category is commonly subdivided into two other groups: 1) indirect reuse for potable uses, as it occurs during infiltration of reclaimed water in a natural aquifer from where water is subsequently extracted as raw material for the production of drinking water, and 2) direct reuse for potable uses, when reclaimed water is directly introduced in the drinking water supply distribution system, as it happens in the city of Windhoek, Namibia, during episodes of surface water scarcity. Direct potable reuse is generally considered an exceptional option by public health agencies.

It has to be emphasized that non potable water reuse projects are those that have reached a highest development in numerous parts of the world, and have achieved high levels of reliability and public acceptance both from users and the public at large. This has been particularly applicable in countries where environmental protection requirements have promoted the widespread adoption of wastewater treatment processes. The resulting availability of high quality secondary effluents and the water scarcity prevailing in some semi-arid coastal areas like those in the Mediterranean have been determining factors for the current interest and development of water reuse projects in those areas.

Tables 1, 2, and 3 summarize the reclaimed water flows used in areas so different as the Consorcio de la Costa Brava in northeastern Spain, and the states of California and Florida. Total flows of reclaimed water in Israel amounted to 350 hm^3/year in 2000, to 24 hm^3/year in Tunisia in 1995, and 10 hm^3/year in Cyprus in 1995. The results in Tables 1, 2, and 3 indicate the considerable amounts of reclaimed water involved. Although the overall percentage values for the state of California are close to 10%, the actual regional percentage normally reaches up to 30%, particularly in the semi-arid areas of Southern California. The 20% reclaimed water use in Consorcio de la Costa Brava includes a significant portion of groundwater recharge, through surface infiltration into an aquifer used for agricultural and industrial water supply.

Table 1. Planned water reuse in the Consorcio de la Costa Brava, with a total annual flow of 5,4 hm^3 in 2004 (20% from 28 hm^3 of secondary effluent).

Reuse type	%
Groundwater recharge	55
Environmental enhancement (wetlands)	25
Landscape and golf course irrigation	13
Agricultural irrigation	5
Facilities use and non potable urban uses	2

Table 2. Planned water reuse in California, with a total annual flow 495 hm^3 in 2000 (330 hm^3/year in 1987).

Reuse type	%
Agricultural irrigation	48
Landscape irrigation and ornamental use	20
Groundwater recharge	12
Habitat restoration	6
Industrial reuse	5
Recreational lakes	4
Seawater intrusion barrier	3
Other uses	2

Table 3. Planned water reuse in Florida, with a total annual flow of 810 hm^3 in 2001.

Reuse type	%
Agricultural irrigation	19
Irrigation of public access areas	44
Groundwater recharge	16
Industrial reuse	15
Wetlands and others	6

The ongoing debate on the potential and future development of planned water reuse, and consequently on the technical means adopted in areas with significant and leading water reclamation projects, is currently focused on the adequacy of either promoting new projects for indirect potable reuse, or just concentrate and restrict water reuse to the numerous non potable beneficial uses that have been developed over the last decades. This technical debate, and the associated political debate, has frequently distracted from recognizing an overwhelming fact: the great success achieved by planned water reuse for non potable uses in numerous parts of the world, and particularly in areas with a large number and diversity of reuse projects, such as the states of California and Florida, Mediterranean states as Cyprus, Israel and Tunisia, as well as coastal zones of the Costa Brava, inland cities as Vitoria-Gasteiz, in Spain, and inland areas of the Canary Island, Spain, where planned water reuse for non potable use has markedly advanced since the 1980's.

8. RECLAIMED WATER USE

The use of reclaimed water for agricultural and landscape irrigation is a well-known agronomic practice in numerous parts of the world. However, it has been only during the last few decades that planned water reuse for agricultural and landscape irrigation in urban areas has reached a significant application in countries with high standard of living and adequate levels of water resources, but with recurrent temporal or geographical deficits, such as California and Florida, in the USA, and some Mediterranean coastal areas. Periodic and prolonged drought episodes have further contributed to the expansion of planned water reuse in those areas and other semi-arid areas of the world.

Publication in 1984 of the Guidance Manual for Irrigation with Reclaimed Municipal Wastewater, edited by Pettygrove and Asano (1984) and published by the California State Water Resources Control Board, and also edited in Spanish by the Universidad Politécnica de Cataluña and the Generalitat de Catalunya (Mujeriego, 1990), represents a historical landmark in the process of defining the criteria and standards necessary for the design, construction, operation and maintenance of irrigation projects using reclaimed water. A companion study was the 5-year research and demonstration project sponsored by the state of California, with a total budget of 7 million dollars, on sprinkler irrigation of horticultural crops using reclaimed water, conducted in Monterey, California from 1982 to 1987 (Sheikh et al., 1990).

As a complement to those studies, the Environmental Protection Agency of the United States published in 1992 the Guidelines for Water Reuse (USEPA, 1992), which have been recently revised (USEPA, 2004). The Guidelines offer widely documented recommendations that can be used by municipal, regional, state and international agencies to promote and develop planned water reuse in an adequate and efficient manner. Those guidelines are mainly applicable to planned reuse of reclaimed water in non potable urban uses, industrial uses, and agricultural and landscape uses, based on consensus reached on its benefits and requirements. Furthermore, the Water Pollution Control Federation (1989) published a Practical Manual covering the technical, economic, and management aspects of water reuse. The proceeding of several International Symposia and a Technical Workshop on Water Reclamation and Reuse (Mujeriego and Asano, 1991; Angelakis et al., 1996; Asano, 1998; Bonomo et al., 1999; Brissaud et al., 2001; and Jimenez, 2004) include numerous examples of studies and projects conducted in several parts of the world.

As a result from those studies and demonstration projects, reclaimed water is considered a new water source in California and other southern states of the USA, and in Mediterranean states like Cyprus, Israel, Tunisia, and Spain. Reclaimed water has become the only water source available to implement new irrigated agriculture projects, new programs of urban irrigated landscape, or new golf courses. Planned reuse of reclaimed water for landscape and golf course irrigation projects has become a familiar feature of water resources management in numerous areas in California, Florida and other southern states of the USA. Similarly, sprinkler irrigation of horticultural crops likely to be eaten raw is a practice currently accepted both by public health agencies and the public at large, based on water quality limits derived from research and demonstration projects, and on review processes applied to water reclamation facilities, under the supervision of water resources agencies, water quality protection agencies and public health agencies (Asano et al., 1991).

The Guidance Manual for Irrigation with Reclaimed Municipal Wastewater (Pettygrove and Asano, 1984; Mujeriego, 1990) and subsequent experiences in California (Asano et al., 1991) and also in Cataluña, Spain, (Mujeriego et al., 1996; Sala and Millet, 1995) offer a sound and practical basis for the design and operation of planned water reuse projects for agricultural and landscape irrigation projects. Aside from the public health water quality limits established in California, those studies offer a methodology useful for approaching planned water reuse projects in other parts of the world, and particularly in coastal and inland areas of the Mediterranean region. This methodology and the experimental results obtained have been helpful in defining the most adequate agronomical parameters in each case.

Planned reuse of reclaimed water for agricultural and landscape irrigation, and particularly for golf course irrigation, raises two basic issues concerning water quality: 1) its agronomic quality, and 2) it public health quality. The following sections cover the water quality criteria and standards currently considered to satisfy those two concerns of reclaimed water.

9. AGRONOMIC QUALITY CRITERIA AND STANDARDS

The agronomic quality of reclaimed water should be assessed in a similar way as it would be conducted when using water from conventional sources such as rivers, wells or lakes. The agronomic adequacy of a water source should be determined by its salt concentration and not by their origin. However, reclaimed water commonly contains significant amounts of organic matter (BOD_5, COD) and particularly nitrogen and phosphorous salts, which make necessary a more specific management program for the irrigation project. The objective of that program is to prevent over fertilization and unbalanced salt contributions that could adversely affect the plants, the soil or the groundwater. The Guidance Manual (Pettygrove and Asano, 1984), the recommendations on the use of reclaimed water for golf course irrigation (Sala and Millet, 1995), and the Guidelines on Physical and Chemical Parameters for Water Reuse in Irrigation (UNEP, 2005) offer very valuable information on those issues.

Agronomic management of the quality of reclaimed water used for agricultural irrigation and golf course irrigation includes basically four categories of quality parameters (Pettygrove and Asano, 1984; UNEP, 2005): 1) water salinity, 2) macronutrients content (N, P, and K), 3) micronutrients and trace elements content, particularly boron and some metals (copper, nickel, zinc), and 4) other parameters such as residual chlorine and dissolved oxygen.

Salinity of reclaimed water is determined by: 1) the quality of the drinking water supplied to the urban area that generates the treated effluent reaching the reclamation plant, 2) the urban uses adopted for the water, 3) the scope and implementation degree of local ordinances concerning wastewater disposal into the sewerage network, and 4) the condition of the sewage network itself, particularly considering its potential for infiltration and inflow. Conventional water reclamation processes do not modify the salt content of reclaimed water. Salinity remains normally stable, as long as there are no significant salt inputs from seawater or brackish water intrusion, either by episodic discharges or by diffuse inflows from coastal areas. Continuous monitoring of electrical conductivity is a very practical method for determining its potential for agricultural and landscape irrigation, and provides a fast indication on the convenience to discontinue its use, when it exceeds recommended limits. To ensure an adequate quality of turf species, the most adequate management strategy is to use species that are tolerant to the salinity levels expected in the reclaimed water available for irrigation.

Macronutrients (nitrogen, phosphorous, and potassium) concentrations in reclaimed water are normally higher than those in conventional water sources, and consequently require a more specific agronomic management of irrigation activities. The objective is to adjust water application rates and fertilizer application rates, tanking into consideration reclaimed water fertilizer content and additional mineral fertilizers added. That process requires a systematic information system on macronutrients content, which is normally provided by the reclaimed water supplier, or has to be determined eventually by the user itself. The unusually high concentrations of macronutrients in reclaimed water makes necessary a change in conventional fertilization practices of golf courses (Sala and Millet, 1995) both between irrigation seasons (summer vs. winter) and also on the relative proportion of nitrogen, phosphorous, and potassium at any given time. While nitrogen contributions of reclaimed water are usually higher than those needed by plants, particularly during the summer, phosphorous contributions are commonly similar to those needed by plants. On the contrary, potassium contributions are lower than those needed by plants, and particularly considering its relative proportion to nitrogen content. The specific characteristics of the reclaimed water produced at a given facility, together with the specific requirements of each golf course prompt the need for specific agronomic management practices, through the use of specific irrigation systems, mowing systems, and fertilization programs (Sala and Millet, 1995).

The relative concentrations of nitrogen species in reclaimed water used for irrigation of a golf course will vary significantly depending on the facilities used for water storage, such as ornamental lakes and small storage reservoirs. In general, water storage in open lakes will favor development of an eutrophic ecosystem, where proliferation of phytoplankton and zooplankton will introduce significant seasonal variations of the total concentration and the relative speciation of dissolved nitrogen and phosphorous. As the residence time increases beyond approximately 20 days, larger fractions of ammonia nitrogen will be lost and higher levels of nitrification and denitrification will be reached.

The presence of certain micronutrients, such as boron, reinforces the need for specific agronomic management practices, through an adequate turf species selection and adapted mowing protocols. Finally, the presence of residual chlorine and dissolved oxygen are two practical features of great interest for irrigation system management. Residual chlorine concentration in reclaimed water in concentrations up to 5 mg/l has no significant effects on turf leaves; when chlorine concentrations rises above 10 mg/L, normally due to breakdowns in the chlorination system, a visual damage of turf leaves can be expected (Pettygrove and Asano, 1984). Reclaimed water storage in ornamental lakes or reservoirs will result in a net loss of the residual chlorine initially present in the effluent of the reclamation facility. Chlorination of reclaimed water that has not been nitrified, and thus contains a significant concentration of ammonia nitrogen, will generate chloramines, with a lower oxidation power than free chlorine.

The lack of dissolved oxygen in reclaimed water will promote offensive odors due to the potential generation of hydrogen sulfide. The presence of dissolved biodegradable organic matter in reclaimed water, and the lack of an adequate aeration process, mainly through contact with the open atmosphere, are the determining factors of this nuisance. A prolonged stay of reclaimed water in transport pipelines and a density stratification in storage lakes or ponds are the most common environmental conditions responsible for those nuisances.

Although phytoplankton growth in ornamental lakes has the potential to ensure oxygenation levels higher than those of saturation conditions, it is also responsible for restricting light penetration down to the upper 2 meters. This condition, together with density stratification of the water column below this depth during the summer season, and the depletion of dissolved oxygen in bottom layers caused by biological oxidation of organic matter accumulated in the sediments, are responsible for the development of anaerobic conditions in deep water zones, particularly during the summer, and thus for the promotion of hydrogen sulfide generation.

When irrigation water is extracted from the bottom zones of storage lakes or ponds, dissolved hydrogen sulfide will be carried away and subsequently transferred to the surrounded atmosphere during the sprinkler irrigation process. Two basic criteria for preventing hydrogen sulfide generation are: 1) to design shallow ornamental lakes or storage ponds (1 to 2 m), and 2) to install some mixing devices that prevent density stratification of the water column.

In summary, landscape irrigation and particularly golf course irrigation with reclaimed water has three basic agronomic features (Sala and Millet, 1995): 1) a planning and management process for the irrigated area, more specific than that adopted when using conventional water sources, and involving selection of turf species and coordination of irrigation, mowing and fertilization practices, 2) a significant economic advantage, due to the commonly lower cost of reclaimed water and its higher nutrients contribution, which can be estimated at a savings of 12,000-18,000 euros annually for a 30 ha golf course, and 3) a water supply reliability considerably higher than that of conventional water sources, particularly when they are affected by the prevailing arid or semi-arid conditions of numerous Mediterranean coastal areas. Conventional water sources are normally considered a priority source for urban water supply, and consequently their use is normally restricted for agricultural and landscape irrigation during water scarcity and drought episodes.

10. PUBLIC HEALTH CRITERIA AND STANDARDS

The two basic technical references available when approaching microbiological quality criteria and standards for water reclamation and reuse are:

1. The Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture proposed by the World Health Organization (1989, 2006). Table 4 summarizes the current version of the guidelines (WHO, 1989). A brief discussion of the forthcoming new edition of the guidelines (WHO, 2006) is also included in Table 5. The new Health Guidelines (WHO, 2006) are expected to be formally approved in 2006.

2. The Guidelines for Water Reuse published by the Environmental Protection Agency of the United States in 1992 and recently revised (2004). The Guidelines

are based on criteria and standards currently applied by different states, particularly California and Florida, where planned water reuse has reached widespread application. Table 6 summarizes the water quality requirements recommended for irrigation of landscape areas with no restriction to public access (unrestricted irrigation).

10.1. WHO GUIDELINES FOR AGRICULTURE AND AQUACULTURE

The World Health Organization (WHO) has been providing guidance for the safe use of wastewater for quite some time. In 1971, WHO sponsored a meeting of experts on water reuse, which culminated in a 1973 report recommending health criteria and treatment processes for various wastewater applications. The 1973 criteria were revised in 1989 (WHO, 1989); the most recent, third edition of the WHO Guidelines is expected to be published in 2006.

In general, WHO guidelines are significantly less restrictive than water reuse regulations or guidelines adopted by various states of the United States. The goal of WHO and other international organizations has been to introduce at least some level of wastewater treatment, and to achieve a positive transmission interruption or exposure prevention to the pathogens present in irrigation water, prior to food crop irrigation. WHO guidelines satisfy that intent and can be considered appropriate as an interim measure in the context of the socio-economic reality of many countries, until they develop the capacity to produce higher quality reclaimed water.

The current Health Guidelines for the Use of Wastewater for Agriculture and Aquaculture were published by WHO in 1989. Table 4 summarizes the guidelines proposed by WHO (1989) for agricultural irrigation, pending their revision and modification to be published during 2006. The guidelines were based on the premise that the main health risks associated with the use of wastewater are associated with helminth infections and, therefore, a high degree of helminth egg removal was considered necessary for the safe use of wastewater in agriculture and aquaculture. Waste stabilization ponds were identified as the technical choice in meeting the proposed guidelines in warm climates, where land is available at reasonable cost, more sophisticated treatment methods are not affordable, and adequate technical back-up support is lacking. Based on helminth removal, the guidelines recommend a pond retention time of eight to ten days, with at least twice that time required in warm climates, to reduce fecal coliforms to the guideline level of 1,000 FC/100 mL. However, based on actual field experience at existing full-scale and demonstration stabilization pond systems, it has been found that the desired reductions of helminths and fecal coliform organisms may be difficult to achieve in practice.

In 2001, a WHO expert meeting in Stockholm, Sweden developed a framework that facilitates an integrated approach to control water-related diseases, by combining risk assessment and risk management. This approach harmonizes the process of developing health-based guidelines and standards, in terms of water-and sanitation-related microbial hazards, and provides the conceptual framework for all WHO water-related guidelines. The Stockholm framework involves: 1) the assessment of health risks, prior to the setting of health-based targets and the development of guideline values, 2) the definition of basic control approaches, and 3) the evaluation of the impact of these combined approaches on public health (Bartram et al., 2001; WHO, 2006).

Table 4. Recommended microbiological quality guidelines for wastewater use in agriculture. WHO (1989).

Category	Reuse conditions	Exposed group	Intestinal nematodes eggs/L (b)	Faecal coliforms Number/100 mL (c)	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks (d)	Workers, consumers, public	≤ 1	≤ 1000 (d)	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees (e)	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

a) In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
b) Arithmetic mean. Ascaris and Trichuris species and hookworms.
c) Geometric mean. During the irrigation period.
d) A more stringent guideline (≤ 200 faecal coliforms/100 mL) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
e) In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

The Stockholm framework allows countries to adjust guidelines to local social, cultural, economic and environmental circumstances, and to compare the associated health risks with the risks that may result from microbial exposures through wastewater use, drinking water and contact with recreational or occupational waters. This approach requires that diseases be managed from an integrated health perspective, and not in isolation. This implies that determination of acceptable risk or tolerable risk needs to be put into the context of actual disease rates in a population related to all the exposures that lead to a particular disease, including other water and sanitation-related exposures. Different countries may, therefore, set different health targets, based on their own contexts. Furthermore, disease outcome from one exposure pathway, or from one illness to another, can be compared by using a common measure, such as disability adjusted life years.

The Disability Adjusted Life Years (DALYs) is a compounded measure of population health. A decrease of DALYs is an indicator for the burden of disease due to a specific illness or risk factor. The main intention of DALYs is to measure the time lost through disability or death from a particular disease, by comparing it to a long life free of disability, in the absence of the disease. DALYs are calculated by adding the years of life lost (YLLs), due to premature death, to the years lived with a disability (YLDs). YLLs are calculated from age-specific mortality rates and the standard life expectancies of a given population. DALYs are calculated from the number of cases recorded multiplied by the average duration of the disease and a severity factor, which ranges from 1 (death) to 0 (perfect health) depending on the disease. When risk is measured using

DALYs, different health outcomes can be compared (e.g. cancer can be compared to giardiasis) and risk management decisions can be prioritized in a cost-effective way (Aertgeerts and Angelakis, 2003).

The concept of tolerable (acceptable) risk can be derived using numerous criteria (Hunter and Fewtrell, 2001). Among other criteria, a risk value can be adopted considering that: 1) it is smaller than an arbitrary, defined probability, 2) it is smaller than some level that is already tolerated, 3) it is smaller than an arbitrary, defined attributable fraction of the total disease burden in the community, 4) the cost of reducing the risk would exceed the costs saved when the "costs of suffering" are also considered, 5) money would be better spent on other, more pressing public health problems, 6) public health professionals say that it is acceptable, 7) the public at large say that it is acceptable (or more likely, do not say that it is not acceptable), and 8) politicians say that it is acceptable.

Tolerable risk levels do not necessarily remain constant with time. Risk levels that are tolerable today may decrease, as tools for managing water-related disease transmission improve. Tolerable risks can therefore be set on the basis of continuous improvement. For example, smallpox and polio were eradicated because it was technologically feasible to do so, not because of the continually decreasing global burden of disease attributed to these pathogens.

WHO has determined that a disease burden of 10^{-6} DALYs (i.e. one micro-DALY) per person per year from a disease that is caused by either a chemical or an infectious agent through water-related exposures, and that is transmitted through drinking water is a tolerable risk (WHO, 2006). This level of health burden is equivalent to a mild illness (e.g. watery diarrhoea) with a low fatality rate (e.g., 1 person in 100,000 per year) at an approximately 1 in 1,000 annual risk to an individual, which is equivalent to a 1 in 10 risk over a lifetime.

Tolerable risk can be used as a tool to assess the relative importance of risks from different exposures. Risk management decisions can then be used to address the greatest risks first. For example, if 99 percent of cases of salmonellas were related to food, then halving the number of cases attributed to drinking-water would have very little impact on the disease burden. The incidence of diarrhoea or gastrointestinal disease is often used to represent all waterborne infectious diseases associated to microbial contaminants through water-related exposures.

The third edition of the WHO Guidelines for the safe use of wastewater, excreta and grey water, expected to be published in 2006, has been extensively updated compared with the previous two editions (1973 and 1989, respectively), to take account of new scientific evidence and contemporary approaches to risk management, encompassing the Stockholm Framework discussed above. The guidelines are presented in four separate volumes: Vols. I Policy and regulatory aspects; II Wastewater in agriculture; III Wastewater and excreta use in aquaculture; and IV Excreta and grey water use in agriculture. The Guidelines are intended to be used as the basis for the development of international and national approaches (including standards and regulations) for managing the health risks from hazards associated with wastewater use in agriculture and aquaculture, as well as providing a framework for national and local decision-making (WHO, 2005).

Three types of evaluations were used in the Guidelines to assess risk: 1) microbial and chemical laboratory analysis, 2) epidemiological studies, and 3) quantitative microbial risk assessment (QMRA). Wastewater contains a variety of different pathogens, many of which are capable of survival in the environment (in the wastewater, on the crops or in the soil) long enough to be transmitted to humans. In places where wastewater is used without adequate treatment, the greatest health risks are usually associated with intestinal helminths. QMRA evidence indicated that the risks for rotavirus transmission were always estimated to be higher than the risks associated with Campylobacter or Cryptosporidium infections.

Health-based targets define a level of health protection that is relevant to each hazard. A health-based target can be based on a standard metric of disease, such as a DALY (e. g., 10^{-6} DALYs), or it can be based on an appropriate health outcome, such as the prevention of the transmission of vector-borne diseases resulting from exposures associated with wastewater use in agriculture. Health protection measures can be developed to achieve a health-based target. Usually a health-based target can be achieved through a combination of health protection measures, targeted at different components of the system, to achieve an overall tolerable risk of 10^{-6} DALYs.

WHO's health-based target for rotavirus present in wastewater used in agriculture is shown in Table 5. The health-based targets are based on QMRA and reflect the pathogen reduction required to achieve a 10^{-6} DALYs for different exposures. Epidemiological evidence was used to develop the corresponding health-based targets for helminth infections. This evidence indicates that no excess helminth infections (for both consumers and farmers) could be measured when the wastewater used for irrigation had ≤1 helminth egg /L. This level of health protection for consumers of raw vegetables could also be met by a combination of wastewater treatment processes, according to the "multiple barriers" approach, or by a combination of "multiple vector control barriers", such as wastewater treatment and produce washing; or by protection of workers by wastewater treatment and the use of personal protective equipment (shoes, gloves). When children less than 15 years old are exposed to irrigation water in the fields, either additional wastewater treatment (to achieve a wastewater quality of ≤0.1 helminth egg/L) or the addition of other health protection measures (e.g., anti-helminthic treatment such chemotherapy) should be considered.

A variety of health protection measures can be used to reduce health risks to consumers, workers and their families, and local communities. Strategies for managing health risks to achieve the proposed health targets include "multiple vector control barriers" such as wastewater treatment to achieve appropriate microbiological quality guidelines, crop restriction, wastewater application methods, control of human exposure, chemotherapy, and immunization. Phased implementation of microbial water quality standards may be necessary as treatment is gradually introduced or upgraded over a period of time, e.g., 10-15 years. For a maximum public health effect, the guidelines should be co-implemented with other health interventions such as hygiene promotion, provision of adequate drinking water and sanitation, and other health care measures (Carr, et al., 2004).

Table 5. Health-based targets for rotavirus present in wastewater used in agriculture, based on rotavirus reduction and effluent helminth eggs content (Adapted from WHO, 2006).

Exposure scenario	Health-based target (DALY per person per year)	Log pathogen (rotavirus) reduction needed	Helminth eggs, number/L
Unrestricted irrigation			
Lettuce	$\leq 10^{-6}$	6 [a]	≤ 1 [b,c]
Onion	$\leq 10^{-6}$	7 [a]	≤ 1 [b,c]
Restricted irrigation			
Highly mechanized	$\leq 10^{-6}$	3 [a]	≤ 1 [b,c]
Labor intensive	$\leq 10^{-6}$	4 [a]	≤ 1 [b,c]
Localized (drip) irrigation			
High-growing crops:[d,e]	$\leq 10^{-6}$	2 [a]	No recommendation
Low-growing crops:[d]	$\leq 10^{-6}$	4 [a]	≤ 1 [b]

a) Rotavirus reduction. The health-based target can be achieved, for unrestricted and localized irrigation, by a 6-7 log unit pathogen reduction (obtained by a combination of wastewater treatment and other health protection measures); for restricted irrigation, it can be achieved by a 3-4 log unit pathogen reduction.

b) When children under 15 years old are exposed, additional health-protection measures should be used (e.g., treatment to ≤ 0.1eggs/L, protective equipment such as gloves or shoes/boots or chemotherapy).

c) Arithmetic mean should be determined throughout the irrigation season. The mean value of ≤1 eggs/L should be obtained for at least 90 percent of the samples, in order to allow for the occasional high-value sample (i.e., with >10 eggs/L). With some wastewater treatment processes (e.g., waste stabilization ponds), the hydraulic retention time can be used as a surrogate to assure compliance with ≤1 eggs/L.

d) No crops should be picked up from the soil.

10.2. USEPA GUIDELINES FOR WATER REUSE

The revised version of the USEPA Guidelines for Water Reuse was published in 2004. They recommend reclaimed water quality limits for a wide variety of water uses. Among those, urban use of reclaimed water for unrestricted irrigation is the one with the highest quality requirements, as to ensure public health protection through direct contact of the public with reclaimed water or products that have been in contact with reclaimed water. The microbiological limit recommended by USEPA (2004) for this water use is absence of faecal coliforms in 100 mL, as compared with the upper limit of 1,000 faecal coliforms per 100 mL recommended by WHO Health Guidelines (1989) for application of reclaimed water used in unrestricted agricultural and landscape irrigation. Table 6 shows the guidelines for urban water reuse proposed by USEPA (2004).

For the most part, Mediterranean states have no regulations concerning water reclamation and reuse. Those with regulations, such as Cyprus, Israel, Italy, and Tunisia have established their quality criteria and standards on the basis of both WHO Health Guidelines (1989) and USEPA Water Reuse Guidelines (1992, 2004). Although Spain has no country level regulations on water reclamation and reuse, several Regional agencies like the Public Health Departments of Andalusia, Balearic Islands, and Catalonia have adopted guidelines for the use of reclaimed water in agriculture and landscape irrigation based on WHO Health Guidelines (1998). The water quality criteria adopted by the Public Health Department of Andalusia and the Public Health Department of Catalonia define operational criteria for the health evaluation of planned water reuse projects using treated wastewater effluents, and recommend that reclaimed water for irrigation of golf course should conform to an upper limit of 200 faecal coliforms/100 mL and of 1 helminth egg/L. Those documents also include valuable guidelines for the technical evaluation of planned water reuse projects.

Table 6. Guidelines for urban water reuse proposed by the United States Environmental Protection Agency (USEPA/AID, 1992, 2004).

Type of Reuse	Treatment (a)	Reclaimed water quality (b,c,d,e)	Reclaimed water monitoring	Setback distances
Urban Reuse	Secondary	pH = 6 - 9	pH: weekly	15 m to potable water supply wells
All types of landscape irrigation (e.g., golf courses, parks, cemeteries)- also vehicle washing, toilet flushing, use in fire protection systems and commercial air conditioners, and other uses with similar access or exposure to the water	Filtration	< 10 mg/l BOD	BOD: weekly	
	Disinfection	< 2 NTU	Turbidity: continuous	
		No detectable faecal coliforms in 100 mL	Coliforms: daily	
		1 mg/l Cl_2 residual (min.)	Cl_2 residual: continuous	

a) At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve ≤ 14 faecal coliforms/100 mL may be appropriate.
b) The reclaimed water should not contain measurable levels of pathogens.
c) Reclaimed water should be clear, odorless, and contain no substances that are toxic upon ingestion.
d) A higher chlorine residual and/or longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed.
e) A chlorine residual of 0.5 mg/L or greater in the distribution system is recommended to reduce odors, slime, and bacterial regrowth.

A comparative evaluation of current WHO Health Guidelines (1998) and USEPA Guidelines for Water Reuse (1992, 2004) indicates that WHO Guidelines are mainly based on an extensive literature review on the epidemiological incidence of water related diseases in developed and developing countries, while USEPA guidelines are mainly based on experimental results from demonstration projects. Those projects include the one conducted in Monterey, California from 1982 to 1987 (Sheick, 1990) and numerous others under operation in different states, where the production of reclaimed water free of faecal coliforms is generally considered equivalent to a non detectable level of virus in reclaimed water. Extensive experience from water reclamation plants in different areas of Spain (Costa Brava, Costa del Sol, and Vitoria) indicate that well treated secondary effluents, as required by EU environmental regulations, are generally free of helminth eggs, depriving this water quality indicator of any practical meaning for assessing the microbiological quality of reclaimed water produced with those effluents. A technical debate is currently taking place on the adequacy of including helminth eggs as a required element of monitoring programs applied to certain types of reclaimed water, particularly those produced with high quality secondary and tertiary effluents.

The ultimate decision about which of those two guidelines should be considered for establishing reclaimed water quality limits implies a formal decision on the actual or the perceived level of acceptable health risk among the population. This acceptable health risk is closely related to population living standards where reclaimed water will be use, and also to the technical and economical resources available to build and operate the treatment facilities required to achieve the quality limits required.

In summary, WHO Health Guidelines and USEPA Water Reuse Guidelines can be considered as steps of a gradual process for improving reclaimed water quality, both for public health and environmental protection. The transition from the limits recommended by WHO to those recommended by USEPA could be achieved with time, as a result of a variety of circumstances, such as improvements in sanitation conditions, an increase of hygienic levels among populations, an expansion of environmental protection measures, a development of existing and new methods for water and wastewater treatment, and ultimately by an advancement of the overall living standards of populations.

The level of acceptable health risk perceived by local populations or officially required by public health agencies in some regions of Spain, like Vitoria-Gasteiz, Spain has resulted in reclaimed water quality limits similar to those suggested by the USEPA (1992, 2004) for projects planned during the 1990's. The high sanitation level and the high living standards of the populations, the significant public demands for environmental protection, the convenience of expanding the potential of water reuse projects to cover agricultural irrigation and also landscape irrigation in high density urban areas, and finally the enthusiasm and the business vision of a series of irrigation districts, willing to use and to pay high quality reclaimed water as a way to increase supply reliability and crop yield, while preventing any potential health handicaps for their crops either at national and international level, have resulted in emblematic projects that may serve as examples to be considered and improved. A visual inspection of the reclaimed water produced at those facilities can hardly bring the "wastewater" designation to anyone's mind, but rather the vision of a "surface water" of equal or even better quality than that of rivers flowing nearby.

The experienced gathered in current water reclamation and reuse projects in Spain from 1985 to 2006 indicate that implementation of water reuse projects for agricultural and landscape irrigation, with no restriction on the access or exposure of the public to reclaimed water, and particularly for irrigation of golf courses, should be planned considering the highest water quality possible. That proposal is in accordance with the living standards associated to golf courses and the planned residential communities frequently associated to them, and also with the technical and economic resources available to satisfy those water quality limits. On the other hand, agricultural irrigation of fodder, fiber, and seed crops, as well as surface irrigation of orchards and vineyards, and crops that have no contact with reclaimed water could be conducted using effluents from wastewater stabilization ponds or equivalent natural treatment systems, whose microbiological quality conforms to the guidelines proposed by WHO.

11. WATER REUSE FOR AGRICULTURAL IRRIGATION

The quality level applicable to reclaimed water is closely related to its beneficial use. Physico-chemical quality requirements depend among other factors on whether reclaimed water is used for non potable or potable uses, and the potential exposure of the public or the user to reclaimed water. Irrigation of parks and gardens calls for physico-chemical quality requirements, to ensure normal growth and maintenance of plant species.

Among those basic quality requirements, it has to be mentioned salinity (commonly measured in terms of electrical conductivity), and chloride and boron contents. Those requirements are clearly established in Manuals and specialized publications devoted to agricultural and landscape irrigation (Pettygrove and Asano, 1985; Asano, 1998; Mujeriego, 1990; UNEP, 2005), and others describing best management practices for agriculture and landscape fertilization (Sala and Millet, 1995). The requirements included in those publications show wide variation intervals, as a function of the plant species considered. The agronomic experience available provides valuable guidance for adjusting water use to the practical variations of quality parameters, while preventing any significant deterioration of the irrigated crops quality.

Although dual distribution systems for distribution of reclaimed water to agricultural irrigation are very limited or non existent in Europe, the operation and maintenance of this type of reclaimed water distribution networks is a common practice in numerous urban and sub-urban areas of California, Florida and even Japan, where they have become a familiar feature of water supply and sanitation agencies. The public widely accepts and even openly promotes this practice within its residential and working areas.

The Workshop on Integrating Reclaimed Water into Resources Management held in October 2005 in Lloret de Mar, Girona (CCB, 2005) clearly pointed out the operational features of this type of supra-municipal water distribution networks in the Mancomunidad del Sureste de Gran Canaria, Canary Island, Spain for agricultural irrigation, and also the ongoing plans for implementing a regional distribution network in some coastal municipalities of the Costa del Sol Occidental, Málaga, Spain for golf course irrigation.

The basic criteria commonly adopted in the design and operation of a dual distribution network for reclaimed water supply (non potable use) are: 1) to ensure that no connection can be established, accidentally or otherwise, between the irrigation network and the drinking water distribution network, and 2) to ensure that the dual distribution network is water-tight. The requirement that no interconnecting can be established between the reclaimed water network and the drinking water supply network appears as one of the basic objectives of municipalities in which those types of networks are established.

The operational criteria commonly adopted by the USA water industry to comply with those requirements have been: 1) to use conduits of similar properties to those used for drinking water supply, but provided with different appurtenance sizes in the household point of use, and 2) to use color coded conduits for reclaimed water distribution, using pink colored materials or pink colored covering tape, and a printed text indicating "reclaimed water". Color coding is an almost universally adopted practice for drinking water (blue), natural gas (yellow), and industrial water (green). Furthermore, municipal water services have well defined protocols to ensure that user connections to drinking water lines and to reclaimed water lines are adequately installed, as to prevent any accidental interconnection between them.

The planned reuse of 495 hm^3/year in California (2000) and of 810 hm^3/year in Florida (2001) (Tables 2 and 3) and in due proportion of 5.4 hm^3/year in Costa Brava, Spain (Table 1) clearly illustrate the benefits that reclaimed water is providing, particularly through agricultural and landscape irrigation, as an essential component of integrated water resources management in a context of permanent and increasing water deficits.

12. PLANNED WATER REUSE IN COASTAL ZONES

The urban, tourist, and agricultural growth experienced by Mediterranean coastal areas over the last few decades implies a significant increase in water use, both to supply household uses and the expanding surface areas devoted to agricultural and landscape irrigation. Water resources management in those conditions is commonly approached with two complementary objectives: 1) to achieve water use efficiency, preventing unnecessary uses, and 2) to promote reclaimed water use for non potable uses, particularly landscape and agricultural irrigation, and environmental enhancement, as to develop new water sources and prevent coastal waters deterioration. Some of the initiatives adopted to achieve those objectives are public education and public participation, new water use regulations, water pricing protocols, and water reclamation and planned water reuse.

Mediterranean coastal areas are characterized by the similarity between the largest flows of treated wastewater produced during the summer months and the largest water uses required for agricultural and landscape irrigation during that season. Aside from the technical and financial requirements that those seasonal demands pose to drinking water supply and wastewater treatment systems, planned water reuse in coastal areas offer clear economic and environmental benefits for numerous uses: 1) landscape irrigation, with the resulting advancement of living standards, 2) agricultural irrigation, as a source of economic resources of high strategic value, and 3) groundwater recharge in coastal areas and wetland areas, as a way to protect natural resources of significant public interest and environmental value.

Although planned water reuse in inland areas does not provide net additional resources, it does offer the possibility for improving water resources management, by replacing waters that can be used as a source for drinking water by reclaimed waters that can be applied to uses that do not require potable quality. Furthermore, a water reclamation facility for agricultural and landscape irrigation, or other uses, in the Mediterranean region has the potential to become a major technological symbol and a source of prestige in this geographical area, offering a leading edge position in the water resources management field.

13. COSTS OF PLANNED WATER REUSE IN SPAIN

The Water Reuse Technical Workshop organized by Consorci de la Costa Brava in October 1985 in Castell-Platja D'Aro, Spain marked the cornerstone of planned water reuse in Spain. The discussions and practical experiences offered by professional and researchers from California, Florida, Israel, and numerous Spanish regions were instrumental for the success that planned water reuse has reached in numerous Spanish areas, particularly coastal areas with arid and semi-arid climates.

The studies conducted since then by the Universidad Politécnica de Cataluña, in collaboration with the Consorcio de la Costa Brava (CCB) and other public and private agencies has fostered the implementation of a reclaimed water management system in the CCB that includes (Mujeriego, 1988): 1) a water reclamation process including sand filtration of biologically treated secondary effluent, followed by disinfection with UV and liquid chlorine, 2) a follow-up program for reclaimed water quality changes in ornamental lakes used for storage and distribution of water for golf course irrigation, and 3) an information system covering several water quality parameters, such microbial indicators, electrical conductivity, and nutrient content (nitrogen and phosphorous), to optimize golf course fertilization programs.

The water reclamation and planned reuse program implemented in Vitoria-Gasteiz (Diputación Foral de Álava, 1995) for agricultural irrigation was designed according to the quality requirements specified by the Title 22 of the California Water Code (Mujeriego, 1990, Asano et al. 1991), and it includes coagulation-flocculation, lamellar settling, conventional rapid sand filtration, and disinfection with liquid chlorine (2 hours contact time). Reclaimed water is used for sprinkler irrigation of several food crops, some of them intended to be eaten raw. The irrigation project includes 10.000 ha of agricultural land, as of July 2005, with sprinkler irrigation applied once every three consecutive summers. The management program includes the provision of high quality reclaimed water (absence of parasites, bacterial indicators, and several pathogenic protozoa and bacteria), and an information system covering electrical conductivity and nutrient contents of reclaimed water, to allow farmers to adjust their fertilizations programs.

Implementation of several planned water reuse projects in Costa Brava, promoted by Consorcio de la Costa Brava, and the water reclamation plant of Vitoria-Gasteiz, promoted by the Arrato Irrigation District and the Álava Regional Government, with a capacity to produce 35,000 m^3/day of reclaimed water for unrestricted irrigation, has marked a first decade of planned water reuse in Spain. The main achievement of this decade was: 1) to document the personal and technical ability of the agencies to produce reclaimed water of comparable quality to that obtained by similar facilities in other parts of the world, and 2) their ability to use water efficiently for landscape irrigation, and agricultural irrigation of food crops intended for both direct consumption and commercial processing.

Completion in 2004 of the first lake for reclaimed water storage, as an essential component of the integrated water resources management plan of Vitoria-Gasteiz, and the expansion of several planned water reuse projects in Costa Brava and other Spanish areas have marked a second decade of planned water reuse development in Spain. Its main achievement has been to extensively document the actual cost of producing reclaimed water of high quality, in the framework of integrated management plans comparable to those of leading countries of the world. The cost of 0.06 euro/m^3 initially estimated in Vitoria-Gasteiz has become an accepted reference for other regions, where it has been formally included in the annual budgets of wastewater and sanitation agencies. The storage lake of Vitoria-Gasteiz, with a capacity of 7 hm^3 represents an investment of 13 million euros for the Álava Regional Government, equivalent to 1.7 euro/m^3.

The most recent information provided by the Arrato Irrigation District, responsible for operation and maintenance of the Vitoria-Gasteiz water reclamation facility, (Julio López, personal communication, 2006) provides a definite reference value for the cost of reclaimed water in Spain. Table 7 shows the investment costs, and the operation and maintenance costs associated to the Vitoria-Gasteiz water reclamation facility, with a production capacity of 35,000 m^3/day.

Table 7. Investment costs and operation and maintenance costs of the water reclamation plant of Vitoria-Gasteiz, with a production capacity of 35,000 m^3/day, during the summer of 2005.

Concept	Items	Individual cost, euro/m^3	Total cost, euro/m^3
Investment	3,25 million euros	0,026	0,026
Reagents	coagulant polyelectrolyte disinfectant	0,010 0,001 0,005	0,016
Energy	180 hp installed	0,002	0,002
Personnel	2 workers	0,010	0,010
Preventive maintenance	Spare parts	0,005	0,005
Water analysis		0,003	0,003
Total cost			**0,062**

Nitrogen and phosphorous contributions of reclaimed water have an effective role in plant species fertilization, both in agricultural fields and golf courses. Farmers and greenkeepers have to pay special attention to balance reclaimed water fertilizer contributions and external contributions of mineral fertilizers. Their intent is to prevent unnecessary and excessive fertilization doses, with the resulting detrimental effects for plant species, cultivated soils, and underlying groundwater.

Although the inherent fertilization potential of reclaimed water may be unnecessary during certain seasons or plant growth stages, its adequate consideration can reduce the treatment costs required by nutrient removal during wastewater treatment, and represents a real savings for farmers and greenkeepers. The savings incurred by using the fertilization potential of reclaimed water in golf course irrigation were estimated at 18,000 to 24,000 euros annually (Sala and Millet, 1995).

Almost all the planned water reuse projects in Spain have been promoted by users, as a result of water scarcity episodes. All the projects have been implemented following a case by case approval process, but in the absence of an overall regulatory system that defines water rights, economic and financial programs (including grants and water fees), contractual obligations, process reliability, and particularly the quality levels required for each beneficial use considered. This has been due to the lack of quality criteria and standards for reclaimed water, and water use requirements.

Aside from the success achieved so far, the limiting factor of planned water reuse projects has been the absence of a framework for integrated management of water resources, which has prevented an overall consideration of the project costs and the project benefits, either direct or indirect (externalities). Many of those projects have reached a very positive acceptance among users, and a very favorable perception from the public at large, particularly when applied to landscape and golf course irrigation. It has become evident that the main goal of the third decade for planned water reuse in Spain, beginning in 2005, will be to render planned water reuse an actual component of integrated management of water resources, through extensive agreements among urban, agricultural and ornamental users.

The integrated water resources management plan for Vitoria-Gasteiz offers an excellent framework to evaluate the economic implications of planned water reuse:

1. An operation and maintenance cost of 0.4 million euros, to produce 12.5 hm^3 annually of reclaimed water with a quality suitable for unrestricted irrigation.

2. An investment of 3.25 million euros to build a water reclamation plant, with a production capacity of 35,000 m^3/day (400 L/s).

3. A capital investment of 28 million euros to build an irrigation network capable of supplying reclaimed water to 10,000 ha, including a pumping station and a storage lake of 7 hm^3 (specific investment of 13 million euros) to store water produced during the fall, winter and spring seasons, so it can be used for irrigation during the summer.

These figures illustrate that the largest economic requirements are associated to water reuse (distribution network for supplying water to users), while the water reclamation cost and particularly the operation and maintenance costs (water reclamation) are considerably lower. Those figures clearly indicate that improvements in reclaimed water quality, as to achieve levels suitable for unrestricted irrigation, are relatively insignificant when contemplating a planned water reuse project from a perspective of future developments (urban and industrial uses). This is particularly applicable in the context of the environmental and public health protection goals expected from a society like that of Spain at the beginning of the XXI Century.

Table 8 summarizes the investment cost and the energy consumption associated to water reclamation, water storage in off-stream reservoirs, and seawater desalination. The values indicated for water reclamation correspond to a reclaimed water quality in conformity to Title 22 of the California Water Code regulations and also to the 200 faecal coliforms/100 mL limit included in the WHO Health Guidelines (1989). That reclaimed water is being used for unrestricted irrigation in agriculture and landscape projects in different areas of Spain.

Table 8 indicates the significant increase in investment costs experienced when moving from water reclamation to water storage and seawater desalination. The differences between investment costs per water production unit become even more evident when the different payback periods are considered: the unit costs for water storage become the lowest, followed by those of water reclamation, and those of seawater desalination. A complete economic assessment of planned water reuse projects requires necessarily a consideration of the investment costs of the dual distribution network that may be necessary. As a result, planned water reuse projects are commonly implemented in a gradual manner, starting with users located close to the reclamation facility and having the largest capacity for using reclaimed water.

Table 8. Investment costs and energy consumption of different options of water resources management. Consorcio Costa Brava, 2001-2004 (Sala and Serra, 2004), California, 2000, Palma de Mallorca, 2001 and Vitoria, 2004.

Option	Investment, euros/m^3-year	Payback, years	Consumption, kWh/m^3
Reclamation (unrestricted irrigation)	0.26 (Vitoria)	15 - 25	0.001- 0.73 (CCB)
Storage (off-stream)	1.7 (Vitoria) 2.0 dollars (California)	> 100	—
Storage (groundwater)	0.83 dollars (California)	25	—
Seawater desalination (Blanes, Carboneras, future Barcelona, Palma de Mallorca)	3.0 – 4.0	5 (membranes) 25 (facilities)	3.8 – 4.0

Table 9 also indicates that energy consumption by those three water management alternatives is clearly different. While water reclamation has specific energy consumptions lower than 1 kWh/m^3, seawater desalination reaches commonly values close to 4 kWh/m^3. Aside from the economic costs involved, the environmental impacts associated to that specific energy consumption are also different. Considering an average carbon dioxide contribution from energy generation in Spain close to 460 g/kWh, and a carbon dioxide emission fee close to 20 euros per ton, each kWh consumed in Spain represents an added environmental cost of 0.01 euros/m^3 for reclaimed water and 0.04 euros/m^3 for desalinated seawater. Those incremental costs will vary according to the country's specific carbon dioxide emission rates, in g/kWh, and the prevailing carbon dioxide emission fees, in euros per ton.

Table 8 does not include energy consumptions for surface or underground water storage, as it may vary considerably depending on local conditions. Groundwater recharge by surface infiltration may require low energy inputs; furthermore, water extraction from recharged aquifer wells will have an evident benefit to users, as the pumping head will be smaller than that prevailing before artificial recharge.

Table 9 shows the average energy consumption of commonly used processes for drinking water purification, wastewater treatment, and water reclamation in the Consorcio de la Costa Brava facilities, using surface waters. Table 9 indicates the values corresponding to seawater desalination in Blanes, Spain with a production capacity of 20,000 m^3/day. Table 9 also shows the cost increases associated to all the additional operations necessary for incorporating treated water into the corresponding distribution network. The resulting values indicate that the energy consumption associated to drinking water purification, wastewater treatment, and water reclamation are relatively similar, and range from 1.1 a 1.7 kWh/m^3. The need to ensure that drinking water distribution systems maintain a minimum pressure, particularly in urban areas with variable topography, explains the higher energy consumption required in some cases. Wastewater collection is commonly done using gravity systems; although it may require localized pumping stations, it has generally lower energy requirements.

Table 9. Energy consumption, in kWh/m^3, of water treatment and distribution within the Consorcio de la Costa Brava, 2001-04 (Sala and Serra, 2004).

Treatment process	Treatment only	Extraction, treatment and pumping
Water purification	< 0.17	0.15 – 1.7
Wastewater treatment	0.30 – 0.90	0.38 – 1.1
Water reclamation	0.001 – 0.73	0.001 – 1.3
Seawater desalination (Blanes and future Barcelona)	3.8 – 4.0	4.9 – 5.4 (Blanes)

One of the most emblematic water reclamation and reuse project for indirect potable reuse is the one jointly sponsored by the Orange County Water District (OCW, 2005) and Orange County Sanitation District, in California and designated Groundwater Replenishment System (GWRS; gwrsystem.com). The first construction phase of the GWRD project has a total budget of 427 million dollars and an annual production capacity of 90 hm^3 of reclaimed water. The project has received 5 institutional grants for a total of 92.5 million dollars. The cost of reclaimed water at the infiltration ponds will be close to 0.40 dollars/m^3, which is the maximum price paid in 2005 for surface water delivered by wholesale agencies in the area for similar uses. The GWRS project is expected to become operational during the first part of 2007. The main elements of the GWRS project are:

1. A central facility housing the treatment processes based on microfiltration, reverse osmosis, ultraviolet light disinfection and oxidation with hydrogen peroxide, which will produce reclaimed water of high quality.

2. An expansion of the number of injection wells in the existing seawater intrusion barrier located in Talbert Street, as to allow injection of 43 hm^3 of reclaimed water annually produced at the central facility.

3. A 21-km pipeline, with a diameter gradually decreasing from 1.9 to 1.5 m, and capable of conveying the remaining 47 hm^3 of reclaimed water produced, from the reclamation plant to the Kraemer infiltration basin, upstream of the Santa Ana River.

4. A pumping system to convey reclaimed water from the central facility to the Talbert seawater intrusion barrier and the Santa Ana River infiltration basin, as well as several control systems that will allow surface water from outside sources to be incorporated into the injection and infiltration systems

14. ECONOMIC MANAGEMENT OF RECLAIMED WATER

Drought episodes frequently become sources of strong tension and debate among water users, while at the same time promote the interest of all of them for new sources of water that can compensate the lack of reliability of conventional and traditional sources. The absolute priority assigned by Spanish laws to domestic water supply, over any other valid water use, prompted strict water allocations and water use restrictions during the drought episode experienced in 2005, and particularly in certain populated and agricultural coastal regions such as Cataluña, Valencia, Murcia, Andalusia, and even in Madrid. Those legal provisions resulted in strong debates among urban, agricultural, and landscape users, while promoting a renewed interest in planned water reuse as a viable option to solve the episodic or permanent water deficits of some regions.

Establishing the price and the cost of reclaimed water is a determining factor for the viability and success of any planned water reuse project. It is a complex process, as the costs involved in supplying reclaimed water are generally higher than those required to maintain an existing drinking water distribution system, even more so when considering that reclaimed water quality is commonly ranked as inferior to drinking water quality (Cuthbert and Hajnosz, 1999). While drinking water supply costs are commonly based on past investments, largely paid in many cases, planned water reuse projects have to face investments and operation and maintenance costs that, according to traditional costs assignment methods, bring the cost of reclaimed water to levels similar or even higher than those of available drinking water.

The dilemma in those cases is evident: if reclaimed water is priced at its actual production cost, users will not have enough incentives to use it; on the other hand, if reclaimed water is priced at a lower value than its production cost, a compensation from other budget sources will be necessary. The question posed in that case is to determine how to cover the unbalanced costs, and how large should they be. In spite of those concerns, the long term benefits of reclaimed water are persuading numerous drinking water agencies and irrigation districts to adopt reclaimed water as an additional water source for uses that don't require potable water quality.

Economic management of planned water reuse projects becomes a particularly complex process in certain urban and agricultural areas of the USA (Asano and Mills, 1991), because water resources are usually managed by two separate public agencies: 1) water districts, mainly devoted to production and distribution of drinking water, and 2) sanitation districts, mainly devoted to collection, treatment and disposal of wastewater.

Planned water reuse reaches a new dimension when it is approached from a largest perspective than that traditionally adopted (separate public agencies devoted to different aspects of the water cycle). Reclaimed water has the potential for providing numerous benefits: 1) to prevent the higher costs involved in developing new sources of drinking water supply, and 2) to prevent the largest costs involved in expanding wastewater treatment and disposal facilities, as required by current health and environmental regulations. An emblematic example that illustrates this situation is the Groundwater Replenishment System, jointly promoted by the Orange County Water District and the Orange County Sanitation District, in Southern California, with the main objective to reclaim and reuse 90 hm^3 of water annually, with a total budget of 427 million dollars. The project construction began in 2003 and is expected to become operational by early 2007 (Mujeriego, 2004; OCWD.com; OCSD.com).

Water resources management under a watershed framework (Water Cycle), as it has been applied in Spain for quite some time, and as the European Union Framework Water Directive requires, offers an excellent and more favorable framework for implementing integrated management of water resources. In those conditions, the economic and financial requirements of planned water reuse become an additional component of the overall watershed balance of costs and benefits. The watershed agencies already established in Spanish regions, and responsible for the integrated management of water resources, offer an excellent framework for water reclamation project to benefit from the savings derived from not having to resort to new and costly sources of drinking water. Current regulatory developments concerning water resources rights and the recent approval of Centers for the Exchange of Water Use Rights offer a great opportunity for a more flexible and better management of water resources, by fostering the consideration of reclaimed water as a new contribution, capable of expanding the water resources system.

Planned water reuse has two significant benefits: 1) its ability to increase the availability of pre-potable water, when it is replaced by reclaimed water, and 2) its ability to provide the higher reliability that reclaimed water offers for irrigation. Reclaimed water can reduce or eliminate the frequent restrictions applied during drought episodes, and prevent the large economic losses that rain scarcity causes to agricultural projects. The potential for coordinating surface water resources and groundwater resources, while considering the storage capacity of aquifers, and the potential for water conservation and efficient use of water for irrigation, offer additional benefits for integrated management of water resources and promote the ability of reclaimed water to increase the availability and reliability of supplies.

Although water rights exchanges among water users has been taking place in the Mediterranean costal areas since ancient times, the recent drought episodes and the spectacular increase in urban and agricultural water consumption experienced during the last few decades have made those exchanges even more frequent in some Spanish coastal areas. Those unofficial water right exchanges between agricultural users, and also between agricultural and urban users, have been prompted by their ability: 1) to keep water rights unaltered, and 2) to provide economic benefits to all those involved. The gradual introduction of Centers for the Exchange of Water Use Rights is expected to provide contractual options that respond adequately to those two users concerns, and to promote water right exchanges under regulated protocols.

15. INTEGRATED MANAGEMENT OF WATER RESOURCES

15.1. CONCEPTS AND CRITERIA

Two of the most significant advances made in understanding water resources dynamics in the biosphere have been: 1) the existence of a quantitative and qualitative relationship between the different physical forms of those resources, and between those and other components of the biosphere, such as living organisms and energy fluxes; this system is commonly designated as the "natural ecosystem", and 2) the inclusion of the environment as a legitimate beneficiary of those water resources (OJEC, 2000).

Water resources are a complex series of physical and chemical aquatic elements related between them and with other elements of the biosphere. According to this systemic view, any change introduced in one element may result in a consequent change in others, in addition to changes induced in the energy fluxes. This integrated approach has resulted in the concept of "aquatic environment", and also of "hydrological cycle" or "water cycle". Furthermore, the recognition of water as an essential element of the ecosystem, beyond the uses that human beings may assign to those resources, has prompted new visions of what should be a more balanced management of water resources, such as the one included in the Water Framework Directive (OJEC, 2000).

In this context, the main goal of integrated management of water resources is to establish an orderly and balanced distribution of water among different users and beneficial uses, taking into account the existing interactions among them and particularly the essential role that water has in environmental preservation and enhancement.

To satisfy urban, agricultural and industrial water uses, and also to ensure environmental protection, a series of option are available, each with its associated reliability. The available options, according to an increasing degree of complexity and specificity, are: 1) protection and improvement of conventional water sources, 2) water conservation, through efficient use, 3) storage of additional volumes of water, 4) exchange of water resources among different users, 5) water reclamation and planned water reuse, and 6) desalination of brackish water and seawater.

Adoption of any of those management options requires a sound assessment of its benefits, requirements and limitations, as to reach sound and consistent conclusions. Environmental, social and economic criteria become essential elements to consider in that process, as to achieved a sustainable solution. The results from this assessment process, mainly of technical character, provide a sound basis for future plans, programs and policies that may be adopted by administrations and governments.

Water resources management builds upon three operational criteria:

1. To diversify the management options available, as to ensure the reliability of the overall solution. As developed countries have reached almost complete exploitation of nearby and accessible sources of water supply, it becomes almost impossible to find new "unique" or "absolute" solutions to current needs. As a result, it is usually necessary to resort to a series of coordinated management options, capable of providing a reliable solution.

2. To use a balanced combination of both infrastructures and management strategies, as to expand their potential for jointly matching, in a flexible and rapid manner, water supplies and water uses, as they evolve in space and time.

3. To plan systematically those actions, particularly infrastructure building, but also management strategies, as to ensure they reach their technical and economic

goals, while undergoing debate, revision and acceptance by all stakeholders, including those responsible for environmental preservation and enhancement.

Recent European regulations like the Water Framework Directive (OJEC, 2000), and proposals formulated by international agencies and professional associations emphasize the relative importance of this operational criteria. The recently published Action Plan *No Time to Waste*, prepared by the Association of California Water Agencies (ACWA, 2005), illustrates the interest and the relative priorities of those management alternatives. The Action Plan describes a mix of actions and investments directed to solve California water needs during the coming decades, so state and federal agencies can contribute to the development of the water supply system that California needs to support its population, its work force, and its ecosystems in the future (ACWA, 2005).

The main recommended actions of this plan are: 1) to improve the water supply and conveyance systems from the Delta of the Sacramento-San Joaquin rivers, 2) to evaluate the long-term threats to the Delta levee and conveyance systems, 3) to pursue the protection of the state systems for water supply and the environment, 4) to develop additional groundwater and surface water storage, 5) to support and fund local efforts to expand recycled water use and implement best management practices for urban and agricultural water use efficiency, 6) to work with local agencies to overcome constraints to developing seawater and brackish groundwater desalination, and 7) to support integrated regional water management plans.

As an example of the similar concerns expressed by ACWA (2005) and those of the proponent of the Spanish Master Water Plan of 2000 (MMA, 2000), it may be noted that one of the most basic limitations affecting Spanish river flows in the 1990's was its low quality along certain river stretches and reservoirs, as to render practically impossible any water transfer among watersheds. The significant improvements achieved by the implementation of environmental protection programs by regional governments, and the gradually increasing compliance with the effluent discharge limits established by EU Directive 91/271 (OJEC, 1991) have greatly helped in promoting and enforcing integrated management of water resources.

15.2. ALTERNATIVE ACTIONS

Planned water reuse brings new dimensions to integrated management of water resources, particularly by offering a water supply source of high reliability. The following are some planned water reuse strategies being adopted, or considered for adoption, among government agencies, urban users and agricultural users in Spain:

1. Substitution of pre-potable surface waters used for non potable uses by new reclaimed water. Considering that the marginal cost of additional surface waters in a water scarcity situation is usually much higher that the cost of reclaimed water, a water rights exchange process can be considered taking as a reference the cost of available surface waters. The water right owner could use reclaimed water, without any obligation to cover the additional costs (reclamation and conveyance costs) involved, which would be covered by the beneficiary of the pre-potable surface waters made available.

The considerable marginal cost of surface waters made available offers the possibility to balance the costs associated to water reclamation and conveyance to the existing irrigation network. Initial water right owners would receive reclaimed water of similar quality to that of surface waters previously used, but with much higher supply reliability. Urban users would gain a new or additional source of surface water that could be used for drinking water production. Supply reliability has been one of the determining factors for this type of water exchanges, and particularly in states with a large private water rights system like California, where reclaimed water is been used for agricultural irrigation and industrial cooling. Recent regulations adopted by Spanish government, in the form of Centers for the Exchange of Water Use Rights are intended to promote those exchanges. Although the few exchanges recorded so far refer to water surface among urban and agricultural users, o between agricultural users, it may be expected that they will be extended to include reclaimed water.

2. Supply of reclaimed water to irrigation projects with insufficient water supplies or to new irrigation projects. Access to those water rights could be approached within the economic and financial framework applicable to available water alternatives, as to encourage water users to cover the cost of reclamation projects, under similar conditions to those applicable to users of conventional water resources. Although the production cost of reclaimed water is generally lower than that of conventional surface waters available, the conveyance and distribution system needed to bring reclaimed water to the point of use may represent a considerable additional cost for agricultural users. However, if the distribution system is already in place, as it is normally the case in irrigation projects with insufficient water supplies, the new costs will be limited to the conveyance system extending from the reclamation plant to the irrigation network.

3. Artificial groundwater recharge with reclaimed water. The Groundwater Replenishment System promoted by Orange County Water District and Orange County Sanitation District in Southern California represents the most emblematic and the largest project of this type, with an annual production of 90 hm^3 of high quality reclaimed water. About 47 hm^3 of reclaimed water will be devoted to groundwater recharge by infiltration into a potable aquifer, while the other 43 hm^3 will be used to supply the seawater intrusion barrier located in the coastal borderline of this aquifer.

Other options for integrated management of water resources are being adopted without the consideration of reclaimed water, so far. However, they offer a considerable potential for reclaimed water to be included as an added option. The following are practical examples taken from urban and agricultural water supplies in Spain and other areas:

1. Rehabilitation of agricultural irrigation systems, to improve conservation and efficiency, in exchange for an economic compensation associated to the water conserved. This approach has been adopted in several cases in Spain, the most recent and emblematic being the Ebro Delta Plan (Consorci d'Aigües de Tarragona, 1995). The rehabilitation and improvement of 197 km of irrigation channels, and of numerous associated facilities, with a total budget of 140 million euros in 2000, resulted in water savings of 12 m^3/s (1.04 hm^3/day) of

surface water that was infiltrating through the irrigation channels. In exchange for that investment, the sponsor of the project, Consorci d'Aigües de Tarragona, got an allocation of 4 m^3/s, equivalent to 126 hm^3 annually. In summary, an investment of 1.10 euros/m^3 in 2000 resulted in a new surface water source that has been used for drinking water production.

2. Imperial Irrigation District of Southern California (www.iid.com) announced early in 2006 that a similar agreement had been signed to line 37 km of the All-American Canal, which supplies 3,800 hm^3 of Colorado River water for agricultural irrigation. The agreement provides for the San Diego County Water Authority to pay 135.56 million dollars for lining 37 km of canal; in exchange, the Water Authority will receive 83.5 hm^3 of water that currently infiltrates through the dirt section of the canal. In summary, an investment of 1.62 dollars/m^3 will provide a new surface water allocation that can be used for drinking water production, while the agreement is in force. It may be noted that this agreement takes effect within a context of rapid urban growth, very limited rainfall, and multi-annual droughts such as those prevailing in Southern California, where the cost of surface water delivered by wholesale water agencies varies from 0.35 to 0.45 dollars/m^3.

3. Groundwater recharge as an strategy for storing surface water supplies. Although artificial recharge of groundwater has been widely studied and debated in Spain for the last few decades (ITGE, 2000), its implementation has been rather limited, even after the drought episodes and the water scarcity situations experienced during the last few years in numerous areas of the country, and particularly in agricultural areas of the Mediterranean coast.

   The potential of this management strategy is clearly illustrated by the groundwater recharge program promoted over the last decade by Metropolitan Water District of Southern California (MWD; www.mwdh2o.com), wholesale distributor of urban and agricultural water to 18 million inhabitants in Southern California. MWD has established agreements with a total of 6 municipalities and irrigation districts using groundwater supplies, as to expand its storage capacity by 230 hm^3, a capacity slightly higher than that of Lake Matthews, the second largest reservoir in Southern California. An agreement was signed in February 2005 with the city of Compton, with a duration of 25 years, which provides for storing up to 2.8 hm^3 of water flows from the aqueduct going from Sacramento to Los Angeles, in exchange for a payment of 2.42 million dollars. Those funds will be used for rehabilitation of the pipelines and wells used by the city to extract and convey water into its water supply system. This agreement represents a unit investment of 0.86 dollars per m^3 of storage capacity, with a payback period of 25 years. This value is comparable to the unit cost of 2.0 dollars per m^3 associated to the construction of Diamond Valley Lake, owned by MWD, with a storage capacity of 1.000 hm^3; however, the payback period for this facility may be easily considered 100 years.

4. Exchange of water rights between irrigation districts from different watersheds. The severe drought conditions experienced by extensive agricultural zones in the Mediterranean coastal areas of Spain during 2005 have intensified controversies among urban and agricultural users of different watersheds, particularly when transfer facilities had been previously used to transfer surplus

water among them. An agreement was signed in March 2006 by two irrigation districts to exchange their irrigation water rights: the Irrigation District of Estremera, including 900 farmers in the Tajo River watershed, located 65 km from Madrid, and the Central Irrigation District from Murcia and Alicante, just about 450 km southeast from Madrid. The Estremera Irrigation District is currently rehabilitating its water distribution system and will not be able to use its water allocations effectively; the Central Irrigation District of Murcia and Alicante needs water to prevent major drought damage to its horticultural and orchards areas. The exchange agreement has been established within the framework of recent regulations for Centers for the Exchange of Water Use Rights, will extend for one year, will provide for a transfer of 31 hm^3 of surface water, and will have a cost of 0.195 euros/m^3 for the receiving irrigation district. Government agencies had pledged any additional fees associated with water conveyance through aqueducts and reservoirs. That unit cost is just twice as much as Murcia and Alicante farmers pay for water transfers under normal water supply conditions.

The main benefits derived from this type of urban-agricultural agreements are: 1) a higher reliability of water supplies (extra water is stored that can be used under well defined protocols), 2) shallower pumping heads, as the groundwater levels rise with recharged water, and 3) improved irrigation facilities, by direct investments and economic contributions offered by project sponsoring agencies. It has to be noted that elaboration and approval of those agreements require the continued and considerable efforts of dedicated teams that are able to complete them under a well planned schedule.

The experience in water resources management gained in different parts of the world, with permanent or seasonal water deficits for urban, agricultural and landscape uses, offers a variety of technical, economic, financial and management options able to resolve the strong tensions that normally rise between users during severe drought episodes, as those experienced in Spanish Mediterranean coastal areas during 2005, and even more so when environmental protection and enhancement measures have to be considered to conform to the European Water Framework Directive.

Adoption of contractual agreements between urban users and agricultural users, within a context of integrated management of water resources as that offered by watershed agencies in Spain, and using regulatory instruments as the Centers for the Exchange of Water Use Rights, or others that could be established, offers a very viable alternative to satisfy the water needs for drinking water supply in urban areas and those for agricultural and landscape irrigation projects.

Implementation of contractual agreements for the use of reclaimed water, that satisfy the quality concerns and the supply reliability of irrigation projects, while preserving the legitimate economic interests of current users, offers to agricultural and landscape users a practical alternative to solve the real challenges posed by gradually increasing water deficits, particularly in coastal areas, while offering regulatory support for the quality of the agricultural products irrigated with reclaimed water.

The initiatives and promotional efforts taken by public agencies, particularly those responsible for water resources management at a watershed level, together with those of agricultural users themselves have been determining factors of the success reached in arid and semi-arid areas of the world with a marked tradition of agricultural activity, like California, or landscape activity, like Florida.

16. RECLAIMED WATER PROJECTS IN SPAIN

This section covers several successful case studies of planned water reuse in Spain, which illustrate its potential application in numerous other inland and coastal areas of the Mediterranean region. The following are some of the most emblematic and successful planned water reuse projects implemented or under consideration in Spain, to satisfy a wide variety of beneficial uses:

1. Irrigation of Golf d'Aro, en Castell Platja d'Aro, Costa Brava.
2. Irrigation of Golf Santa Cristina, Santa Cristina d'Aro, Costa Brava.
3. Environmental enhancement at the Empuriabrava wetland, in Costa Brava.
4. Irrigation of a selected variety of vineyard in Costa Brava.
5. Stream flow augmentation and agricultural irrigation at El Prat de Llobregat, Barcelona (under construction)
6. Intrusion barrier in El Prat de Llobregat, Barcelona (under construction).
7. New urban distribution network in Sabadell, Barcelona, to supply reclaimed water for urban and industrial process. The study is completed, and ready for implementation.
8. The use of reclaimed water in the integrated water resources management plan of Vitoria, where water is being use for irrigation of 10.000 ha of agricultural land, plus urban landscape areas.
9. Planned water reuse projects in the Canary Islands, and the Costa del Sol, where several reclamation facilities are being interconnected to supply a large number of golf courses, landscape irrigation and agricultural irrigation sites.

The following are three selected case studies that describe the perception, the advancement, and the future prospects of reclaimed water for agricultural irrigation, landscape irrigation of golf courses, and reclaimed water storage (agricultural irrigation and in-stream ecological river flows).

17. CASE STUDY 1: AGRICULTURAL IRRIGATION

The Mas Pijoan ranch is located in Solius, a small community belonging to the municipality of Santa Cristina d'Aro, and was founded in 1913 as a family agricultural project. By gradual farmland acquisition and use agreements with neighboring land owners, it has developed into a small irrigation farm capable of producing the food crops necessary to feed a small cattle ranch. Business has grown according to the farming land available. The 12 ha available by 1979 have been gradually extended up to the 150 ha of farmland managed by 2006, with 40 ha dedicated to irrigated agriculture. Farm production is mainly centered on seed crops (barley) on dry land, and fodder crops in irrigated land (oat and triticale during the winter season and corn during the summer season). The cattle ranch includes 300 cows, of which 140 are milking cows.

Until 2003, agricultural irrigation at Mas Pijoan was conducted on 30 ha of farmland using local groundwater sources. However, while flows available at the beginning of the summer season could reach 150 m^3/hour, they would gradually decrease down to 20 m^3/hour after 2 months of operation, leaving the final growth stages of the corn plantation with very limited water application rates. This excessive pumping of groundwater was also affecting nearby residential and agricultural users, which were having difficulties in extracting the water necessary for theirs crops and gardens.

By 2000, the Mas Pijoan owner realized that reclaimed water from the Castell Platja d'Aro water reclamation plant was used for horticultural irrigation in small plots around the plant. Managers of the neighboring Costa Brava Golf Course, also in Santa Cristina d'Aro, had shifted to reclaimed water in 1998, when their groundwater supplies had been seriously reduced by a local drought episode. Reclaimed water was conveyed to the golf course through an existing pipeline that had been rehabilitated for that purpose. All that was necessary to connect the Mas Pijoan ranch to the reclaimed water pipeline was a 3-km stretch between the ranch and the golf course.

After securing an overall agreement with neighboring water users, the Mas Pijoan ranch submitted a funding request to the Agricultural Service of the Catalonian Government that could cover from 60 to 70 % of the investment costs of the new pipeline and the associated pumping station. The land agreements and the favorable response of the grant agency offered the possibility to Mas Pijoan to expand the initial 30 ha of irrigated land to the current 40 ha of irrigated land, with a potential to add another 10 ha using only limited irrigation.

The main and basic driving force for that initiative was the water supply reliability offered by reclaimed water during all the summer irrigation season, rendering crop production independent from varying rainfall patterns. However, other important benefits have become apparent after 2 years of active operation of the system: 1) the nutrient contribution of reclaimed water, which has diminish the need for chemical fertilizer application, and 2) the higher productivity and quality of the corn field, which reaches up to 80 tons/ha, with a seasonal water application of 5,600 m^3/ha.

The reclaimed water supply project included: 1) a 3-km pipeline of 200 mm diameter, 2) a 1,800 m^3 storage pond, and 3) a 50-hp pumping station. The total budget of the project was 170,000 euros, and it received a government grant of 100,000 euros. The construction process was completed by September 2003, and the process was ready for operation by the summer of 2004. The project includes water meters at the point that reclaimed water leaves the golf course pipeline to enter the last portion of the conveyance system, which ends at the storage pond. Different fertilization programs are applied in the areas irrigated with reclaimed water and those with well water. The 20 ha irrigated with reclaimed water receive only a cow manure application, while the other 20 ha are irrigated with well water, and receive similar doses of manure plus enough mineral fertilizers to reach a 250 kg N/ha application dose.

The schedules for agricultural irrigation at Mas Pijoan and landscape course irrigation at Costa Brava golf course are closely coordinated as to ensure a smooth operation. Reclaimed water pumping operates 20 hours a day, with a 4-hour stop to skip the highest electricity rate period. However, the pumping station remained in continuous operation for 6 days during the summer of 2005. Golf course irrigation operates from

9 pm to 7 am, and agricultural irrigation is supplied during the rest of the day, up to complete the 20 h operating cycle. Golf course irrigation with reclaimed water has been conducted for 8 years with only a 8-day water supply interruption. The technical agreement between Mas Pijoan and the Santa Cristina d'Aro golf course includes also a reversible pumping station, so golf course irrigation can be supplied from the storage pond of Mas Pijoan, using well water if necessary. That arrangement has provided added reliability and flexibility to both users.

Table CS1-1 summarizes the microbiological and chemical quality of the reclaimed water used for agricultural irrigation at both Mas Pijoan ranch and Costa Brava Golf Course, as it leaves the Castell Platja d'Aro reclamation facility. The cost of reclaimed water for Mas Pijoan ranch is 0,084 euros/m^3, including water production, analytical control and pumping from the reclamation plant to the storage pond. Figure CS1-1 shows the reclaimed water use patterns for agricultural irrigation at Mas Pijoan ranch during the summer seasons of 2004 and 2005.

Table CS1-1. Microbiological and chemical quality of reclaimed water used for agricultural irrigation at Mas Pijoan ranch, Spain, CCB (2004, 2005).

Parameter	2004	2005
Faecal coliforms, cfu/100 mL		
Number of samples	27	27
Geometric Mean	2	2
90th percentile	5	10
Maximum level	30	29
Turbidity, ntu		
Number of samples	29	36
Arithmetic Mean	2,0	2,6
90th percentile	3,4	4,8
Maximum level	11,5	7,3
Total nitrogen, mg N/l		
Number of samples	31	43
Arithmetic Mean	28	32
90th percentile	45	48
Maximum level	56	55
Total phosphorous, mg P/l		
Number of samples	33	55
Arithmetic Mean	3,9	5,1
90th percentile	8,2	8,8
Maximum level	14,0	11,o

The benefits derived from using reclaimed water for agricultural irrigation at Mas Pijoan are: 1) water availability during all the summer season, 2) water supply reliability during the irrigation season, 3) a net nutrients contribution, which provides valuable fertilizer savings, 4) a sense of contributing to an integrated management of water resources, and 5) an improvement of environmental quality by preventing discharges of treated effluent into coastal areas and river beds.

Agricultural users perceive with great concern the increasing interest of environmental agencies for implementing biological nutrient removal from wastewaters. They believe it is not only unnecessary for agricultural and landscape irrigation, but it has a detrimental effect for both uses, as it forces application of additional amounts of mineral fertilizers. Agricultural and landscape irrigation with reclaimed water is an alternative way for the beneficial use of both water and its mineral contents.

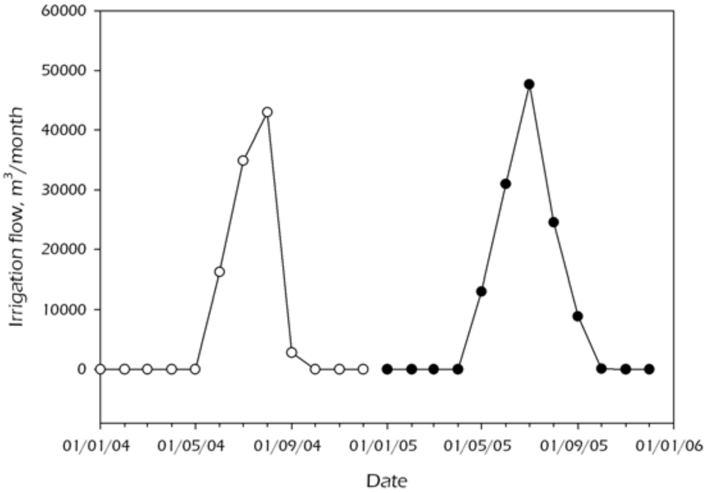

Figure CS1-1. Reclaimed water used for agricultural irrigation at the Mas Pijoan ranch, Costa Brava, Spain, 2004 and 2005.

The official permit of the Mas Pijoan irrigation project includes a series of requirements that are considered by the user as unjustified and discriminatory. The official application required a detailed study of the irrigation zone, where no urban supply wells exits. The authorization requires a complete annual analysis of reclaimed water, similar to that applicable to drinking water and valued at 800-1000 euros, plus a systematic series of microbiological parameters similar to those conducted at the reclamation plant. The question raised at this point is the need to duplicate the analyses that are conducted at the reclamation facility, considering that there is no evidence that those contaminants may develop during water transport to the storage pond. Furthermore, the agricultural user is required to determine the residual chlorine concentration and the faecal coliform concentration in the agricultural storage pond. Those analyses are conducted by the water reclamation agency, with an estimated cost of 300 euros/year.

The Mas Pijoan ranch has officially requested a waiver to that large series of analyses, based on its unjustified nature (an extreme application of precautionary principles on the water quality achieved at the reclamation plant) and its discriminatory character. A much larger flows of reclaimed water are discharged into the Ridaura River, downstream of the reclamation plant, where they infiltrate into surrounding groundwater basins regularly used as a source for urban water supply, and no such series of analyses are required by regulatory agencies. All those regulatory requirements are perceived as clear impediments for a optimal advance of planned water reuse.

Nonetheless, the Mas Pijoan ranch is satisfied with the possibility of using reclaimed water for agricultural irrigation, is proud of the way reclaimed water and nutrients are used for this beneficial use, is convinced that regulatory requirements should be justified and balanced, and believes that planned water reuse is an opportunity for the future, and a basic element of integrated management of water resources.

18. CASE STUDY 2: GOLF COURSE IRRIGATION

Green Turf Consult (GTC) is a small service company devoted to golf course irrigation, based on Sant Gregori, Girona, Spain. It started in 1991 when its manager, Xavier Millet, a biologist specialized in plant growth, took over the responsibility of green keeper in a golf course in Costa Brava, Spain. The company currently includes 4 additional agronomic engineers. Golf course irrigation with reclaimed water became an early challenge for Xavier Millet, who has been able to turn it into a new opportunity for application in the different golf courses under his supervision.

Although public perception raises considerable issues concerning the use of reclaimed water, Xavier Millet emphasizes that, if properly managed, there is absolutely no difference in managing agronomic properties of reclaimed water and that of waters normally used for landscape irrigation. Emphasis should be switched from the name used to designate the water to the actual quality of the water.

Current responsibilities of GTC include:

1. Two 36-hole golf courses in Madrid, one irrigated with reclaimed water and other with groundwater.
2. A 36-hole golf course in Valencia, irrigated with groundwater. Reclaimed water is available in the area, with a better agronomic quality than the water currently used.
3. A 18-hole golf course in Valladolid, irrigated with groundwater which has an electrical conductivity close to 3,000 µS/cm.
4. Four golf courses in Costa Brava and Barcelona: three 18-hole golf courses and one 36-hole golf course.

The main success of GTC has been to recognize and promote the value of reclaimed water as a new water resource. That observation has been certainly possible thanks to the significant progress of sanitation projects around the country, which have made available increasing flows of high quality treated effluents.

The main driving force for the use of reclaimed water in golf course irrigation has been the regulatory requirement to use it, as a substitute for water from conventional sources. The water supply agency in Madrid, Canal de Isabel II, began requiring the use of reclaimed water in 1996, and has extended that requirement to the whole regional area of Madrid during 2005, as a result of the severe drought conditions experienced during that year. That requirement comes about 10 to 20 years after reclaimed water use was locally promoted for golf course irrigation in Costa Brava. The gradual application of that requirement is resulting in a more collaborative attitude between water reclamation agencies and users. Reclamation agencies provide detailed information on reclaimed water quality, as it has been practiced by Consorcio de la Costa Brava for more than 15 years. Reclaimed water users already realize the great benefits derived from that systematic information, regardless of the expenses involved in getting it.

The golf course in Valladolid is irrigated with groundwater, which has a significantly high salinity level. To improve water quality, demineralization was applied for some time; however, the resulting increase in sodium concentrations in the soil due to unfavorable SAR values, and the higher production costs involved brought the demineralization process to a halt. The current challenge for water user like this one is to become aware of the benefits and requirements of using non conventional water resources, such as reclaimed water. The lower salinity concentration of drinking water, as compared to current groundwater sources, renders reclaimed water a more favorable solution. Furthermore, treated effluent reliability is a significant characteristic of this new water source.

Water scarcity and recurrent drought episodes are the main driving forces for golf course irrigation with reclaimed water in the Valencia area. Although irrigation is currently practiced with surface waters, frequently borrowed to irrigation districts, environmental concerns, urban demands for surface waters, and increasing availability of high quality treated wastewater effluents are gradually promoting the use of reclaimed water.

Golf course irrigation with reclaimed water in the Costa Brava has been practiced since 1989, when the City of Castell Platja d'Aro required the use of reclaimed water for irrigation of a new golf course. The experience gained over the last 16 years shows the interest of using ornamental lakes as a strategic storage of irrigation water, while using reclaimed water for irrigation as it comes from the reclamation plant. Direct use of reclaimed water ensures compliance with disinfection requirements, without the need to implement any additional disinfection process at the point of use, and provides a more stable and controlled physico-chemical quality, as water quality is not affected by biological processes taking place over time in the storage facilities. Analytical information provided by the reclamation agency can be directly used to closely manage the irrigation and fertilization systems. Stored water can be used sporadically, in case that additional flows are necessary, or that reclaimed water quality has to be modified by mixing to achieve a given fertilization strategy.

The basic observation obtained by GTC from all the golf course irrigation projects under its supervision is the need to "get back to basic agronomic principles". To promote that approach, it is necessary that water reclamation agencies expand their operation and maintenance programs to wastewater treatment facilities, take a leading role in developing and providing relevant information on reclaimed water quality, and favor the integrated management of water resources beyond the plants territorial boundaries, within the watershed limits. By a continuous evaluation process, in collaboration with reclaimed water users, reclaimed water use will be promoted and optimized, simultaneous recycling of water and nutrients will be further advanced, and fertilizer inputs to the natural environment will be reduced.

The most obvious practical benefit of using reclaimed water for golf course irrigation is water supply reliability. However, some of the golf courses still feel comfortable with the conventional sources they have, even if water quality poses real operating challenges due to its salinity or its seasonal availability. Increasing appreciation of the supply reliability of reclaimed water, particularly in the context of recent supply restrictions, is gradually changing the traditional approach, and convincing golf course managers on the benefits derived from expending close to 10,000 euros annually to cover the cost of a reclaimed water supply. That figure compares favorably with the charges they have to face to use conventional water supplies.

Nutrients contributions are perceived as an added benefit, as they may add up to 30% of all the nitrogen needs, amounting to annual savings close to 10,000 euros for a 18-hole golf course. This poses a serious dilemma in relation to the growing interest of sanitation agencies for incorporating biological nutrient removal in wastewater treatment processes. Nutrient contributions of reclaimed water are seen by green keepers as beneficial by themselves, and also as an added expense for the water user, when they have been removed by wastewater treatment. The quality of the nutrient species themselves, as compared to those provided by industrial fertilizers, is seen as an added benefit of reclaimed water.

The need for improved management of irrigation water quality in golf courses has prompted a larger participation of irrigation specialists, which has indirectly promoted lower water consumptions. Control of soil salinity has become an added concern for irrigation projects, as soil salinity build-up can be induced even when irrigating with the best mountain quality water. Similarly, extensive irrigation of golf course runs, using a full load of nitrogen fertilizers, has normally resulted in excessive nutrient percolation and potential contamination of nearby groundwater and surface waters.

Two of the main concerns related to reclaimed water use for golf course irrigation are the potential odors generated during sprinkler irrigation, and the potential need for using chemical pest control. Odor prevention can be achieved using reclaimed water of good quality and particularly using adequate management techniques for water storage. Golf course irrigation has less limitations than an horticultural irrigation project, and allows for a simpler adjustment of wastewater treatment to the water quality required for irrigation. Although it is well known that reclaimed water alters the life cycles of certain turf pests, there is nothing unusual that can not be controlled using well known agronomic practices, to render pest control measures more effective. Streamlining certain administrative aspects of integrated management of water resources, and improving the efficiency of those services will further contribute to promote reclaimed water use.

The future prospects for reclaimed water quality look very favorable. The quality of urban water supplies is expected to improve, as a result of the public's positive perception on good drinking water quality, the increasing controls on discharges to sewerage systems, and the growing concern for environmental conditions of surface water and groundwater. Those same environmental concerns will further improve the levels and reliability of wastewater treatments currently applied. As a result, reclaimed water quality will gradually improve, even more so in a context marked by the deterioration of other marginal waters. Spanish society is immersed in a dynamic process by which reclaimed water will gradually gain a more favorable position, up to become a prime resource for landscape and agricultural irrigation. The political will to promote this trend will be a determining factor for its practical advancement.

In summary, the use of reclaimed water for golf course irrigation does not present any technical problem that can not be solved using well known agronomic principles. The experience gained so far in numerous golf courses in Spain has served to identify the costs involved in its production, the practical ways to use it, and the management strategies applicable to the irrigation and fertilization programs. The overall costs, including nutrient contributions, compare very favorably with those of conventional water sources. The supply reliability of reclaimed water will become a paramount factor in coming years, as a result of competition among urban and agricultural users. Reclaimed water quality is expected to improve gradually, as a result of advances in water quality of urban supplies, better wastewater treatments, optimized reclamation processes, and deterioration of available marginal water sources. Trihalomethanes generation can be adequately controlled using chloramination processes. Soil salinity build-up can be adequately managed taking into consideration rainfall series of up to 8 years; the relative proportion of cations is certainly of higher concern that salinity in general. Widespread use of reclaimed water for golf course irrigation will require a profound restructuring of water resources management, and of the cultural attitudes of users and the public at large, as well as further improvements in monitoring strategies of reclaimed water quality.

19. CASE STUDY 3: RECLAIMED WATER STORAGE

This study case covers the initiatives taken in Vitoria-Gasteiz, Spain by several Irrigation Districts and the Álava Regional Government to build the Azúa Valley Lake for storing reclaimed water produced during the fall-winter-spring period, so it can be used for agricultural and landscape irrigation during the summer season. The text included is an excerpt of the paper submitted for presentation at the International Symposium on Dams in the Societies of the XXI Century, Barcelona, 18 June 2006 (Mujeriego and López, 2006).

The city of Vitoria-Gasteiz is the capital of both the Álava Regional Territory and the Regional Government of the Basque Country in Spain. With a population of 220,000 inhabitants, it includes a very diverse industrial activity that contributes about 30% of its wastewater flows. The city of Vitoria-Gasteiz shares its water supply system with the city and the regional area of Bilbao, with a population of 1 million inhabitants, through the conjunctive use of the water reservoirs of the Zadorra River, with a total useful capacity of 180 hm^3.

The urban water supply requirements of Bilbao and Vitoria-Gasteiz have been exceeding the storage capacity of the existing reservoirs in a steady increasing manner during the last decades. This situation has prompted the need for the current water users to obtain additional water resources, particularly by Vitoria-Gasteiz, the user with the largest deficit. An Integrated Water Reclamation and Reuse (IWRR) Plan for Vitoria-Gasteiz was prepared by the Álava Regional Government in 1992 (Diputación Foral de Álava et al., 1995) as a coordinated response to the water demands of urban, industrial, and agricultural users in the Vitoria region. The main objectives of the plan were to improve water supply reliability, to decrease the risk of flooding, and to ensure the environmental protection of the tributary streams.

19.1. OBJECTIVES

The main objective of this case study is to present the role of the Azúa Valley Lake as an essential component of the IWRR Plan of Vitoria-Gasteiz, with particular emphasis on: 1) the quality of the reclaimed water that will be stored in the lake, 2) the environmental and economic benefits that will be derived for the region, 3) the improvement in water supply reliability that will provide for the current water supply system, 4) the reduction of flooding risks associated with the current management policies of the surface water supply reservoirs, and 5) the definition of water quality management strategies to be followed for maintaining the aesthetic and environmental status of the reclaimed water stored in the lake.

19.2. WATER RESOURCES AND WATER USES

Table CS3-1 summarizes the storage capacity of the Zadorra river reservoirs and the water demands of the surrounding populated areas. Table CS3-1 clearly shows two basic and important facts: 1) the flows provided by the reservoirs are devoted exclusively to urban water supply and to preservation of the rivers environmental conditions, and 2) the annual water demands corresponding to those two uses exceed the useful capacity of the reservoirs.

This inadequate water supply reliability, historically estimated at a minimum deficit of 20 hm^3 per year, has resulted over the last decades in serious coordination difficulties for the Inter-regional Watershed Agency (Confederación Hidrográfica del Ebro, CHE), the Regional Governments of Álava and Vizcaya, the City Councils affected, and the Irrigation Districts in the area.

Table CS3-1. Available water resources and water allocations from the Zadorra River reservoirs.

Reservoir capacity	
Urrunaga	67 hm^3
Ullibarri	139 hm^3
Total	206 hm^3
Authorized maximum volume	180 hm^3
Current allocations	
Water supply to Bilbao	145 hm^3
Water supply to Vitoria	25 hm^3
In-stream flows of the Zadorra and Santa Engracia Rivers	30 hm^3
Total	200 hm^3

19.3. PLANNED WATER REUSE AND INTEGRATED MANAGEMENT

The Irrigation Districts affected, in cooperation with the CHE and the Álava Regional Government, have been implementing since 1996 an Integrated Water Reclamation and Reuse Plan, with the following main objectives:

1. To use reclaimed water for irrigation of 10,000 ha of several food crops, including orchards and raw eaten vegetables. Irrigation started in 1996, and covered initially a surface area of 4,000 ha. The additional 6,000 ha began irrigation with surface water during the summer of 2005, waiting for the corresponding volumes of reclaimed water that will be stored in the Azúa Valley Lake by the end of 2006.
2. To replace a fraction of the in-stream ecological flows currently provided from surface water reservoirs by the corresponding flows of reclaimed water, with the quality level required for supporting fish life, namely salmonid and cyprinid waters (European Council, 1978). Those replacement flows would be introduced just below the water supply dams, using the pumping stations and the pipelines of the existing irrigation network.
3. To use reclaimed water for landscape irrigation of parks and public gardens in the city of Vitoria-Gasteiz. Table CS3-2 shows that landscape irrigation in Vitoria-Gasteiz represents more than 10% of the city's surface water supply. When the

currently proposed new landscape areas become operational in the forthcoming years, that fraction will reach an estimated 15% value.

19.4. WATER RECLAMATION PLANT

The water reclamation facility of Vitoria-Gasteiz began operating in 1995, and has a capacity of 35,000 m^3/day, equivalent to 12 hm^3/year. That water volume is sufficient to irrigate 10,000 ha of agricultural land during the summer season. The edaphic characteristics of the agricultural areas of the Vitoria region render summer irrigation a recommended practice under a schedule of once every three consecutive years. This practical requirement results in an agricultural surface area actually irrigated during a summer season close to 3,300 ha, just about one third of the 10,000 ha available to the Irrigation Districts.

Table CS3-2. Surface water consumption for urban water supply and landscape irrigation in the city of Vitoria-Gasteiz.

Year	Landscape area, ha	Urban supply, hm^3	Urban irrigation, hm^3 (% total use)
2003	460	24,6	3,1 (13)
2002	437	24,6	2,5 (10)
2001	402	25,2	2,8 (11)
2000	402	24,8	2,5 (10)
1999	400	24,5	2,4 (10)
1998	380	25,3	2,0 (7,9)

The water reclamation plant of Vitoria-Gasteiz was designed according to the quality criteria for reclaimed water required by the Title 22 of the California Water Code (Asano, 1998, Asano et al. 1991). Planned water reuse for agricultural irrigation was designed according to the guidelines and technical criteria included in the Guidance Manual prepared by the California State Water Resources Control Board (Pettygrove and Asano, 1984; Mujeriego, 1990).

The optimal operation of the water reclamation plant was limited by the ability of the system to store the reclaimed water produced during the fall-winter-spring seasons. The flow capacity of the water reclamation plant allows irrigation of a maximum of 4,000 ha (1,300 ha effective) under continuous operation during the summer season. However, storing the reclaimed water produced during the rest of the year would provide enough water supply to irrigate up to 10,000 ha (3,300 ha effective). To achieve that objective, the IWRR Plan of Vitoria-Gasteiz included the construction of an off-stream reservoir, where reclaimed water could be stored during the fall-winter-spring season, and subsequently used for irrigation during the summer season. Table CS3-3 summarizes the water flow provisions of the IWRR Plan of Vitoria-Gasteiz.

Tables CS3-4, and CS3-5 show the water quality achieved by the water reclamation plant of Vitoria-Gasteiz since 1996, when it became operational. Reclaimed water satisfies the quality criteria specified by the Title 22 of the California Water Code (Asano et al. 1991), the health guidelines recommended by the World Health

Organization (1998) and the water reuse criteria proposed by the US Environmental Protection Agency (2004).

Table CS3-3. Integrated Water Reclamation and Reuse Plan for Vitoria-Gasteiz.

Capacity and Uses	Objectives
Reclamation capacity (2003)	12,00 hm^3/year
Agricultural uses (2003)	2,40 hm^3/year
Agricultural uses (2006)	7,00 hm^3/year
Storage capacity	7,00 hm^3/year
Existing irrigation network	350 km pipelines

Table CS3-4. Organic and microbiological quality of reclaimed water produced at the water reclamation plant of Vitoria-Gasteiz, from 1996 to 2006.

Bromodichloromethane	< 5 µg/cm
Bromoform	1 µg/l
Chloroform	< 30 µg/l
Dibromochloromethane	< 1,0 µg/l
Chlorophenols	Non detectable
Total coliforms	Absence
Nematode eggs	Absence
Giardia lamblia	Absence
Cryptosporidium	Absence
Legionella	Absence
Salmonella	Absence

Table CS3-5. Quality of the water produced at the water reclamation plant of Vitoria-Gasteiz, during the summer of 2006.

Turbidity	< 0,5 NTU
Electrical conductivity	< 900 µS/cm
Ammonia nitrogen	< 1,5 mg/l
NO_3	< 7 mg/l
Phosphorous	< 1 mg/l
BOD_5	< 5 mg/l de O_2
COD	<10 mg/l de O_2
Permanganate oxygen demand	< 5 mg/l de O_2
Metals	< 0,1 mg/l
Trihalomethanes	<15 mg/l
Chlorophenols	Absence

19.5. AZÚA VALLEY LAKE

The Azúa Valley Lake is the last significant construction included in the IWRR Plan of Vitoria-Gasteiz. Is it an off-stream storage reservoir, shaped by two earth dams that form an artificial lake with a capacity of 7 hm^3. The lake has been designed and built considering the environmental requirements applicable to a high value natural landscape environment. The lake is located 75 m higher than the water level of the nearby surface water reservoirs of the Zadorra River, and just about 2 km from them.

This topographic situation offers a unique condition to contemplate the possibility for future water transfers from the Azúa Valley Lake to the Ullibarri reservoir, after water undergoes the purification processes that may be considered necessary at that time.

The Azúa Valley Lake is an essential component of the IWRR Plan of Vitoria-Gasteiz, for the following reasons:

1. It provides the reclaimed water volumes required for in-stream flow substitution in the Zadorra River, in case of a prolonged failure of the biological treatment processes of the municipal wastewater treatment plant of Vitoria-Gasteiz, or the physico-chemical processes of the water reclamation facility of Vitoria-Gasteiz.
2. It ensures the water flows necessary for agricultural and landscape irrigation of the regional and the urban areas of Vitoria-Gasteiz during the summer season.
3. It provides a mechanism for nutrients removal from the reclaimed water stored in the lake. This will be achieved by alternating anoxic and aerobic conditions in the water column, and the addition of atmospheric oxygen through a deep aeration system. Compressed air will be generated by photovoltaic energy panels located in the inner slopes of the earth dams.

The reclaimed water storage reservoir was considered a basic element of the IWRR Plan of Vitoria-Gasteiz, according to similar water resources management initiatives widely adopted in Southern California (Mujeriego, 2004, 2005). The Azúa Valley Lake promotes a more sustainable use of the hydroelectric energy generated with surface waters stored in the Zadorra river reservoirs, and also results in an overall lower generation of carbon dioxide (Sala & Serra, 2004, Mujeriego, 2005).

The water reclamation plant of Vitoria-Gasteiz has a design capacity able to satisfy the water required for agricultural and landscape irrigation, and to contribute a flow of up to 0.4 m^3/s for substitution of the in-stream (ecological) flows discharged from the surface water reservoirs. That flow contribution represents just 40% of the 1 m^3/s in-stream flow currently established by regulatory requirements.

The indirect benefits of this flow substitution are: 1) the availability of the corresponding 0.4 m^3/s of surface water that can be diverted from the reservoirs and used for urban water supply in the Bilbao region, and 2) the production of an additional amount of hydroelectric energy, generated by that same flow when descending the 300 m altitude difference existing between the surface water reservoirs and the hydroelectric power station in the Bilbao region. The hydroelectric energy generated by those flows will be close to 2 million kWh annually.

The reclaimed water discharged into the Azúa Valley Lake will be of excellent physico-chemical and microbiological quality (see Tables CS3-4, and CS3-5). However, it contains significant concentrations of nutrients (ammonia nitrogen, nitrates and phosphorous). Those nutrient concentrations need to be controlled, to prevent the development of anoxic conditions during ammonia nitrogen oxidation, and thus to ensure suitable biological and aesthetic conditions in the lake. An ammonia nitrogen limit of 0.5 mg N/l (equivalent to 2.3 mg/l of dissolved oxygen) has been adopted to ensure that the biological quality of the water in the reservoir and its potential to maintain aerobic conditions in the lake remain acceptable at all times. To achieve that objective, the Azúa Valley Lake design project incorporates a deep aeration system, using compressed air diffusers located at 1 m above the bottom of the lake, with a capacity to maintain a minimum dissolved oxygen concentration of 3 mg/l.

The considerable amount of compressed air that will be required to satisfy the oxygen demand of the lake water makes necessary to consider an inexpensive energy source, with a low carbon dioxide emission rate. A large surface area of photovoltaic plates will be installed on the inner slopes of the dams, preventing any undesirable aesthetic impact from the outside. The top line of the earth dams has a length of 900 m, which allows for a total surface area of photovoltaic plates of 1,800 m^2, with a power capacity of up to 150 kW. The direct current produced by the plates will be stored and subsequently converted to alternate current, which will be used for running the air compressors.

19.6. CONCLUSIONS

The Azúa Valley Lake is the most emblematic element of the ambitious Integrated Water Reclamation and Reuse Plan of Vitoria-Gasteiz that began in 1992. Construction of the Azúa Valley Lake was completed in June 2004, and full operation is expected by late 2006, once the required safety and operation protocols are completed and approved. The lake has been designed to store the fall-winter-spring excess of reclaimed water produced at the Vitoria-Gasteiz water reclamation plant, so it can be used for agricultural and landscape irrigation during the summer, and also for in-stream ecological flow substitution. The Azúa Valley Lake is a unique infrastructure in Spain, but similar to others built in Southern California and Israel to store reclaimed water for multiple uses.

Operation of the Azúa Valley Lake will serve the following main objectives:

1. To provide the reclaimed water flows necessary for substitution of the in-stream (ecological) flows of the Zadorra River, especially during the summer season.
2. To provide the reclaimed water flows necessary for agricultural and landscape irrigation in both the Vitoria region and the city of Vitoria-Gasteiz during the summer months.
3. To promote nutrient removal from the stored reclaimed water, mainly in the form of ammonia nitrogen and nitrates.
4. To provide a future option to complete recycling of a fraction of the reclaimed water produced by the city of Vitoria-Gasteiz.

Furthermore, operation of the Azúa Valley Lake will satisfy the following secondary objectives:

1. To gradually restore the water allocations of the Bilbao region, which have been increasingly used for drinking water supply in the Vitoria region.
2. To allow for a more sensible management protocols for the water levels in the surface water reservoirs, as to ensure a higher protection level in relation to flooding episodes in the Vitoria region.
3. To produce an additional 2 million kWh annually of hydroelectric energy.

20. CONCLUSIONS

The review and discussions included in the preceding sections can be summarized in the following conclusions:

1. Planned water reuse has become an essential component of integrated management of water resources, particularly in costal zones, where it can significantly contribute to augment the net water resources available for agricultural and landscape irrigation, and groundwater recharge.

   Advancement of water reclamation and reuse will require more that technological advances in water treatment processes. A suitable legal and regulatory framework and the political will to implement it are determining factors for the future development of planned water reuse. The overall management of this water supply strategy, from project planning, to economic and financial analyses, public information process, and operation and maintenance of the facilities play a significant role in implementing a successful planned water reuse project.

2. Planned water reuse for agricultural irrigation offers a much higher supply reliability than conventional water sources. It ensures water flows availability particularly during the summer season, provides an opportunity for the uptake of plants nutrients (nitrogen and phosphorous) present in reclaimed water, and promotes a more efficient management of water resources, by allowing the allocation of pre-potable waters to drinking water supply.

   Agricultural and landscape irrigation with reclaimed water is the beneficial use most widely adopted in developed areas with a long agricultural tradition like California (68% of 495 hm^3/year in 2000) and landscape tradition like Florida (63% of 810 hm^3/year in 2001), as well in Mediterranean countries like Cyprus, Israel, Tunisia, and Spain. The main characteristic of those arid or semi-arid areas is a permanent and increasing water deficit, on a geographical or seasonal scale. Agricultural uses of reclaimed water vary from irrigation of horticultural products to industrially processed products, cereals, orchards and vineyards using sprinkler irrigation, micro-sprinklers, drop irrigation, and surface irrigation.

3. Available agronomic and public health criteria, guidelines and recommendations for reclaimed water quality provide a sound practical basis for planning, implementing and operating a planned water reuse project, able to satisfy the public health and environmental requirements applicable in each case. By a rational application of the gradual requirements established by international guidelines and recommendations as those proposed by WHO and USEPA, it is possible to match the type of irrigation system most suitable to the reclaimed water quality available at any given time. The gradual progress of water sanitation systems, under the motivation of higher hygienic conditions and environmental protection measures, will result in higher quality wastewater treated effluents, which will in turn favor the production of higher quality reclaimed water. In this manner, raw wastewaters will gradually become treated effluents, and then reclaimed water, with little resemblance to the raw water initially available.

The experience gained from planned water reuse projects in Spain indicates that the limiting factor of the projects implemented so far has been the lack of a regulatory framework, including water quality standards, more so than the quality requirements themselves. Reclaimed water projects have been promoted by users and water agencies, as to confront water shortages, while achieving the highest reclaimed water quality they considered was tolerable or acceptable by users, the public at large and public health agencies. Acceptable risks estimated by public health agencies, as well as tolerable risks perceived by populations and politicians will have a determining role in establishing the quality requirements applicable to reclaimed water.

4. A watershed framework offers a most suitable framework for implementing integrated management of water resources. The economic and financial requirements of planned water reuse become one more element to consider when balancing the costs and benefits of the whole watershed management.

   The following are some of the planned water reuse options currently applied to advance integrated management of water resources:
   a) Substitution of pre-potable waters by reclaimed water.
   b) Use of reclaimed water as an additional irrigation supply in projects with insufficient water supplies.
   c) Groundwater recharge with reclaimed water.

   Other management options currently applied, in conjunction or aside from reclaimed water use, are the following:
   a) Rehabilitation of agricultural irrigation systems (to improve their efficiency), in exchange for a fraction of the irrigation flows conserved by applying those corrective actions.
   b) Groundwater recharge, for temporary storage of surface water surpluses.
   c) Exchange of water rights between irrigation districts from different watersheds.

5. The reference cost of reclaimed water in Spain is 0.06 euros/m^3 at the outlet of the reclamation plant, including capital and operation and maintenance costs. This value has to be adjusted with the costs of pumping and distribution through the irrigation network. The largest economic requirements are associated to the planned reuse stage (distribution to users), while the capital costs of the reclamation plant and particularly the operation and maintenance costs (water reclamation) are comparatively smaller.

   The cost of reclaimed water for agricultural irrigation, when used for pre-potable water substitution, could be established taking as a reference the marginal cost of the pre-potable water made available. In this manner, the initial water rights holder could implement the reclaimed water irrigation project (reclamation and distribution) without additional costs. As the marginal cost of pre-potable water is generally higher than the reclaimed water made available, the cost differential could provide enough economic incentives to cover the costs of reclamation and connection to the existing irrigation system. The cost of reclaimed water supplied to new irrigation projects, irrigation projects with insufficient supplies and artificial recharge of over drafted groundwater could be approached according to the prevailing water resources economic framework, taking into account the quality of the reclaimed water available.

6. A comprehensive framework agreement between agricultural users and urban users offers a very favorable solution to satisfy the needs of pre-potable water for public water supply and that of irrigation water for agricultural and landscape irrigation. That agreement can be established in a context of integrated management of water resources, such as the watershed agency recommended by the European Framework Directive, and using management tools as the Centers for the Exchange of Water Use Rights, or others that could be established.

7. Contractual agreements for the use of reclaimed water offer a very effective solution to overcome the challenges posed to agricultural irrigation by seasonal and geographical water shortages, particularly in coastal areas. Those agreements can satisfy the concerns for water quality and supply reliability of irrigation users, as well as the economic interests of water rights holders, while providing a regulatory support to the quality of agricultural products irrigated with them.

8. The water reclamation and reuse case studies reviewed illustrate the potential of planned water reuse to satisfy the requirements and the needs of agricultural irrigation, landscape irrigation, and surface water storage. Those case studies show the practical approach adopted by users to implement their projects, and the expectations those beneficial uses raise among current and future users. Compilation, review and publication of similar projects in the Mediterranean region should greatly contribute to further advance the interest and the advancement of planned water reuse in the region.

21. RECOMMENDATIONS

The following are a series of recommendation on how to formulate: 1) convincing arguments to raise interest for planned water reuse, 2) incentives to promote existing or future water reuse projects, and 3) approaches to further advance the benefits of reclaimed water use.

21.1. CONVINCING ARGUMENTS FOR PLANNED WATER REUSE

Developing convincing arguments for implementation of planned water reuse projects will have to take into account the numerous perspectives of planned water reuse: 1) technical, 2) public health, 3) economic and financial, 4) regulatory, 5) managerial, 6) environmental 7) public perception, and 8) water policy, among others.

Among the positive aspects associated to using reclaimed water, the following can be addressed:

1. Water supply reliability, to be contractually defined and established. This aspect ensures that water will be available when the user needs it, together with the technical assistance provided by reclaimed water producers. Those responsibilities include maintenance and operation of the network, and the quality of the reclaimed water produced, and may be covered by the user itself, if appropriate.

2. More economical water supply than conventional sources, particularly during scarcity or drought periods. In those conditions, the opportunity cost of water may be out of reach for most users, other than domestic and industrial users. This aspect may be analyzed from two different perspectives:
   a. When reclaimed water serves to prevent the use of some pre-potable water flows that would otherwise occur (flow substitution/replacement). Those water flows can be used for domestic supply or other uses that require potable quality. In those conditions, reclaimed water users contribute to improve overall water supply and could be either exonerated from any economic charge or even compensated, through capital investments to improve their water distribution and storage system.
   b. When reclaimed water serves to supply a new beneficial use that was not taken place previously. In this case, reclaimed water use could be charged with either the cost of making reclaimed water available or even the opportunity cost of water prevailing under specific scarcity conditions. Other possibilities may be considered within the applicable water resources policy.
   c. The economic benefits of the nutrients present in reclaimed water may be an economic factor to be considered while determining the monetary compensation for reclaimed water availability and delivery.

3. Development and follow-up of planned water reuse projects will contribute to convert reclaimed water into a conventional water source. Reclaimed water is a new water source, and consequently has to be accepted by users before it becomes a common water source.

4. Promotion of planned water reuse requires a level of institutional cooperation and support (environmental, and public health particularly) higher than that commonly adopted when managing traditional water supplies. The relatively novel condition of reclaimed water, particularly for potential users, and the critical water scarcity conditions generally prevailing when planned water reuse becomes a favorable solution, make necessary a more flexible and supporting attitude from the part of all agencies involved in water resources management.

21.2. INCENTIVES FOR PLANNED WATER REUSE

Among the incentives that can be considered for promoting planned water reuse, the following can be considered:

1. To develop a suitable regulatory framework, with especial consideration to reclaimed water quality and water use requirements. The recommendations and guidelines offered by the World Health Organization and other specialized agencies, like the US Environmental Protection Agency, provide a sound basis for developing water quality regulations that ensure public health protection during direct contact with reclaimed water and consumption of products irrigated with it.

2. To offer systematic and reliable technical assistance to users. Reclaimed water producers, water utilities, water professionals, and public health agencies can greatly contribute to this goal.

3. To promote demonstrations projects, as a means to familiarize potential users with water reclamation and reuse practices, as well as with actual users of reclaimed water.

4. To sponsor public information and outreach programs and campaigns, describing the benefits and the requirements of water reuse for specific beneficial uses, and the technical, legal and economic conditions applicable to each type of water reuse project.

5. To critically evaluate the negative consequences that natural drought conditions have had for some water users. They should be compared to the benefits that can be achieved by having access to reliable and timely flows of reclaimed water, during water restrictions typical of drought episodes.

6. To develop legal and contractual frameworks that ensure access of potential reclaimed water users to this new water source, while offering them the assurance that their traditional water allocation can be honored, if reclaimed water doesn't provide the expected benefits.

21.3. APPROACHES TO ADVANCE THE USE OF RECLAIMED WATER

Promotion of reclaimed water use can be further advanced by combining planned water reuse with other elements of integrated water resources management, as follows:

1. Identifying the synergies that can be achieved with other elements of integrated water resources management, like water flows replacement.

2. Promoting water conservation, by investing in new ways of improving water use efficiency in irrigation or other significant water uses.

3. Promoting water storage, through contracts among urban utilities and irrigation districts; pre-potable water can be stored during periods of water abundance, so it can be extracted during periods of water scarcity. This storage option offers the possibility for further treatment during water percolation through the soil (soil-aquifer treatment), and also transport at further away distances, downwards from infiltration points, so it can be extracted after a significant period of stay in the aquifer and used for multiple beneficial uses. This storage process can be also achieved using surface water reservoirs, commonly dedicated to store reclaimed water, and located off-stream of any river bed.

4. Sponsoring reclaimed water rights exchanges.

5. Offering technical assistance on the use of reclaimed water through traditional agencies as agricultural extension units, and providing technical support to farmers and even greenkeepers, in addition to the increasing professional expertise that users themselves will gradually developed.

6. Promote economic and operational efficiencies, with multi-purpose water reuse projects, by which investments in a water distribution system may serve to supply water not only to the main investor/beneficiary, like a golf course, but

also to other users like nearby farmers. In some cases, agricultural distribution systems may serve for water supply to industrial parks and city landscape areas.

22. ACKNOWLEDGEMENTS

The information and data presented in this report have been developed thanks to the collaboration and economic support that numerous public institutions have offered us since 1985, among them the Consorcio de la Costa Brava, the Catalan Water Agency, the Álava Regional Government, the Arrato Irrigation District, the Spanish Ministry of Science and Education, the Spanish Ministry of the Environment, the Orange County Water District, and the University of California at Berkeley, Davis and Irvine, the Mediterranean Action Plan of the Regional Office for Europe of the World Health Organization, and the US Environmental Protection Agency. The numerous and extensive discussions with Dr. Takashi Asano, from UC Davis, and Richard Mills, from the California State Water Resources Control Board, and other colleagues from many parts of the world have been instrumental in developing this material; their assistance and inspiration are highly appreciated.

23. REFERENCES

Aertgeerts, R. and A. Angelakis (eds.) (2003). *State of the Art Report: Health Risks in Aquifer Recharge Using Reclaimed Water*, SDE/WSH/03.08, WHO, Geneva, Switzerland, and WHO Regional Office for Europe, Copenhagen, Denmark.

Angelakis, A., T. Asano, E. Diamadopoulos and G. Tchobanoglous (eds.) (1996). Wastewater reclamation and reuse 1995. *Water Science and Technology*, Vol. 33, No. 10-11. IAWQ, Pergamon Press.

Asano, T. (ed.) (1998). *Wastewater Reclamation and Reuse*. Water quality management library, Vol. 10. Technomic Publishing Co. Inc. Lancaster, PA, USA.

Asano, T., D. Richard, R.W. Crites and G. Tchobanoglous (1991). Evolution of tertiary treatment requirements in California. *Water Environment and Technology*. vol. 4, no. 2.

Asano, T. and R.A. Mills (1990). Planning and Analysis for Water Reuse Projects. *Journal of the American Water Works Association*.

Association of California Water Agencies (ACWA) (2005). *No Time to Waste, A Blueprint for California Water*. www.acwa.com. Sacramento, California.

Bartram, J., L. Fewtrell, and T-A Stenström (2001). *Water Quality: Guidelines, Standards and Health*, Chap. 1 (eds. L. Fewtrell and J. Bartram), IWA Publishing, London, UK.

Bonomo, L., C. Nurizzo, R. Mujeriego, and T. Asano (eds.) (1999). Advanced wastewater treatment, recycling and reuse. *Water Science and Technology*. Elsevier Science Ltd., Vol 40, No 4-5, 461 pp, 55 articles. ISSN: 0273-1223.

Brissaud, F., J. Bontoux, R. Mujeriego, A. Bahri, C. Nurizzo, and T. Asano (eds.) (2001). Wastewater reclamation, recycling and reuse. *Water Science and Technology*, IWA Publishing, Vol 43, No 10, 352 pp, 43 articles, ISSN: 0273-1223.

Carr, R. M., U. J. Blumenthal, and D. D. Mara (2004). Health Guidelines for the Use of Wastewater in Agriculture: Developing Realistic Guidelines. In: C. Scott, N. Faruqui, and L. Raschid-Sally (eds.), *Wastewater Use in Irrigated Agriculture: Confronting the Livelihood and Environmental Realities*, CAB International, London.

Consorci d'Aigües de Tarragona (1995). *El Plan Delta*. www.ccaait.com.

Consorci de la Costa Brava (2005). Actas de las Jornadas técnicas sobre *La Integración del Agua Regenerada en la Gestión de los Recursos: el Papel Dinamizador del Territorio*. Lloret de Mar, octubre de 2005. www.ccbgi.org/jornades2005.

Cuthbert, R.W. and A.M. Hajnosz (1999). Setting reclaimed water rates. *Journal of the American Water Works Association*, Vol. 91, no. 8, pág. 50-57.

Del Río, F., J. López, and I. de Juana (1996). Reutilización del agua residual, experiencias prácticas en Vitoria. Comunicación presentada en la *XVII Jornadas de la Asociación Española de Abastecimiento y Saneamiento*.

Hunter, P.R. and L. Fewtrell (2001). Acceptable risk, Chap. 10, In: Fewtrell, L. and J. Bartram (eds.) *Water Quality: Guidelines, Standards and Health; Assessment of risk and risk management for water-related infectious disease*, IWA Publishing, London.

Instituto Tecnológico Geominero de España (2000). *Identificación de Acciones y Programación de Actividades de Recarga Artificial de Acuíferos en las Cuencas Intercomunitarias*. Ministerio de Medio Ambiente, Madrid.

Jimenez, B. (ed.) (2004). Wastewater Reclamation and Reuse IV. *Water Science and Technology*, IWA Publishing, Vol 50, No 02, 352 pp, 44 articles, ISSN: 0273-1223.

Ministry of the Environment of Spain (2000). *Propuesta de Plan Hidrológico Nacional*. Madrid.

Mujeriego (2005). La reutilización, la regulación y la desalación de agua. *Ingeniería y Territorio*, No. 72. ISSN: 1695-9647. Colegio de Ingenieros de Caminos, Canales y Puertos. Madrid. www.ciccp.es/revistait/

Mujeriego, R. (2004). La gestión del agua en el sur de California. *Ambienta, no. 38, noviembre de 2004, pág. 31-38.* Ministerio de Medio Ambiente, Madrid. www.mma.es/publicacion/ambienta/

Mujeriego, R., and T. Asano (1999). The role of advanced treatment in wastewater reclamation and reuse. En Advanced Wastewater Treatment, Recycling and Reuse, *Water Science and Technology* (IAWQ), Elsevier Science Ltd., Vol 40, no. 4-5, pp 1-10. ISSN: 0273-1223.

Mujeriego, R. and T. Asano (1991). Wastewater reclamation and reuse. *Water Science and Technology*, Vol. 24, No. 9. IAWQ, Pergamon Press.

Mujeriego, R. (ed.) (1990). *Manual Práctico de Riego con Agua Residual Municipal Regenerada*. Universidad Politécnica de Cataluña, Barcelona.

Official Journal of the European Communities (1991). *Council Directive 91/271/CEE concerning waste water treatment.*. L135/40-52.

Official Journal of the European Communities (2000). *Directive 2000/60/EC of the European Parliament and the Council establishing a framework for the Community action in the field of water policy. EU Water Framework Directive*. L 327/1-71.

Pettygrove, G. S., and T. Asano (1984). Irrigation with Reclaimed Municipal Wastewater - A Guidance Manual. Published by the California State Water Resources Control Board. Reprinted by Lewis Publishers, Inc. in 1985. ISBN 0-87371-061-4.

Sala, L. and M. Serra (2004). Towards Sustainability in water recycling, *Water Science and Technology*, Vol 50, No 2, pp 1-8. IWA Publishing.

Sala, L. And X. Millet (1995). *Aspectos básicos de la reutilización de las aguas residuales regeneradas para el riego de campos de golf.* Technical Workshop of the Golf Spanish Federation. Madrid. Published by Consorcio de la Costa Brava, Girona, 1997.

Sheikh, B., R.P. Cort, W.R. Kirkpratick, R.S. Jaques and T. Asano (1990). Monterey Wastewater Reclamation Study for Agriculture. *Research Journal of the Water Pollution Control Federation*, Vol. 62, No. 3.

United Nations Environment Programme and World Health Organization (2005). Guidelines on Phsysical and Chemical Parameters for Water Reuse in Irrigation. Report UNEP(DEC)/MED WG.264/inf.10. Mediterranean Action Plan, Athens.

Water Environment Federation and American Water Works Association (1998). *Using Reclaimed Water to Augment Potable Water Resources*, Special Publication. ISBN: 1-57278-125-4.

World Health Organization (WHO) (expected 2006) *WHO Guidelines for the Safe Use of Wastewater, Excreta and Grey Water, Third Edition, Volume II Wastewater Use in Agriculture.* Geneva, Switzerland.

World Health Organization (WHO) (1989). *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture.*. Report of a WHO Scientific Group. Technical report series 778. Geneva, Switzerland.

United States Environmental Protection Agency and United States Agency for International Development (2004). *Guidelines for Water Reuse.* EPA/625/R-04/108, September 2004. Office of Water, Washington, D.C., and Office of Research and Development, Cincinnati, Ohio.

United States Environmental Protection Agency and United States Agency for International Development (1992). Manual on *Guidelines for Water Reuse.* EPA/625/R-92/004, September 1992. Center for Environmental Research Information, Cincinnati, Ohio.