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ASSESSMENT OF WASTEWATER REUSE PRACTICES IN THE MEDITERRANEAN REGION

In cooperation with

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ASSESSMENT OF WASTEWATER REUSE PRACTICES

IN THE MEDITERRANEAN REGION

FORWARD

Mediterranean regions are characterized by severe water imbalance particularly in summer months due to low precipitation and uneven distribution and high temperature. At the same time, there are increased demands for irrigation and domestic water use as a result of tourist industry. On the other hand, water is recycled through the global hydrological cycle. However, planned local water reuse is becoming increasingly important for two reasons. Firstly, discharge of sewage effluent into surface water is becoming increasingly difficult and expensive as treatment requirements become more and more stringent to protect the quality of the receiving disposal sites. Secondly, municipal wastewater often is a significant water resource that can be used for a number of purposes, especially in water short areas. The most common reuse is for non-potable purposes like agricultural and landscape irrigation. This requires treatment of the effluent to meet the quality requirements for the intended use. Besides the health related aspects, aesthetic and public acceptances are important aspects of water reuse, especially where the public is directly affected.

An alternative water resource to be considered in arid and semi-arid areas are treated wastewater effluents. At present, in several states and countries such as California, Arizona, Florida, Australia, Israel, South Africa, and Japan, wastewater reclamation and reuse technology have been well established and the value of reclaimed water as a water resource has been recognized. This innovative technology of advanced wastewater treatment and reuse has been adapted in many Mediterranean countries. At present the Mediterranean countries, Contracting Parties to the Barcelona Convention in alphabetical order are the following, Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Italy, Israel, Lebanon, Libya, Malta, Monaco, Morocco, Slovenia, Spain, Syria, Tunisia, and Turkey.

The basic goal of this report is to present the wastewater and reuse practices (if and where they exist) in the Mediterranean countries. In addition, to present the basic concepts of wastewater reclamation and reuse technologies and in the framework of these technologies, suitable for Mediterranean countries, to show their importance for the whole region.

The material of this Report is arranged in two chapters. In the first one, a review of wastewater reclamation and reuse is included and the status of wastewater reuse practices in each Mediterranean country is included in the second one. In addition, a brief review of the present developments in wastewater reuse quality criteria is considered.

Table of Contents

1. WASTEWATER RECLAMATION AND REUSE

1.1 Introduction

The South Mediterranean and Middle East region is characterised by one of the lowest per capita amounts of water supply in the world, unequally distributed in space and time both at the regional level and within each country. In the study (MAP/BP, 2000), "Water in the Mediterranean Region", it is showed that 28 million persons, 7% of the entire Mediterranean population, lie below the poverty line of 500 m^3/year per capita and 115 million persons, 29% of the population is below the threshold of 1000 m^3/year per capita (Margat and Valée, 2000). Based on current analysis, in the absence of structural changes and increasing efficiency in the water sector an ever-increasing gap is anticipated between supply and foreseeable medium and long-term demand by various uses. Such alarming analysis is mainly based on the present demographic and socio-economic dynamics, and sets the perspective of limitations posed by water resources and fragile ecosystems to sustainable development, regional and global integration. Specifically, the forecasted population growth of the Mediterranean Partners will extend from 200 mi people today to 340 mi people by 2020 characterised by increasing urbanisation trends. During the same period, the outlook of the main economic sectors influencing water demand suggests an expansion in irrigated agriculture, where possible, as well as in the industry, energy, and tourism sectors. A valid indication of the evolving situation is that the traditional large-scale use of water for agriculture (60-90% of water use in Mediterranean Partners) has increasingly become under pressure from alternative uses, being industrial or domestic.

In conclusion all existing data, evidences and scenarios regarding the future of water resources status in Mediterranean and Middle East region demonstrates that water supply will be severely strained during the next 20 years. Therefore, all efforts should be focused on the following areas: (a) to increase the use efficiency of conventional water resources and (b) to extend the use of non-conventional resources, such as water recycling. In this report, issues related to water recycling are considered.

The uneven atmospheric precipitation (spatially and regionally) in most of the Mediterranean countries, continued growth of the population, contamination of water resources, the rapid growth of the touristic industry, and the periodic droughts have forced water services and other water agencies to search for new and reliable water sources. The use of reclaimed or recycled wastewater for various non-potable uses has proved to be the most reliable of the sources and has been accepted as that by the Mediterranean society (Angelakis and Tchobanoglous, 1995). The types of wastewater treatment for obtaining effluent suitable for reuse are considered in this Chapter.

Natural treatment systems for wastewater (NTSW), especially those based on land treatment, which involve water reuse, overlap with both irrigation (agricultural and landscape) and artificial groundwater recharge. Also, considerations for effluent reuse including the benefits of reusing the water and nutrients are discussed in this Chapter. In addition, regulations and/or guidelines and various issues in implementing treated wastewater are included.

1.2 The Role of Wastewater Reclamation and Reuse in the Water Cycle

The inclusion of planned wastewater reclamation, recycling, and reuse in water resource management systems reflects the application of complementary developments in technology, health risk understanding, and public acceptance to mitigate limitations imposed by the increasing scarcity of water resources. As the link between wastewater, recycled water, and water reuse has become better defined, increasingly smaller recycle loops can be developed. The hydrologic cycle is a conceptual model of the continuous transport of water in the environment. The water cycle consists of fresh and saline surface water resources, subsurface groundwater, water associated with various land use functions, and atmospheric water vapour. Many subcycles to the large scale hydrologic cycle exist, including the engineered transport of water, such as an aqueduct. Wastewater reclamation, recycling, and reuse have become significant components of the hydrologic cycle in municipal, industrial, and agricultural areas. An overview of the cycling of water from surface and groundwater resources to water treatment facilities, irrigation, municipal, and industrial applications, and to wastewater reclamation and reuse facilities is shown in Figure 1.1 (Asano, 1998).

Water reuse may involve a completely controlled "pipe-to-pipe" system with an intermittent storage step, or it may include blending of recycled water with natural water either indirectly through surface water supplies or groundwater recharge or directly in an engineered system. The major pathways of water reuse are depicted in Figure 1.2 and include groundwater recharge, irrigation, industrial use, and surface water replenishment. Surface water replenishment and groundwater recharge also occur through natural drainage and through infiltration of irrigation water and stormwater runoff. The potential use of reclaimed wastewater for potable water treatment is also shown, although this application is reserved for extreme situations. The quantity of water transferred via each pathway depends on the watershed characteristics, climatic and geohydrological factors, the degree of water utilization for various purposes, and the degree of direct or indirect water reuse (Asano, 1998).

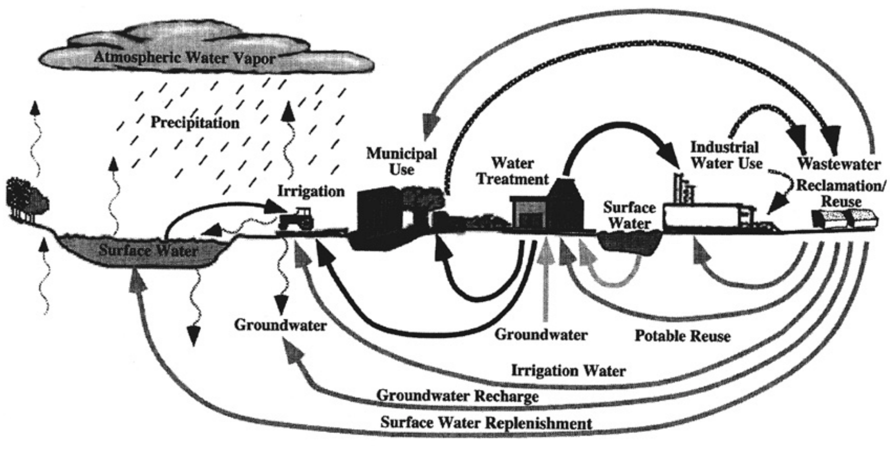

Figure 1.1 The role of engineered treatment, reclamation, and reuse facilities in the cycling of water through the hydrologic cycle (Asano, 1998)

The water used or reused for agricultural and landscape irrigation includes agricultural, residential, commercial, and municipal applications. Industrial reuse is a general category encompassing water use for a diversity of industries that include power plants, food processing, and other industries with high rates of water utilization. In some cases, closed-loop recycle systems have been developed that treat water from a single process stream and recycle the water back to the same process with some additional makeup water. In other cases, reclaimed municipal wastewater is used for industrial purposes such as in cooling towers. Closed-loop systems are also under evaluation for reclamation and reuse of water during long-duration space missions by National Aeronautics and Space Administration (NASA).

1.3 Treatment Operations and Processes for Wastewater Reclamation

With respect to wastewater treatment, it is now possible to produce any required treated effluent quality. While the cost may be high with some decentralized (such as NTSW) technologies, developments are proceeding at such a rapid way that it is fair to say that treatment costs will be competitive with centralised, conventional facilities or even less, especially so when the costs of wastewater collection and/or transportation are also considered. Thus, (Tchobanoglous, 1999) the multiple quality concepts for the treatment of wastewater were introduced. So, different levels of treatment should be used, regarding the disposal site and/or reuse practice planned (Fig. 1.2). In such a scheme NTSW are playing an important role.

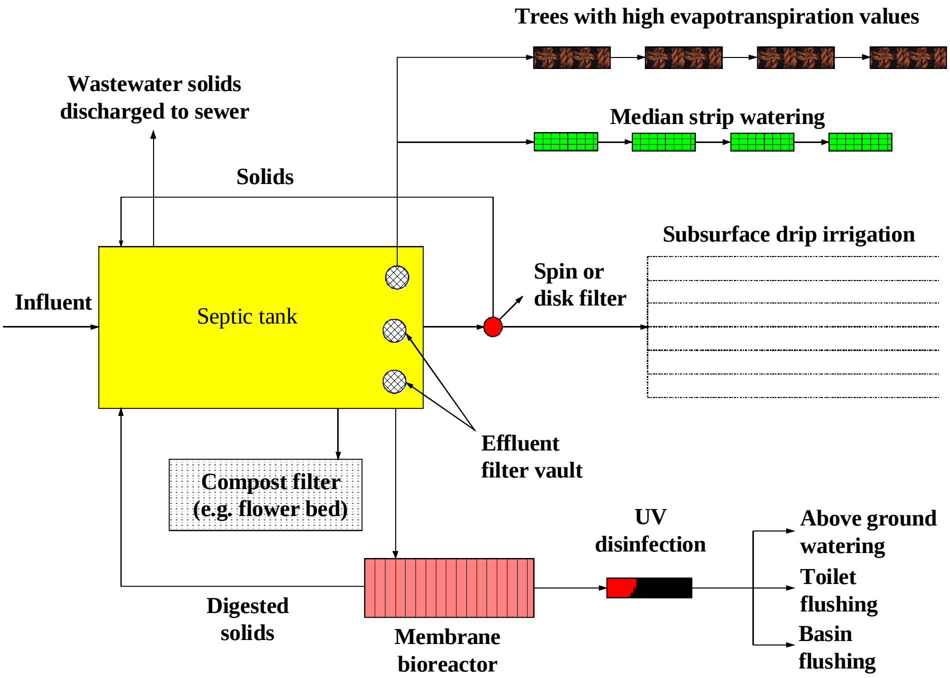

Figure 1.2 Multiple quality concept treatment and reuse scheme for an apartment building (Tchobanoglous, 1999)

Treatment operation and processes for reclamation and reuse usually include packed-bed filtration, membrane filtration (MF, UF, NF, and RO), chemical precipitation (for P removal), and disinfection (with chlorine, ozone or UV radiation). The three principal processes for tertiary treatment are full treatment, direct filtration, and contact filtration. The full or complete treatment is essentially a water treatment that involves coagulation, flocculation, clarification, filtration, and disinfection. Such a treatment performance in terms of TSS and pathogens is substantial and virus free water can be attained following disinfection using secondary effluent as the feed source (Crites and Tchobanoglous, 1998).

Direct filtration is the full treatment process with the clarifier removal when the turbidity of the secondary effluent is above 7 to 9 NTU, a filtered effluent turbidity value of 2 NTU will usually require chemical addition and the filters may need to be operated at lower loading rates. Direct filtration is only partially effective for the removal of protozoan oocysts and cysts.

In contact filtration, flocculation and clarification facilities are omitted and the system relies on inline coagulation prior to filtration. It was demonstrated in California (in the Pomona Virus Study) that, with adequate disinfection contact time, the equivalent of full treatment virus kill could be achieved (Crites and Tchobanoglous, 1998). Contact filtration is also only partially effective for the removal of protozoan oocysts and cysts. Typical design criteria for tertiary treatment prior to reuse are presented in Table 1.1.

Table 1.1

Typical design criteria for tertiary treatment prior to reuse
(adapted from Crites and Tchobanoglous, 1998)

Design parameter	Unit	Value	
		Range	Typical
Coagulation rapid mix Hydraulic detention time	sec	0.5-5	<1
Flocculation			
Hydraulic detention time	Min	10-30	20
Velocity gradient G	sec^{-1}	20-100	40
Mixing energy x detention time (G·t)	Unitless	20.000-150.000	50.000
Sedimentation			
Peak overflow rate	$m^3/m^2 \cdot d$	32.56-40.70	32.56
Filtration			
Rate with one filter out of service	$m^3/m^2 \cdot d$	0.16-0.24	0.20
Chlorination			
Rapid-mix detention time	sec	<1	<1
Peak-flow modal contact time	Min	30-120	90
Reactor design	N/A	Plug-flow	
UV disinfection			
Dosage at peak weekly flow	$mW \cdot sec/cm^2$	100-160	140
Reactor design	N/A	Plug-flow	

1.4 Typical Flow Diagrams for Reclamation Systems

With the technology nowadays available, reclamation systems can be developed to produce any quality of treated wastewater desired. The constraints to be considered at any case include cost, energy required, by-product disposal, and social acceptance.

Treatment levels achievable with various combinations of unit operations and processes used for wastewater treatment are referred in Table 1.2. It is interesting to note that flow diagrams containing septic tanks and intermittent sand filters, will result in effluent qualities that are comparable to or superior to activated sludge systems with filtration (Crites and Tchobanoglous, 1998). The use of membrane processes, such as RO, can be added to any flow diagram to reduce the nutrients and other constituents content of the effluent. Clearly technology at present is available for production of high quality effluent from wastewater, regardless of the system size.

Table 1.2

Treatment levels achievable with various combinations of unit operations and processes used for wastewater repurification (adapted from Crites and Tchobanoglous, 1998)

Treatment process	Typical effluent quality, mg/L except turbidity, NTU						
	SS	BOD_5	COD	TN	NH_3-N	PO_4-P	Turbidity
Activated sludge + filtration	4-6	<5-10	30-70	15-35	15-25	4-10	0.3-5
Activated sludge + filtration + carbon adsorption	<5	<5	5-20	15-30	15-25	4-10	0.3-3
Activated sludge/nitrification, single stage	10-25	5-15	20-45	20-30	1-5	6-10	5-15
Activated sludge/nitrification-denitrification separate stages	10-25	5-15	20-35	5-10	1-2	6-10	5-15
Metal salt addition to activated sludge + nitrification-denitrification + filtration	<5-10	<5-10	20-30	3-5	1-2	<1	0.3-2
Biological phosphorus removal[a]	10-20	5-15	20-35	15-25	5-10	<2	5-10
Biological nitrogen and phosphorus removal[a] + filtration	<10	<5	20-30	<5	<2	<2	0.3-2
Activated sludge + filtration + carbon adsorption + RO	<1	<1	5-10	<2	<2	<1	0.01-1
Activated sludge/nitrification-denitrification and phosphorus removal + filtration + carbon adsorption + RO	<1	<1	2-8	<0.1-0.5	<0.1-0.5	<0.1-0.5	<0.01-1
Septic tank with effluent filter vault	25-40	80-120	120-260	40-80	30-60	8-12	10-20
Septic tank with internal trickling filter	20-40	40-60	60-100	10-20	8-16	8-12	8-20
Septic tank with effluent filter vault + intermittent sand filtration	0-5	0-5	10-40	10-20	0-2	6-10	0.01-2
Septic tank + absorbent biofilter	5-15	5-15	30-80	10-20	8-16	6-10	1-2

[a] Removal process occurs in the main flowstream as opposed to sidestream treatment.

1.5 Historical Developments

Wastewater reuse has a long and illustrative history as evidenced by elaborated sewerage systems associated with ancient palaces and cities of the Minoan civilization. Indications for utilization of wastewater for agricultural irrigation extend back approximately 4500 years (Angelakis and Spyridakis, 1996). However, early developments in the field of water recycling are synonymous with the historical practice of land application of the disposal wastewater. With the advent of modern sewerage systems in the 19th century, domestic wastewater was used at “sewage farms” and by 1900 there were numerous sewage farms in Europe and in the USA (Asano, 2001). During the past century, the growing need for reliable water has resulted in the development of numerous wastewater reclamation and reuse projects in various parts of the world. Selected examples of wastewater reclamation and reuse in chronological order are given in Table 1.3.

Table 1.3

Selected examples of historic development of water reuse in different parts of the world

Year	Location	Water reuse examples
1912-1985	Golden Gate Park, San Francisco, California, USA	Watering lawns and supplying ornamental lakes.
1926	Grand Canyon National Park, Arizona, USA	Toilet flushing, lawn sprinkling, cooling water, and boiler feed water.
1929	City of Pomona, California, USA	Irrigation of lawns and gardens.
1942	City of Baltimore, Maryland, USA	Metals cooling and steel processing at the Bethlehem Steel Company.
1960	City of Colorado Springs, Colorado, USA	Landscape irrigation for golf courses, parks, cemeteries, and freeways.
1961	Irvine Ranch Water District, California, USA	Irrigation, industrial and domestic uses, later including toilet flushing in high-rise buildings.
1962	County Sanitation Districts of Los Angeles County, California, USA	Groundwater recharge using spreading basins at the Montebello Forebay.
1962	La Soukra, Tunisia	Irrigation with reclaimed water for citrus plants and to reduce saltwater intrusion into ground-water.
1968	City of Windhoek, Namibia	Advanced direct wastewater reclamation system to augment potable water supplies.
1969	City of Wagga Wagga, Australia	Landscape irrigation of sporting fields, lawns, and cemeteries.
1970	Sappi Pulp and Paper Group, Enstra, South Africa	Industrial use of reclaimed municipal waste-water for pulp and paper processes.
1976	Orange County Water District, California, USA	Groundwater recharge by direct injection into the aquifers at Water Factory 21.

1977	Dan Region Project, Tel-Aviv, Israel	Groundwater recharge via basins. Pumped groundwater is transferred via a 100 km-long conveyance system to southern Israel for unrestricted crop irrigation.
1977	City of St. Petersburg, Florida, USA	Irrigation of parks, golf courses, schoolyards, residential lawns, and cooling tower make-up water.
1984	Tokyo Metropolitan Government, Japan	Water recycling project in Shinjuku District of Tokyo providing reclaimed water for toilet flushing in 19 high-rise buildings in highly congested metropolitan area.
1985	City of El Paso, Texas, USA	Groundwater recharge by direct injection into the Hueco Bolson aquifers, and power plant cooling water.
1987	Monterey Regional Water Pollution Control Agency, California. USA	Monterey Wastewater Reclamation Study for Agriculture - agricultural irrigation of food crops eaten uncooked including artichoke, celery, broccoli, lettuce, and cauliflower.
1989	Shoalhaven Heads, Australia	Irrigation of gardens and toilet flushing in private residential dwellings.
1989	Consorci de la Costa Brava, Girona, Spain	Golf course irrigation.

1.6 Membranes in Wastewater Treatment and Reuse

The wastewater treatment by the use of membranes has proved to be an essential sector for membrane applications, according to the requirements of environmental protection, and water saving and reuse. Unfortunately, the unruly industrial activity has induced major pollution problems in many natural water resources causing their downgrade to significantly low quality sources. Membrane technology is to be used for the wastewater treatment before waste gets into the water resources, and also for the recovery and reuse of valuable components, such as water and other constituents. Additionally, the water deposits are continuously decreasing while the drainage cost is increasing, so as the idea of industrial wastewater recovery and reuse gains ground since such investment are economically viable. The countries with critical water quality problems due to the development have begun to enact increasingly stringent effluent guidelines for the wastewater discharges, demanding in this way, advanced wastewater treatments.

1.7 Reuse Categories of Treated Wastewater

Planned local water reuse is becoming increasingly important for two reasons (Bower, 1993). One is that discharge of sewage effluent into surface water is becoming increasingly difficult and expensive, as treatment requirements become more and more stringent to protect the quality of the receiving water for aquatic life, recreation, and downstream users. The second reason is that treated wastewater often is a significant water resource that can be used for a number of purposes, especially in water short areas. A wide range of options for water reuse exists (Angelakis and Tchobanoglous, 1995). For small and decentralized wastewater systems the most common reuse is for non-potable purposes, like agricultural and landscape irrigation. This requires treatment of the effluent so that it meets the quality requirements for the intended use.

Typical reclaimed water reuse include: (a) irrigation (agricultural and landscape), (b) industrial, (c) groundwater recharge, (d) recreational, environmental uses and habitat wetlands, (e) miscellaneous uses, (f) aquaculture, and (g) potable uses. These categories including potential issues/constraints are shown in Table 1.4.

Table 1.4

Categories of municipal wastewater reuse and potential issues/constraints
(adapted from Tchobanoglous and Angelakis, 1996)

Wastewater reuse categories	Issues/Constraints
Agriculture irrigation Crop irrigation Commercial nurseries	(a) Surface and groundwater pollution if not managed properly, (b) marketability of crops and public acceptance, (c) effect of water quality, particularly salts, on soils and crops, (d) public health concerns related to pathogens (bacteria, viruses, and parasites), (e) use for control of area including buffer zone, (f) may result in high user costs
Landscape irrigation Parks School yards Freeway medians Golf courses Cemeteries Greenbelts Residential	
Industrial recycling and reuse Cooling water Boiler feed Process water Heavy construction	(a) Constituents in reclaimed wastewater related to scaling, corrosion, biological growth, and fouling, (b) public health concerns, particularly aerosol transmission of pathogens in cooling water
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	(a) Organic chemicals in reclaimed wastewater and their toxicological effects (b) total dissolved solids, nitrates, and pathogens in reclaimed wastewater
Recreational, environmental uses, and habitat wetlands Lakes and ponds Marsh enhancement Streamflow augmentation Fisheries Snowmaking	(a) Health concerns of bacteria and viruses, (b) eutrophication due to nitrogen and phosphorus in receiving water, (c) toxicity to aquatic life
Miscellaneous uses Fire protection Air conditioning Toilet flushing	(a) Public health concerns on pathogens transmitted by aerosols, (b) effects of water quality on scaling, corrosion, biological growth, and fouling, (c) cross-connection
Aquaculture	(a) Constituents in reclaimed wastewater, especially trace reservoir organic chemicals and their toxicological effects, (b) aesthetics and public acceptance, (c) health concerns about pathogen transmission, particularly viruses
Potable reuse Blending in water supply Pipe to pipe water supply	

1.7.1 Agriculture irrigation

Crop irrigation is one of the oldest and most common types of effluent reuse. Conceptually, it is identical to slow rate land treatment (type 2). In California, 63% of the total wastewater reuse is for agricultural irrigation (California SWRCB, 1990). Crops irrigated include trees, pasture grass, corn, alfalfa, and other feed, fodder, and fibber crops. Food crops have also been irrigated with tertiary disinfected effluent (Asano *et al.*, 1992).

Benefits and environmental improvements from the irrigation reuse of effluent include:

(a) Prevention of surface water pollution, which would occur if the wastewaters were discharged into rivers or lakes.
(b) Conservation of fresh water resources and their rational use, which is especially important in arid and semi-arid regions like Mediterranean.
(c) Increase of soil fertility, since effluent is rich in nutrients (especially in nitrogen, phosphorus, and potassium) and thus reduces the application of artificial fertilizers.
(d) Improve soil physical characteristics through the organic matter added. Furthermore, the build-up of soil humus may prevent land erosion.

1.7.2 Landscape irrigation

Landscape irrigation, also referred to as urban reuse, includes irrigation of: (a) parks, (b) playgrounds, (c) golf courses, (d) freeway medians, (e) landscaped areas around commercial, office, and industrial developments, and (f) landscaped areas around residences. Many landscape irrigation projects involve dual distribution systems; one distribution network for potable water and another for reclaimed water. The recycled water distribution system becomes the third water utility, following the wastewater and potable water systems, and is operated, maintained, and managed like the potable water system. The oldest municipal dual distribution in the USA is in St. Petersburg, Florida (US.EPA, 1992). The system provides recycled water for a variety of uses, including a resource recovery powerplant and irrigation of schoolyards, a baseball stadium, residential lawns, commercial developments, and industrial parks.

1.7.3 Industrial reuse

Reuse of treated wastewater for industrial process or cooling water has been practiced at many locations throughout the USA (US.EPA, 1992). The principal uses that industry has made of recycled water are cooling water, process water, boiler feed water, and irrigation and maintenance of plant grounds. Cooling water, both for cooling towers or cooling ponds, creates the single largest demand for water in many industries and is the predominant industrial application (WPCF, 1989). Issues of concern in cooling water use include scaling, corrosion, biological growth, and fouling. Examples of industrial reuse are at Odessa, Texas; Fort Collins, Colorado; Lakeland, Florida; Burbank, California; and in most of northern European countries (US.EPA, 1992; Asano and Mujeriego, 1988); and in most of the northern European countries.

1.7.4 Recreational impoundments, recreational uses, and habitat wetland

Recreational impoundments may serve a variety of functions from aesthetic non-contact uses to boating, and fishing to swimming. The required level of treatment will vary with the intended use of the water and the degree of public contact. The appearance of the recycled water is also of concern because the nutrients in the recycled water will stimulate the growth of algae and aquatic weeds. Removal of phosphorus and possibly nitrogen is usually needed to prevent algae growth in recreational reservoirs. Without nutrient control, there is a high potential for algae blooms, resulting in odors, an unsightly appearance, and eutrophic conditions.

Recycled water impoundments can be incorporated into urban landscape developments. Artificial lakes and golf course storage ponds and water traps can be supplied with recycled water. Examples of recreational impoundments include Las Colinas, Texas; Santee, California; Lubbock, Texas; and the Tillman Water Reclamation plant in Los Angeles (US.EPA, 1992; WPCF, 1989).

Natural or created habitat wetlands can make beneficial use of recycled water. Wetlands provide many valuable functions, including flood attenuation, wildlife, and waterfowl habitat, productivity to support food chains, aquifer recharge, and water quality improvement. The distinction between a “constructed” wetland and a “created” wetland is that the constructed wetland is intended as a treatment unit that can be modified or abandoned after its useful life has been completed. A created wetland, on the other hand, becomes a wetland area to be maintained and protected for its wildlife benefits in perpetuity.

Reclaimed water has been applied to wetlands for a variety of reasons, including: (a) creation, restoration, and enhancement of habitat, (b) provision for additional treatment prior to discharge to receiving water, and (c) provision for a wet-weather disposal alternative for recycled water. Examples of habitat wetlands include Orlando, Florida; Showlow, Arizona; and Arcata, California. The Arcata wetlands consist of three 4 ha marshes and have attracted more than 200 species of birds, provided a fish hatchery for salmon, created a tourist attraction for the City of Arcata, and directly contributed to the development of the Arcata Marsh and Wildlife Sanctuary (US.EPA, 1992).

1.7.5 Groundwater recharge

Groundwater recharge helps provide a loss of identity between recycled water and groundwater. The loss of identity has an important, positive psychological impact where reuse is planned. Restrictions and reluctance to use recycled water can be overcome by groundwater recharge and subsequent recovery and use of the groundwater (Bower, 1993).

Groundwater recharge can be accomplished by either surface spreading or by injection. Artificial recharge of groundwater with both freshwater and pretreated wastewater effluent continues to increase, especially in arid and semi-arid regions of the world. By using pretreated wastewater effluent in a SAT system, with hydraulic loading rates relatively high (50–100 mm/yr) and evaporative losses as a small fraction of applied effluent, most of the applied effluents, percolate through the soil profile, where treatment occurs (Angelakis, 1997). Major issues to be considered in a designed SAT system ate: (a) pretreatment of wastewater required, (b) methods of application, and (c) various constituents removal. Artificial groundwater recharge has been successfully used world wide to control groundwater depletion, to dispose and/or treat wastewater and to control seawater intrusion in coastal areas.

The main purpose of artificial groundwater recharge in wastewater reclamation technology are: (a) enhance the capacity if potable and/or non-potable aquifers, (b) provide further treatment of reclaimed water, (c) ensure storage of reclaimed water, (d) control or prevent ground subsidence, and (e) establishment wastewater intrusion barriers in coastal aquifers. Another supplementary advantage of groundwater recharge is the loss of identity of wastewater effluents, are associated with a positive psychological impact in accepting wastewater reuse. Permeability values of greater than 25 mm/h are necessary for rapid infiltration. Therefore, sand loam, and loamy, or fine sands and gravel are preferred for the surface soils in SAT systems. For municipal wastewater, the appropriate level of pre-application treatment is typically primary sedimentation. An equivalent level of TSS removal can be achieved with a pond under short retention time.

1.7.6 Miscellaneous uses

A variety of miscellaneous uses have been made of reclaimed water: (a) flushing of toilets, (b) supply for public or commercial laundries, (c) fire fighting, (d) snow construction, (e) flushing of sanitary sewers, (f) snow making, and (g) washing aggregate and making concrete.

1.7.7 Aquaculture

Aquaculture is the growth of fish and other aquatic organisms for the production of food sources. Wastewater has been used in a variety of aquaculture operations around the world. However, in most cases, the production of biomass was the primary objective of the system, and any wastewater treatment was only a side benefit. Most of the treatment achieved in aquaculture systems has been attributed to the criteria attached to floating aquatic plants. There is little evidence that fish contribute directly to treatment. Combining wastewater treatment and aquaculture into a single operation requires further research. In particular, the health risks associated with use of aquatic organisms grown in wastewater must be defined (Metcalf and Eddy, 1991). In any way, a high pretreatment of municipal wastewater should be required. To this regard, only wastewaters treated to an appropriate quality level may be suitable for aquaculture.

Aquaculture may be carried out on waters of non-potable quality, including treated municipal wastewaters, as long as their impact on fish life and fish-meat quality is acceptable. Being a food industry, pathogens, heavy metals, toxic compounds and other trace organics are particularly hazardous and must be checked carefully and routinely to avoid negative effects on public health. Finally, coordinated actions should be undertaken, including provisions for incentives, appropriate training, assistance and others, towards protecting public health (Angelakis, 1997).

Even though the use of wastewaters for direct supply of aquacultures cannot be ruled out, considering that its practical feasibility lies in the quality of the water itself, it is to believe that an appropriate government action to promote more advanced methodologies using traditional water resources would be far easier, safer and practical to implement (Pescod, 1990).

1.7.8 Potable uses

Potable supplies can be augmented with reclaimed water; however, for small systems, the prospects are usually limited. Indirect potable reuse has been practiced in Fairfax County, Virginia, and in Clayton County, Georgia (Reed and Crites, 1984). Pipe-to-pipe direct reuse is only practiced at Windhoek, Namibia, and there only intermittently (US.EPA, 1992). Research on direct potable reuse is being conducted at Denver, Colorado; Tampa, Florida; and San Diego, California (Asano and Tchobanoglous, 1995).

1.8 Reuse Conditionings

The acceptability of reclaimed wastewater for any specific use depends on its physical, chemical and microbiological quality; and mainly on the sanitary risk related to this quality. In any case, an adequate infrastructure for reuse must exist. This infrastructure includes the water treatment processes and wastewater reclamation, the entire distribution network, and if it is necessary, storage facilities.

The assessment of treatment reliability, and in general of the entire reuse infrastructure, is one obvious control measure, forgotten from time to time. The design and performances of distribution systems are important to guarantee that reclaimed wastewater does not degrade before its use and is not used improperly. The open-air storage can result in water quality degradation due to microorganisms, algae or suspended solids, and it can cause bad odours or give colour to reclaimed wastewater. Nevertheless, if they are properly managed, the storage systems can improve the quality of the resource.

The control of the areas where wastewater is reused is paramount if an important reduction of sanitary and environment risk is wanted. It is reminded that risk reduction until acceptable levels, is the final objective of all rules and regulations related to the reuse.

When considering wastewater reclamation and reuse, every prospective user must be aware of the legal limitations existing in the country. Regulations can be based on the establishment of the end product (reclaimed wastewater) quality rules or in the definition of the reclamation equipment of wastewater (compulsorily or as a reference). In both cases, equipment and regulations could be complemented with the definition of Good Reuse Practices or similar indications.

In some non agricultural wastewater reclamation practices, different legal problems appear, usually related to the water or resources legislation of every country. For example, when groundwater is recharged with reclaimed wastewater, it must be clear who is the owner of the water in order to avoid undue extractions. In USA these problems occasioned diverse lawsuits (NRC, 1994), while in Spain when an aquifer is recharged, groundwater belongs to the State, it is said that water is Public Hydraulic Dominion. In non coastal areas and arid climates, often occurs that municipal treated or untreated wastewater is quite the only water that flows in streams. The users downstream rely on that flow and have rights on it, so it is sometimes not feasible the water reclamation and reuse for other purposes.

1.9 Issues in Water Reuse

The principal issues in implementing greater water reuse are: (a) the economic value of water, (b) technological, (c) regulatory requirements, and (d) social. Each of these issues is considered briefly below (Tchobanoglous, 1999).

1.9.1 Economic value of water

In many parts of the world, water is an under valued resource. Historically, the supplies of water have been plentiful and the price low (Linsky, 1998). As a result, the perception of value for water is lacking. In turn, because of this lack of perceived value and since water reuse was not considered as an important factor in global water availability and use, the economics of water reuse are difficult to sell. However, because the world's population continues to grow (about $78x10^6$/yr, Linsky, 1998), water shortages are now also common in many parts of the world. One way to maximize the use of existing water supplies is to employ multiple use strategies involving water reuse. By releasing freshwater resources for potable water supply and other priority uses, wastewater reuse is contributing to water conservation and takes on an economic dimension. It is clear that as water pricing becomes increasingly acceptable, the price of the water will change in the future, and the role and importance of water reuse will continue to expand. Water pricing is an issue of great importance in water management because it could affect water allocation, water conservation, cropping patterns, income distribution, efficiency of water management and generation of additional revenue, which could be used to operate and maintain water systems.

1.9.2 Technological issues

A wide range of suitable technologies is now available that can be used to produce any required water quality. Also, as noted previously, the cost of these technologies is continuing to decrease. What is missing is: (a) a consistent set of criteria that can be used to assess performance and allow for valid comparisons between existing and developing technologies, (b) well developed reliability measures defined in terms of the proposed reuse application, and (c) well documented fail-safe measures. These issues must be resolved, if wide public acceptance of water reuse is to be achieved.

1.9.3 Regulatory requirements

To protect environment and public health, without unnecessarily discouranging wastewater reclamation and reuse, many regulations including water quality, treatment process requirements, sampling and monitoring, plant operation and treatment process reability have been established. However, most of the existing standards are based on past experience and on limited and, in same cases, poor science. As a result, different standards are in use throughout the world. Further the relationship between many of the water quality indicators now used and public health is unclear. For example, the shellfish standard in the USA is based on coliform organism. But in fact, the biggest concern for shellfish may be *Cryposporidium* oocysts and *Giardia* cysts. Finally, many of the existing regulatory standards are inconsistent, including the use of Ms2 coliphage as an indicator organism for the evaluation of process performance. Based on recent studies, it is known that Ms2 coliphage is a far more resistant organism than some for the organisms used in the past to develop water quality and treatment performance standards (Tchobanoglous, 1999).

1.9.4 Social issues

Aesthetics and public acceptance are important aspects of water reuse, especially where the public is directly affected. The principal social issues to reuse are: (a) public perception, (b) public trust, and (c) public acceptance. Although difficult to quantify, public perception is of key importance in the acceptance of reclamation projects. In many cases, the public does not trust the ability of the operating agency to produce consistently a treated water that meets all of the applicable requirements. Clearly, this mistrust must be overcome if wastewater reuse is to be accepted by the public (Tchobanoglous, 1999). Strong and well organized institutions for wastewater collection, treatment, and disposal plus user's participation and incentives for reuse (lower price than fresh water) are the key factors for public acceptance.

1.10 Biosolids Management

1.10.1 Introduction

The strong contribution that sewage biosolids (sludge) can make in securing the sustainability of resources is often under-valued, ignored or even distorted. This note attempts to set the record straight. It focuses on the benefits and potential uses of sewage biosolids, the main ones of which could be realised if user and public confidence can be established and retained.

Sewage biosolids results from cleaning urban wastewaters and are an inevitable by-product of the water cycle. As an example, over 12 million tonnes of dry solids are produced every year in the EU, a small fraction of other wastes that are generated in the EU annually (250 million tonnes), and increasing as more wastewaters are collected and treated (EUREAU, Union of EU and EFTA National Associations of Water Suppliers and Wastewater Services).

Fortunately, sewage biosolids are a resource that can be used in a number of sustainable ways. Indeed it represents an environmentally sustainable link between the city, where most biosolids is produced, and the countryside, where it can be recycled to agriculture. It can also be used as a source of energy, reducing dependency on primary fuels, and in several specialist applications, such as the recovery of contaminated land. These uses require consistency in the quality of sewage biosolids according to the use, proper management and effective controls.

Raw sewage biosolids contain traces of the substances that are used or produced by society, some of which may be discharged to sewer and retained in the biosolids phase. A key and ongoing action for the EU, national governments and for producers and users is to reduce harmful and/or persistent substances at source. Specific EU legislation on the use of biosolids in agriculture, now being updated, sets the quality standards and conditions under which sewage biosolids can be applied safely on land. A Directive on incineration ensures that when biosolids is burnt, emissions are within acceptable limits. The quality of biosolids is monitored regularly to ensure that it meets the required standards and is fit for its intended use.

1.10.2 Soil enhancement values Farming practices

Agricultural practices. Sewage biosolids improves soil chemistry (nutrients, pH balance, trace elements), gives better physical characteristics (improved organic matter, water holding capacity, irrigation, stability and workability) and enhances biological activity (greater water retention and aeration stimulating root growth, increased worm and micro-organisms populations). The net effect is improved soil quality and agricultural yields.

The agricultural use of biosolids are linked to the fertilising value of the nutrients, nitrogen and phosphorus. 1-5 % of dry matter is phosphorous and 1-5% is nitrogen. Other compounds present in biosolids of agriculture value are potassium, sulphur, magnesium, sodium and elements like boron, cobalt, and selenium. Biosolids also contain potential contaminants as traces. These are limited by threshold values set out in regulations, ensuring that biosolids can be used safely in agriculture. Biosolids are also used in agriculture indirectly, for example after addition of lime. These treatments are particularly suitable for certain soils and allow applications to land over different times or terrains than otherwise would be the case.

Biosolids can be used to enhance the growth of industrial (e.g. flax) or energy (e.g. biomass) crops. Horticulture Biosolids can be thermally processed or composted using crop residues or municipal solid wastes, green or wood processing wastes etc. The products are aesthetically acceptable and suitable for soil conditioning and fertiliser applications in situations where direct biosolids application might not be acceptable or practicable, such as in gardens, public parks and highway verges.

Soil erosion management. Sewage biosolids is an excellent source of organic matter for poor quality soils and can make a substantially contribution to reducing soil erosion.

Land restoration and reclamation. The surface of derelict and disturbed land is often deficient in organic matter and usually deficient in nitrogen and phosphorus. On some sites, no soil may be available and cover materials would need to be brought in and then converted into a suitable topsoil to be used for sustaining plant growth. Sewage biosolids contain the organic matter and fertiliser value to provide a stable medium for the site and to help plants establish.

Landfill cover. Biosolids can be used as daily and final cover for landfill sites, providing a consistent blanket that serves to reduce nuisance during on-going operations and ultimately to restore the filled site for subsequent beneficial use.

Forestry. Some soils are more suitable for developing woodlands, such as coppicing to produce energy crops and wood products (fencing etc). Biosolids improve tree growth by providing appropriate nutrients.

1.10.3 Energy values

Biosolids have an organic content that can be transformed into or used as a fuel. A combination of technologies - digestion, drying and incineration - makes this possible. By biosolids digestion biogas is produced that can be used as green energy. Biogas can be used on the site of the waste water treatment plant for heating or process purposes. On other occasions it is converted into electricity distributed through national grids. Biogas can also be converted into a green vehicle fuel and be used by buses, trucks and cars which are adapted for fossil gas fuel. Co-incineration in plants not originally built for waste uses dried biosolids as secondary fuel. Examples are cement kilns and power plants. Dried biosolids have a calorific value comparable with brown coal. The co-incineration of one ton dried biosolids avoid nearly one ton of CO_2 emissions. Incineration of dried biosolids produce the same result. Mono-incineration of mechanical dewatered biosolids can be realised in an autothermal way, that is without any additional fuel. Biosolids can also be gasified to produce a pure biofuel, substituting for gas or oil. Also, biosolids can be used to enhance the growth of industrial crops or those used for plant biomass production.

1.10.4 Physico chemical values

The physical and chemical properties make sewage biosolids suitable for a range of alternative products, although most of these are currently not economically viable.

Products. A number of products could be derived directly from biosolids or as an admixture with other materials. These include building materials such as bricks. Biosolids can be used as material for producing the watertight top layer of a landfill. Ash from incineration is a potential source of phosphorus for fertiliser manufacture or a potential building material such as blocks and aggregate or as raw material in the cement industry.

Extractable materials. Various contents of sewage biosolids could be extracted for use. These components include grease, metals such as silver or platinum, proteins, vitamins and coagulants. Usually the concentrations are so low and the processing costs so high compared with conventional production methods that they are not commercially viable. More promising is the extraction of phosphorous from incineration ash for fertiliser manufacture.

1.10.5 Conclusions

Society's demands for a clean water environment produces sewage biosolids. Its production is difficult to reduce. Sewage biosolids is continuously produced and continuously available, in greater amounts as more sewage is collected and treated. It is also a seriously under-valued resource. It has a number of potentially valuable constituents - nutrients, organic matter, etc – and a calorific value that make it suitable for a range of uses. Biosolids could even be processed to provide a flexible range of products most appropriate for the intended use. The quality of sewage biosolids has progressively improved over the years, especially as manufacturing industry has declined/restructured and management and control over its discharges to sewer intensified. Its local quality is predictable and uniform, due to the scale of biosolids collection and treatment. Sewage biosolids has been subjected to close legislative control and careful management. Consistent achievement of environmental standards, conformity with established codes of good practice and recording/publication of performance details, have verified satisfactory operational performance and an absence of adverse environmental impacts. Nonetheless, operators still look for improvements to reassure the public and specific sectors of the community such as food and agricultural interests. In brief, sewage biosolids is a valuable resource particularly for fertiliser, soil conditioning and energy purposes and has the potential to make an important contribution towards a more sustainable society.

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2. WASTEWATER RECLAMATION AND REUSE PRACTICES IN THE MEDITERRANEAN REGION

2.1 Introduction

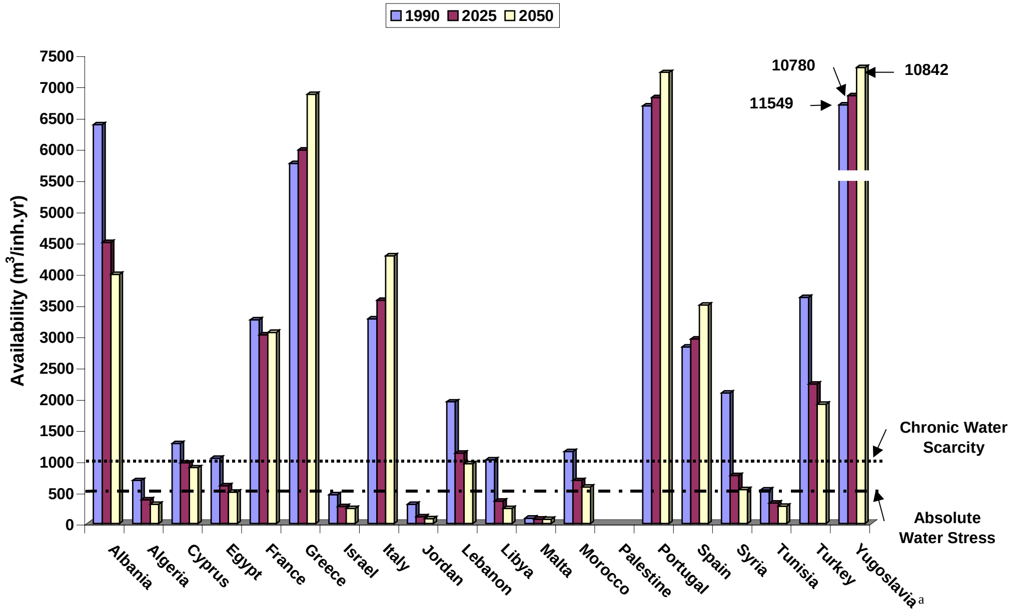
The south-east Mediterranean and the Near East countries are importing more than 50% of their food requirements, and demand for food grows faster than the rate of increase in agricultural production. As a consequence, the mobilization of land and water resources is proceeding fast. The development of irrigation is especially dynamic because it is often the most important factor for increasing agricultural production. Only 30% of the cultivated area in the region is irrigated, but produces about 75% of the total agricultural production. In many areas, agriculture is impossible without irrigation (Papadopoulos, 1995).

This rapid development of irrigation translates into a sharply increasing water demand and the most accessible water resources, such as rivers and shallow aquifers are now almost entirely committed. Alternative water resources are therefore needed to satisfy further increases in demand. This is mainly a necessity, in regions which are characterized by severe mismatches between water supply and demand, often associated to generally low water resources availability and asymmetries of availability and demand in a temporal and regional basis, and a peculiar relationship among water and environment which raise specific problems (Sano *et al.*, 1999)

Water experts and politicians agree that there is an acute water shortage problem in Mediterranean and the Middle East region. They also agree that the problem must be addressed immediately in a regional context; it is an issue ‘which cannot wait (Institute for Peace Implementation, IPI).

Population growth, urbanisation, and industrial development are the main factors which increase the water shortage by perpetually pushing up demand. One approach widely used to evaluate the water availability is the exploitation index, measured as the annual renewable water resources per inhabitant that are available to meet needs for domestic, industrial and agricultural use (Lazarova *et al.*, 2002). On the basis of past experiences of moderately developed countries in arid zones, renewable freshwater resources of 1,000 m^3/inh·yr have been proposed as a benchmark below which most countries are likely to experience chronic water scarcity on a scale sufficient to impede development and harm human health. According to some experts, below 500 m^3/inh.yr, the countries experience absolute water stress (Lazarova *et al.*, 2000b). In certain countries, exploitation indexes of renewable natural fresh resources have reached and exceeded 100%, thus imposing additional burden to the exploitation of non-renewable (fossil) water reserves.

UN projections (UN Population Division, 1994) show that four Mediterranean countries already have less than the minimum required water availability to sustain their own food production (1000 m^3/inh·yr). By 2025, eight countries will be in virtually the same situation. These countries are essentially all on the Southern rim of the Mediterranean (see Fig. 2.1). The crisis is already so acute that in Malta, for example, domestic water consumption exceeds 50% of the available water resources. In such places, the conventional water resources will be insufficient to even meet the domestic water demand at the beginning of the next century. On the other hand, all the Mediterranean countries of the EU are expected to maintain themselves at or above 3,000 m^3/inh·yr (Angelakis *et al.*, 2000b).



[a] Ex-Yugoslavia is not differentiated among Slovenia, Croatia, Bosnia-Herzegovina, and Serbia

Figure 2.1. Annual renewable fresh water availability for 1990, 2025, and 2050 in the Mediterranean countries (UN, Population Division, 1994)

The natural climatic diversity of the Mediterranean region is largely amplified by various characteristics, such as geographic, hydrological and namely the demographic ones. As an example of this situation, it can be observed that the mean actual precipitation varies roughly from 300 mm to 3000 mm, i.e. by a factor of 10. The internal resources per inhabitant vary by a factor of 160 (Correia, 1997).

Regarding the wastewater management in the Mediterranean basin, treated wastewater has been used as a source of irrigation water for centuries. In addition to providing a low cost water source, the use of treated wastewater for irrigation in agriculture combines three advantages. First, using the fertilizing properties of the water (fertirrigation) eliminates part of the demand for synthetic fertilizers and contributes to decrease the level of nutrients in rivers. Second, the practice increases the available agricultural water resources and third, it may eliminate the need for expensive tertiary treatment. Irrigation with recycled water also appears to give some very interesting effects on the soil and on the crops. As a result, the use of reclaimed wastewater for irrigation has been progressively adopted by virtually most of the Mediterranean countries (Marecos do Monte *et al.*, 1996). Because irrigation is by far the largest water use in the world and the quality requirements are usually the easiest to achieve among the various types of wastewater reclamation and reuse, it is by far the largest reuse application in terms of volume.

However, wastewater is often associated with environmental and health risks. As a consequence, its acceptability to replace other water resources for irrigation is highly dependent on whether the health risks and environmental impacts entailed are acceptable. It is therefore necessary to take precautions before reusing wastewater (Asano, 1998). As a result, although the irrigation of crops or landscapes with sewage effluents is in itself an effective wastewater treatment method, a more effective treatment is necessary for some pollutants and an adequate water storage and distribution system must be provided before sewage is used for agricultural or landscape irrigation (Asano *et al.*, 1985).

This chapter provides information on current wastewater reclamation and re-use practices in the Mediterranean basin, presents the benefits and problems incurred and outlines the prospects for this non conventional water resource.

2.2 Addressing Water Shortages

Several regions of Mediterranean countries regularly experience severe water supply and demand imbalances, particularly in the summer months. This is due to the simultaneous occurrence of low precipitation, high evaporation and increased demands for irrigation and tourism. However, water shortages have also affected regions less used to such events, where periods of drought are becoming more frequent and long lasting, maybe as a result of global climate change. Numerous regions in France, Italy, Belgium, and the UK have suffered the negative impact of successive droughts over the last ten years.

Several strategies have been developed in order to face water shortages. One is the construction of transfers from water rich watersheds to water deficient areas. Such projects require very expensive investments and large civil engineering works, potentially creating a large environmental impact. Additionally, as most of the "easy" projects have already been built (e.g. canal de Provence in France, trasvase Tajo-Segura in Spain), such an approach becomes more and more difficult as the areas likely to benefit from the water transfer become ever more remote. One must also note that this practice also raises economic, institutional, cultural and political issues.

Other solutions can be implemented such as water savings (e.g. suppressing the leakage of supply networks, using more efficient irrigation techniques such as drip irrigation and small flush systems), tapping other resources (e.g. desalinating seawater or brackish water), and practicing water recycling and reuse (Lazarova *et al.*, 2000). Reducing demand through pricing is also a possible option but it raises many political difficulties, in particular in countries where water is either for free or paid through a flat fee for more uses.

Wastewater reuse can have two important benefits. The most obvious is the provision of an additional dependable water resource. The second is the reduction of environmental impacts by reducing or eliminating wastewater disposal, which results in the preservation of water quality downstream. Therefore, when considered in the framework of an integrated water management strategy at a catchment scale, the treated wastewater reuse should always be assessed taking into account that it contributes to both enhancing a region's water resource and minimizing its wastewater outflow. In addition, using reclaimed wastewater for irrigation can reduce the need for fertilizer thanks to the nutrients it contains. This may even remove the need for tertiary wastewater treatment in sensitive areas.

The use of recycled water for irrigation has been progressively adopted by the most of Mediterranean countries (Marecos do Monte *et al.*, 1996). Although irrigation with wastewater is in itself an effective treatment (a sort of low-rate land treatment), some treatment must be performed previously for the protection of public health, the prevention of nuisances during storage and prevention of damage to the crops and soils (Asano and Levine, 1996). So far, in only a few countries worldwide is wastewater recycling and reuse well enough established to have led to the drawing of specific regulations or guidelines. In a number of other countries (such as Cyprus and Spain) regulations concerning the use of recycled water for irrigation are under preparation. Notice that regulations refer to actual rules that have been enacted and are enforceable by governmental agencies. Guidelines, on the other hand, are not enforceable but can be used in the development of a reuse program.

2.3 The Status of Wastewater Reuse in the Mediterranean Region

In the Mediterranean basin, Israel was a pioneer in the development of wastewater re-use practices, but soon was followed by Cyprus and Tunisia. However, the full value of reclaimed wastewater has been recognized in relatively few countries worldwide (such as Israel, Tunisia, South Africa and some US states such as California, Florida and Arizona). In these countries, full fledged regulations set the basic conditions for a safe reuse of wastewater. In other places (such as Texas for example) regulations require that a study be conducted to investigate the possibility of using reclaimed water for applications that currently use potable water or freshwater (Crook and Surampalli, 1996). In the USA, until March 1992, 18 states have adopted some form of regulations regarding the reuse of reclaimed water, 18 states had full fledged guidelines or design standards, and 14 states had nothing (US.EPA, 1992). In the 18 states with no specific regulations or guidelines, wastewater re-use projects may be permitted on a case-by-case basis. Further implementation of wastewater reuse in EU countries will very likely depend on the reliable control of enteric viruses. Note, that development of water reuse quality standards at Mediterranean level has been initiated by the Mediterranean Water Institute, Metropolitan Entity for Hydraulic Services and Waste Treatment of Barcelona, Catalan Water Agency, Spanish Ministry of Enviroment (Tecniberia), Agbar Foundation and University of Barcelona, and other Mediterranean Agencies, and they have met twice in Barcelona, Spain (27-28 January, 2000) and in Rabat, Morocco (8-10 October, 2001) without any agreement.

Potable water standards are not very controversial but process reliability. However, public acceptance and trace pollutant issues have so far limited potable reuse of reclaimed wastewater to extreme cases. Because groundwater recharge also provides a form of water treatment that has been shown to be efficient, discussions on recharged water quality remain usually limited to nutrient levels (phosphates and nitrates) and pesticide residues requirements in the case of percolation. Direct injection recharge has higher quality requirements because of potential clogging of the installations.

In most Mediterranean countries, 70 to 80% of water demand arises from agricultural and landscape irrigation. As a result, and because of chronic acute local water shortages, irrigation with domestic wastewater is a common practice, even without appropriate treatment or disinfection. In the EU, where investment in wastewater reuse had remained minimal and limited to the Mediterranean region, the recent acute droughts in Spain, Italy and Greece and the increasing dry periods in other European countries are pushing wastewater reuse to the top of the agenda (Angelakis and Bontoux, 2001). Besides, local water shortages, increasing by environmental constraints and pervasive pollution everywhere in Europe are also generating renewed interest in wastewater reuse. Italy has issued wastewater reuse criteria in 1977 and France in 1991. Some autonomous regions in Spain have also developed criteria and a national standard is in preparation (Angelakis *et al.*, 1999; Cajigas, 2002).

As mentioned above, some countries around the Mediterranean, such as Israel, Tunisia and others, are closely involved in wastewater reuse. However, so far, in many of these countries, wastewater reuse has rarely been considered as an integral component of sanitation and overall water resources management. A review of the current practice of wastewater reuse in the various Mediterranean countries is presented in the following chapters.

2.3.1 Albania

It is expected that the construction of urban wastewater treatment plants for urban wastewater in Vlora will present a possibility for its reuse. A monitoring program for the quality of urban wastewater is implemented in Albania during the last two years (Hema, 2002).

2.3.2 Algeria

The climate in Algeria is Mediterranean, ranging from humid in the extreme North (1000 mm/yr) to desert-type in the extreme south (less 100 mm/yr) and from the extreme east (more 1200 mm/yr) to the extreme west (400 mm/yr).

According to recent estimations, the total renewable water resources are evaluated at $19.1x10^9$ m^3/yr shared between ground water (30%) and surface water (70%); which corresponds to about 600 m^3/capita/yr. The agricultural sector is by far the greatest consumer of water by about 68%, then domestic and industrial sector by 9% and 23% of the total water withdrawal, respectively. Unlike most of the European countries, the ground water resources in Algeria, which are more stable, are less important than the surface. In addition to their limited quantity, the surface water resources are subjected to the low permeability of soils and the poor vegetative cover, and by irregularities of precipitations and hydrologic regimes. Added to this, the water resources mobilization and management are constrained by the uneven availability in space and time, rapid silting of dams, pollution and high costs of investment. Therefore, the water resources in Algeria are limited, vulnerable and unevenly distributed throughout the country (Tamrabet, 2002).

As a result, Algeria is presently looking at improving the situation by adopting a new water resources policy and new alternatives that enable to ease the crisis. Treated wastewater represents a promising alternative that is not only constantly available but also increasingly available, with the development of cities, tourism and industry. In the agricultural sector, reuse of wastewater is a technique that adds to the value of the water resources while it protects the environment.

In Algeria, more than $350x10^6$ m^3 of wastewater were disposed of in 1979, and $660x10^6$ m^3 in 1985. The total wastewater disposal is expected to reach $1.5x10^9$ m^3 by 2010, but, due to sewerage networks conditions carrying the wastewater effluent, the population rate connected to the sewerage network and the availability of wastewater treatment facilities, projections suggest the possibility of reusing not more than $600x10^6$ m^3 in that same year (Tamrabet, 2002).

The Algerian laws prohibit absolutely the reuse of raw wastewater or treated wastewater for the irrigation of raw-eaten vegetable crops; but it is allowed in the production of fodder crops, pasture and trees. The Algerian laws oblige also the cities of more than 10^5 inhabitants to treat their effluents, prior to any disposal or reuse, through a wastewater treatment station, and in less populated areas through wastewater stabilization ponds or sedimentation basins. Consequently, in the last few years, the Algerian authorities have initiated an ambitious program that enables mainly: (a) the rehabilitation of 28 wastewater treatment stations, (b) the construction of new wastewater treatment stations for the cities of more than 10^5 inhabitants (32), and (c) the construction of wastewater stabilization ponds (08) and sedimentation basins (435) for small populated areas. For the success of the program, there must be an efficient follow up and periodic evaluation so that the wastewater valorization becomes fruitful, and the water resources and the environment are protected from negative impacts of pollution (Tamrabet, 2002).

2.3.3 Bosnia and Herzegovina

Before the war, in Bosnia and Herzegovina there was not any type of reuse of wastewater. It was thought to reuse the wastewater of the city Posusje (the treated effluent of the wastewater treatment plant of about 5,000 population equivalent) for irrigation, but nothing happened. In the same line was the combined agricultural scheme for Krajina - Banja Luka, for a project on the reuse of wastewater of bovine feedlots, after their treatment for the irrigation of cereal fields. It was also envisaged to reuse the wastewater of the textile industry of Bileca (carpets production) in the soap industry (reuse of raw materials). Now, within the new country project (the general plan for water management, established for the water management, Sarajevo, 1998, p.218), it is foreseen that Bosnia and Herzegovina irrigate 10% of the agricultural land. For the irrigation process it was planned to use the natural watercourses and the artificial lakes (of the hydro-electric systems). The reuse of wastewater (treated or non treated).is not anticipated (Bajraktarevic-Dobran, 2002)

2.3.4 Croatia

Croatia consists generally of two climatic regions. The northern part belongs to the central European region characterised with typical continental climate and abundant in water resources. In this region there are no problems related to water supply. The coastal western part belongs to the Mediterranean Region. The climate conditions in this region are characterised by long, dry summers and more humid autumn-winter periods. These climate conditions together with specific karstic hydro-geological conditions create limited capacities of the water resources. In certain parts of that Region (most of the islands) the available water sources have already being exploited to their full capacity, creating water supply problems to the population, tourists, industry and especially to agriculture.

Water supply problems in this region manifest in the fact that the largest water consumption for both the tourist resorts and the agricultural needs coincide with the dry season.

Wastewater reuse in Croatia in any form of water supply has not been practiced so far. So far, the problem of water supply for population and tourists has been resolved by transporting the water from the coast to the islands by submarine pipes and from locations reach in water (coastal rivers and spring) to the other coastal regions. But future development of these systems becomes expensive, both by investment and operation cost. Such solutions do not include water supply for agricultural purposes.

That way in this region there are needs for new water supply sources like desalinisation, which have already been practiced for water supply of population and tourists on the small islands near the coast, and like wastewater reuse mainly for agricultural purposes, which has not be practiced (Margeta, 2002).

The main reason that wastewater reuse has not been used is the lack of effective sewerage systems and non-existence of secondary treatment plants. Most of the towns in the coastal region although small, are characterised with high fluctuation of population (tourists) and production of wastewater. The wastewater is discharged through the sewerage system into the sea by long submarine outfalls. Prior to the wastewater discharge there is only preliminary treatment.

The main possible future use of wastewater reclamation could be irrigation of tree crops, vineyards, olives tree etc. as well as landscape irrigation. So far, there are no official plans or policy for wastewater reuse in Croatia.

2.3.5 Cyprus

In Cyprus the annual precipitation is about 510 mm, 80% of which is estimated to be lost by evapotranspiration. Thus, the actual water potential for use in Cyprus is of about 900 Mm^3/yr, from which 600 Mm^3/yr is surface water and 300 Mm^3/yr groundwater. Current total water use is 300 Mm^3/yr, almost 80% used for irrigation.

The wastewater generated by the main cities, about 25 Mm^3/yr, is planned to be collected and used for irrigation after tertiary treatment. Because of the high transportation cost, it is anticipated that most of the recycled water, about 55 to 60%, will be used for amenity purposes (hotel gardens, parks, golf courses, etc.). About 10 Mm^3 is conservatively estimated to be available for agricultural irrigation. The cost of recycled water is low, about 7.5 cents/m^3. This will reportedly allow irrigated agriculture to be expanded by 8-10% while conserving an equivalent amount of water for other sectors (Papadopoulos, 1995).

The provisional standards related to the use of treated wastewater effluent for irrigation purposes in Cyprus are presented in Table 2.1. They are stricter than the WHO guidelines and take the specific conditions of Cyprus into account. These criteria are followed by a code of practice to ensure the best possible application of the effluent for irrigation (Kypris, 1989). However, these criteria are someway apart from California regulations philosophy.

Table 2.1

Provisional quality criteria for irrigation with reclaimed wastewater in Cyprus (Kypris, 1989)

Irrigation of:		BOD_5 (mg/L)	SS (mg/L)	Fecal coliforms (MPN/100 mL)	Intestinal nematodes (No/L)	Treatment required
Amenity areas of unlimited public access		10[a] 15[b]	10[a] 15[b]	50[a] 100[b]	Nil	Tertiary and disinfection
Crops for human consumption. Amenity areas of limited public access	A)	20[a] 30[b]	30[a] 45[b]	200[a] 1000[b]	Nil	Secondary, storage >1 week and disinfection or tertiary and disinfection
	B)	-	-	200[a] 1000[b]	Nil	Stabilization maturation ponds total retention time >30 d or secondary and storage >30 d
Fodder crops	A)	20[a] 30[b]	30[a] 45[b]	1000[a] 5000[b]	Nil	Secondary and storage >1 week or tertiary and disinfection
	B)	-	-	1000[a]	Nil	Stabilization maturation ponds total retention time >30 d or secondary and storage >30 d
Industrial crops	A)	50[a] 70[b]	- -	3000[a] 10000[b]	- -	Secondary and disinfection
	B)	-	-	3000[a] 10000[b]	- -	Stabilization maturation ponds with total retention time >30 d or secondary and storage >30 d

[a] These values must not be exceeded in 80% of samples per month.
[b] Maximum value allowed.
Note:
The irrigation of vegetables is not allowed.
The irrigation of ornamental plants for trade purposes is not allowed.
No substances accumulating in the edible parts of crops and proved to be toxic to humans or animals are allowed in the effluent.

2.3.6 Egypt

Today, although the strategic importance of fresh water is universally recognized more than ever before, and although issues concerning sustainable water management can be found almost in every scientific, social, or political agenda all over the world, water resources seem to face severe quantitative and qualitative threats. Population increase, industrialisation and rapid economic development, impose severe risks to availability and quality of water resources, in many areas worldwide and of course in Egypt.

In Egypt, limited investment in wastewater collection and treatment infrastructure in the past has resulted in a significant shortfall in sanitary coverage and a growing surface water pollution problem. The discharge of raw and insufficiently treated wastes into the Nile and irrigation canals and drains threaten the environment and degradation of fresh water resources. Water pollution in the Delta tends to be higher compared to other regions. Three agricultural drainage reuse pump stations were shut down due to the high level of pollution in drainage water caused by untreated wastewater that mixes with agricultural drainage. The northern lakes are also affected by the pollution that results in fish production loss (MWRI, 2001). In rural areas, both in the Delta and the Valley, wastewater represents a major problem to agricultural drains where untreated wastewater is discharged and which are used in irrigation at some locations along the irrigation network. Therefore, the government started an ambitious program to treat the sewage water of these areas before discharging it into the drains (Bazza, 2002).

The Egyptian water strategy comprises the treatment and reuse of wastewater. Treatment of municipal wastewater is either primary or secondary. At present, wastewater is estimated at 4930 Mm^3/yr, with 22 operational wastewater treatment plants, and about 150 plants under construction. The total capacity of the installed treatment plants amounts to about 1.752 billion m^3/yr (FAO, 2000).

Wastewater reuse in Egypt is an old practice. Sewage farming is deliberated as one of the most environmentally sound practices for disposing off sewage effluent. Since 1900, sewage water has been used to cultivate orchards in a sandy soil area at El-Gabal El-Asfar village, near Cairo. The area gradually increased to about 4,500 ha. According to the law, reuse of treated wastewater is not permitted for food and fiber crops. The Ministry of Agriculture advocates the restricted reuse of treated wastewater for cultivation of non-food crops such as timber trees and green belts in the desert to fix sand dunes.

The major problems and issues related to the current use of treated sewage water in Egypt are summarized below (Shaalan, 2001): (a) not enough infrastructure (treatment plants) to treat the amounts of wastewater produced, (b) only about 50% and 3% of the urban and rural populations, respectively, are connected to sewerage systems, (c) a significant volume of wastewater enters directly into water bodies without any treatment, (d) many wastewater treatment facilities are overloaded and/or not operating properly, (e) some industries still discharge their wastewater with limited or no treatment into natural water bodies, (f) municipal and industrial solid wastes are mainly deposited at uncontrolled sites and/or dumped into water bodies (especially outside Greater Cairo), (g) the quality of treated wastewater differs from one treatment station to another, depending on inflow quality, treatment level, plant operation efficiency, and other factors, and (h) negative impacts of the above problems on both health and environment (Bazza, 2002).

From the institutional standpoint, seven ministries are involved in wastewater treatment and reuse in the country, with unclear delineation of responsibilities and limited coordination among them. The situation is further worsened by the absence of clear policies and action plan on wastewater management as well as standards that are practically impossible to enforce and which limit the effectiveness of pollution control abatement efforts. Dissemination of information among various organizations and to the public is limited, which substantiates the need for increased awareness and capacity strengthening regarding water quality management issues (Shaalan, 2001).

2.3.7 France

France water resources availability is 3,500 m³/inh·yr, and therefore, is considered to be self-sufficient. However, the uneven distribution of this resource, added to the fact that is in growing demand, has led to a situation of seasonal deficits in certain parts of the country. According to government statistics, the average water consumption has increased by 21% in France between 1981 and 1990. The agricultural sector experiences the greatest increase, with 42%. This trend is directly related to the increase in land irrigation, which nearly doubled during the same time. Water consumption has increased in resort areas where water is needed to ensure the development of golf courses and landscape areas. The only sector which experiences a decrease in water consumption is the industrial due to increasing efforts to recycle effluents and to use water efficient technologies.

France has been practicing direct wastewater reclamation since the 19^{th} century: its oldest project is Achères, which started a century ago as a sewerage farm. Today wastewater irrigation remains the first wastewater reuse application in France. The main reason for practicing wastewater reuse is to compensate for local and occasional water deficiencies and to foster public health and environmental protection. The majority of wastewater reuse projects are found in the French islands, in the southern part of France and in coastal areas (Fig. 2.2).

Water shortage and economic concerns drive a number of other projects in coastal areas, as well as one of the largest and most recent projects in Europe at Clermont-Ferrand (6 M€), where 700 ha of corn are being irrigated.

Another element, which favoured the development of water reuse projects in France in the past years, was linked to the risk of contamination in recreational areas and shell farming areas. Projects located on the Atlantic coast such as Saint Armel in the Morbihan bay area, Beauvoir-Mont St Michel in the Channel bay area or in the suburbs of Royan are examples of such applications. This decision has driven certain projects towards zero discharge in some islands (e.g. Mont St Michel). Such solutions can also be applied to surface water. The cases of Melle (Deux Sèvres) or Fuilet and Mesnil en Vallée (Maine and Loire) are examples of the rehabilitation of fresh water recreational areas threatened by eutrophication.

Irrigation of golf courses is the fastest growing reuse application in France (9 reclamation sites, Figure 2.2 and Table 2.2) because of their high water consumption and increasing surface application. Most of them are situated in the Atlantic coastal area in order to prevent the pollution of shell farming areas.

One of the first examples in Europe of integrated water management with water reuse has been implemented in the Noirmoutier island. The lack of water resources (transport of water from the continent) and the intensive agricultural activities (potato production) promoted the implementation of wastewater treatment and reclamation projects (twofold increase of the treatment capacity during the past 10 years, respectively 11,000 and 26,000 p.e.). Moreover, during the summer period the island's population increases by a factor of 7.5. The treatment is achieved with an activated sludge system (1.27 Mm^3/yr) followed by 4 stabilization ponds with an overall volume of 0.193 Mm^3 for storage and disinfection. The recycled water quality is above WHO requirements and ensures effective protection of shellfish farming areas and bathing zones. More than 220 ha of vegetable crops are irrigated (0.33 Mm^3/yr).

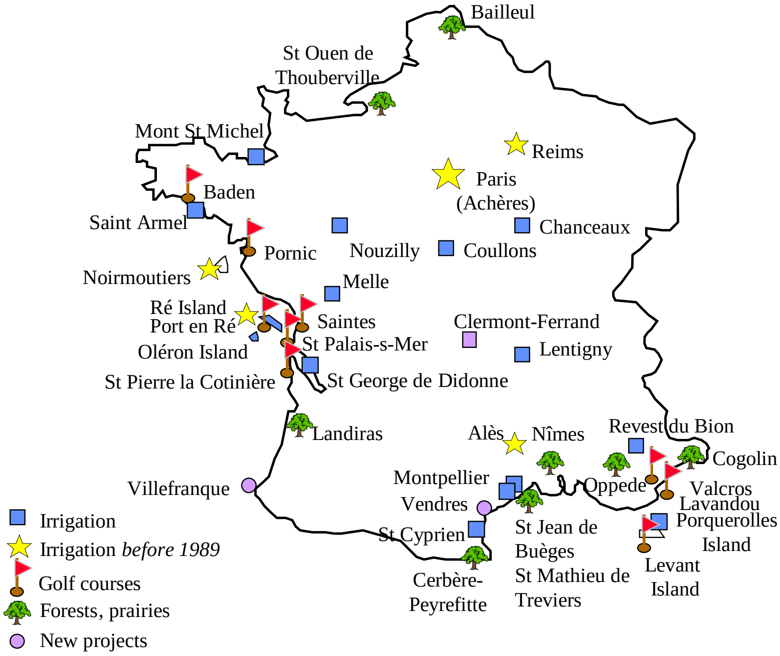


Figure 2.2 Location of French municipal wastewater reuse projects for irrigation

Table 2.2

Reclamation works and specific applications for agricultural and landscape irrigation in France over the past 10 years (lazarova *et al.*, 2001)

Projects	Irrigated area (ha)	Specific application	Geographic location
Saint Armel	120	market-gardening	Atlantic
Saint Georges de Didonne	7	corn, sunflowers	coast
Noirmoutier - La Salaisière	320	potatoes	
Noirmoutier - Barbatre	35	corn	
Mont Saint Michel	265	prairies and maize	Atlantic
Saint Pierre la Cotinière	25		islands
Port en Ré (600 m^3/d)			
Pornic	34		
Baden (500 m^3/d)	7		
Saintes (2600 m^3/d)		golf courses	Atlantic coast
Saint Palais sur Mer (2300 m^3/d)			
Saint Pierre d'Oléron (960 m^3/d)			
Lavandou (1500 m^3/d)			Mediterranean coast
Valcros			

Levant Island (project)			Mediterranean islands
Porquerolles	30	vegetable crops	
Le Mesnil en Vallée	85	maize, poplars	
Chanceaux	5	sport areas, parks	
Clermont Ferrand	600	corn	
Coullons	94	corn	Inland
Melle		corn	
Nouzilly	50	corn, luzerne	
Lentigny	several ha	corn	
Revest du Bion	2	sunflowers	

Numerous cases of unplanned indirect potable reuse exist, where surface water diluted with wastewater is used for potable supply. This is the case, for example, in Aubergenville, Paris region, where the Seine River water containing 25% wastewater effluents is treated and used to recharge the drinking water aquifer.

Chronologically, France first adopted a series of recommendations associated with wastewater reuse for irrigation purposes, and then acknowledged wastewater reclamation as an alternative solution to wastewater discharge. Since January 3, 1992, France's water legislation requires each municipality to define the zone for collective sewerage collection, storage, treatment and discharge or reuse. The above idea that water reuse can be a viable alternative for treated effluents was introduced again in the recommendations associated with decree 94-469 of June 3, 1994, and by the Ministry of the Environment through its December 22, 1994’s ordinance. The latest ordinance advises the use of alternative solutions to discharge wastewater in sensitive areas for which water quality requirements are not economically and technically feasible prior to discharge. In those cases, the legislation recommends that municipalities evaluate other alternatives, such as displacement of the discharge point, temporary storage of the effluent, land applications, or any other viable solution (Lazarova *et al.*, 2001).

The 1994 decree provides the basis for water reuse criteria in France. First, it clearly states that treated effluents can be used for agricultural purposes only if this is conducted without any risk for the environment or the public. Second, wastewater treatment requirements, irrigation modalities, and monitoring programs must be defined according to recommendations from the Conseil Supérieur d' Hygiène Publique de France (CSHPF, 1991), and the Interministerial Water Mission through ordinance of the Ministry of Health, the Ministry of Environment, and the Ministry of Agriculture.

In this political effort to integrate water recycling and reuse in France, the CSHPF published sanitary recommendations concerning the use of municipal wastewater after treatment for the irrigation of crops and landscape areas (Circular No. 51 of July 22, 1991, of the Ministry of Health). The recommendations expressed by the CSHPF are based on those developed by the WHO (1989) but as stressed by Bontoux and Courtois (1996), these have been made more stringent by additional requirements concerning irrigation management and the prevention of health risks related to human exposure. For example, in the cases of spray irrigation, a 100 m distance must be respected between the spraying system and residences, sport and leisure areas and motorway toll gates. In addition to the above microbiological standards, the document requires (a) guaranteeing that the aquifers will not be contaminated; (b) knowledge of the treated wastewater effluent quality and fertilising capacity; (c) trained operation and control personnel. Despite the existence of these recommendations, the approval of a wastewater reclamation and reuse project still depends on the decision of the local representative of the Ministry of Health. It is important to note that reuse regulations in France are tending to become more stringent: in the near future, viruses may be added to the list of regulated microbiological parameters (Lazarova *et al.*, 2001).

In view of these rules and regulations, managing and developing wastewater reclamation and reuse projects is becoming part of France's water resource management policy. Yet local French sanitary authorities impose very strict control on wastewater reclamation and reuse projects. The water quality required for these projects is often more stringent than the recommendations defined by the CSHPF and even California Title 22 in the case of some municipal applications (greywater recycling for example). In addition, the stringent administrative procedures required for a water reuse project has slowed down the emergence of water reuse projects in France.

Note that the new French provisional regulations (November 2000) are based on the following criteria:

(a) Secondary treatment (EU Directive, 1991)
SS < 35 mg/L and total COD < 125 mg/L, for lagoon effluents: SS < 150 mg/L, dissolved COD < 125 mg/L, *Escherichia coli* < 1000/100 mL, and no *Salmonella* and *Tenia* egg
(b) Setback distances (from roads, houses, ...) ≥ 50 m
(c) Aspersion outside opening hours. Low range aspersors are recommended.
(d) Underground irrigation was not taken into account.

2.3.8 Greece

Greece is today inhabited by 10.6 million people living in an area of about 132,000 km², with a coastal area of 15,000 km in length. The country is located in the southeastern part of the EU, bound by the Ionian, Aegean and Libyan open seas of the Mediterranean region. The Mediterranean climate brings hot, dry summers and cold, humid winters.

Water demand in Greece has increased tremendously over the past 50 years. Despite adequate precipitation, water imbalance is often experienced, due to temporal and regional variations of the precipitation, the increased water demand during the summer months and the difficulty of transporting water due to the mountainous terrain. In addition, in many southeastern areas there is severe pressure for freshwater resources, which is exacerbated especially by the high demand of water for tourism and irrigation. In this context, the integration of wastewater reuse into the water resources management is becoming a very important issue. Thus, the potential for reducing the pollution loads entering sea or inland waters should be considered, as well as the possibility for developing new water resources.

One of the salient characteristics of the Minoan civilisation (island of Crete 3,000-1,000 B.C.), was the architectural and hydraulic function of its stormwater and wastewater sewerage systems in palaces and cities. In the entire structures of most Minoan palaces and cities, nothing is more remarkable than the elaborate water supply and sewerage systems, while indications for water reuse for domestic use, extend back to approximately 5,000 years. Several periods of Minoan civilisation were under severe water shortages (Angelakis and Spyridakis, 1996a). Thus, reuse of water was a necessity. In order to maximise and utilise the meagre water resources available, it was necessary to use and reuse water. Thus, elaborated methods were used for collecting rainwater, free from impurities, through percolation in sand beds and sedimentation processes for potable, washing or other domestic purposes. This is only indication of the highly skilled hydraulic knowledge by the Minoans. Non-potable water was included; mainly storm runoff and sewerage was considered. Stormwater could be utilised as irrigation water, especially valuable when enriched by sewage placed up along the way, which converted it into fertiliser. Houses and public buildings customarily had gutters and drains connected with the sewers under the streets (Angelakis and Spyridakis, 1996b).

Today, the situation is much different. In few years, almost 60% of the population will be connected to MWTPs. Today, about 350 centralised MWTP are in operation with 1.45 Mm^3 of effluent per day (Table 2.3). Tsagarakis *et al*. (2001) concluded that by reusing effluent of existing MWTP water use in 1998, particularly for agricultural irrigation, can be increased by 242 Mm^3/yr or 3.2% the current water use. Today, it is estimated that about 5.0% of the current water use can be saved by reusing treated wastewater. The analysis of the distribution of treated domestic wastewater showed that more than 83% of the effluents are produced in regions with deficient water balance (Tchobanoglous and Angelakis, 1996). The above results suggest that wastewater reuse in these areas would satisfy a real water demand, which is the key factor for any successful wastewater reuse project. Another important positive factor is that 88% of the wastewater effluents are located at a distance of less than 5 km from the available farmland. Therefore, the additional cost for irrigation would be low (Tchobanoglous and Angelakis, 1996).

Table 2.3

Municipal wastewater treatment plants in Greece
(Adapted from Tchobanoglous and Angelakis, 1996)

Year	Population served		Number of treatment plants	Effluent flow rate
	(No.)	(%)		(Mm^3/d)
1993	3,344,000	34	170	0.70
1999	5,755,000	59	270	1.30
2005	7,508,000	75	450	1.70

There are only a few MWTPs where effluent is used for direct irrigation of agricultural land, including (Tsagarakis *et al.*, 2001):

(a) Levadia, 3500 m^3/d are used for cotton irrigation. Advanced treatment includes nutrients' control (closed pipe irrigation network).
(b) Amfisa, 400 m^3/d are discharged into a 30,000 m^3 reservoir for the irrigation of olive trees.
(c) Palecastro, Crete, 280 m^3/d are used to irrigate olive trees after loading on a 20 m^3 reservoir (closed pipe irrigation network).
(d) Ko, a small area with agricultural and ornamental plants is irrigated, but it is in the planning process to irrigate more in the future by reusing the 4,000 m^3/d effluent that can be produced, including nutrients' control.

Pefkochori, Kolindros, Chaniotis and Kalithea MWTPs are in the process to change the initial disposal site to irrigation of agricultural lands. In addition, plants that serve Perama, Nea Epidavros, Thermisia, Kranidi, Arahova, Nikita, Nea Kalikratia, Nea Potidea, and Thiva are planing to use treated effluent for irrigation of agricultural lands, when they will be operational. Effluents from some of the waste stabilisation ponds in operation are used for agriculture irrigation from farmers. Local skin infections have been reported, when the effluent comes in contact with farmers' hands. The effluents from four plants are used mainly for landscape irrigation as follows:

(a) Kentarchos (Serifos), 100 m^3/d are used to irrigate trees, after applying sand filtration.
(b) Agios Konstantinos (Samos), 200 m^3/d are used to irrigate trees (mainly pine) using a sub-surface system.
(c) Karistos, 1450 m^3/d are used to irrigate 14,000 trees using up to all the effluent with a close pipe network.
(d) Ierisos, 1200 m^3/d are discharged into a reservoir before irrigating forestry.
(e) Chalkida, by diverting the disposal site from sea, an amount of 13,000 m^3/d of effluent is used for irrigation of the surrounding area.

In addition, at Serifos, Marpisa, Kini, Karterados, Chora (Samos), Nea Artaki and Siviri they are planing to irrigate land for forestry and amenity. It should be noted that unplanned reuse also occurs in some regions, where wastewater is discharged to ephemeral rivers and after infiltration, water is pumped through adjacent wells, by farmers for irrigation.

Industries that are heavy water consumers such as food processing will be increasingly interested in using reclaimed wastewater, particularly in areas under water stress.

In Greece no guidelines or criteria for wastewater reclamation and reuse have been yet adopted. Secondary effluent quality criteria are used for discharging purposes under No. E1b/221/65 Health Arrangement Action (Ministry of Public Health, 1965). However, a preliminary study is under way on the necessity for establishing criteria for reuse of treated wastewater (Angelakis *et al.*, 2000a and Tsagarakis *et al.*, 2001). In this study, six basic categories of reuse are considered (non-potable urban, agriculture, aquaculture, industrial, environmental and groundwater recharge).

2.3.9 Israel

In Israel about 92% of the wastewater is collected by municipal sewers. Subsequently, 72% is used for irrigation (42%) or groundwater recharge (30%). The use of reclaimed wastewater must be approved by local, regional and national authorities. Effluent used for irrigation must meet water quality criteria set by the Ministry of Health (Table 2.4). The trend is towards bringing all effluents to a quality suitable for unrestricted irrigation with wider crop rotation, which will require more storage and higher levels of treatment in the future.

Table 2.4

Criteria for reclaimed of wastewater reuse for irrigation in Israel

Parameters	Group of crops/main crops			
	A	B	C	D
	Cotton, sugar beet, cereals, dry fodder seeds, forest irrigation, etc.	Green fodder, olives, peanuts, citrus, bananas, almonds, nuts, etc.	Deciduous fruits[b] conserved vegetables, cooked and peeled vegetables, green belts, football fields and golf courses	Unrestricted crops, including vegetables eaten uncooked (raw), parks and lawns
Effluent quality				
BOD_5 total, mg/L	60[a]	45[a]	35	15
BOD_5 dissolved, mg/L	-	-	20	10

SS, mg/L	50[a]	40[a]	30	15
DO, mg/L	0.5	0.5	0.5	0.5
TC per 100 mL	-	-	250	12 (80%) 2.2 (50%)
Resid. avail. Chlorine, mg/L	-		0.15	0.5
Mandatory Treatment				
Sand filtration or equivalent	-		-	required
Chlorination, min contact time, min	-		60	120
Distances				
From residential areas, m	300	250	-	-
From paved road, m	30	25	-	-

[a] Different standards will be set for stabilization ponds with retention time of at least 15 d.
[b] Irrigation must stop two weeks before fruit picking; no fruit should be picked from the ground.

Cost-benefit analysis indicates that reclaimed wastewater is a very low cost source of water in Israel. As a result, treated wastewater within the overall water supply, particularly for irrigation, has risen to 24.4 % of the allocations (Table 2.5). The water crisis in Israel and the relatively low cost of treated wastewater, are the main driving forces behind the high percentage of reuse.

Table 2.5

The role of wastewater reuse within the overall water supply of Israel
(Shelef and Azov, 1996)

Water uses	Year			
	1985	1990/91	2000	2010
Total water supply, Mm^3	2,050	1,450	2,090	2,240
Water supply for agriculture, Mm^3	1,490	770	1,260	1,250
Municipal and domestic water supply, Mm^3	445	560	685	770
Municipal wastewater collected, Mm^3	215	260	380	520
Wastewater reuse in agriculture, Mm^3	110	188	350	450
% wastewater reuse in total	5.4	13.0	14.6	20.1
% wastewater reuse in water supply to agriculture	7.4	24.4	24.2	36.0

2.3.10 Italy

Like in most Mediterranean regions, Southern Italy (particularly Sicily, Sardinia and Apulia), suffers from water shortage and lack of good quality water due to recurrent droughts. Moreover, wastewater discharge into rivers or the sea has lead to significant environmental problems and eutrophication. Despite the continuous decreasing in conventional resources availability, water demand for irrigation is rarely fully met. The deficient and unreliable supply of irrigation water, has strongly limited irrigation development.

Normally, municipal wastewater treatment processes are based on two phases: the primary and secondary treatment (mechanical and biological) traditionally used to remove suspended particles, to mineralize organic compounds and implicitly to diminish the bacterial load. For a more striking improvement in the qualitative characteristics of the effluents, additional tertiary treatment processes must be included in the line, The latter generally aim to achieve two objectives: (a) to improve the characteristics of the effluent aimed at the reuse of wastewater; and (b) to protect the quality of receiving bodies by diminishing the nutrients and therefore the extent of eutrophication phenomena.

Owing to the three stages of treatment (primary, secondary and tertiary), municipal wastewater acquires, from a physical, biological and hygienic point of view, the characteristics of a good quality surface water (Table 2.6). The type of treatment and its relative management costs depends therefore on the quality requested by the use of treated water.

Table 2.6

Comparison between characteristics of wastewater treated by MWTP with primary and biological phases, and with a tertiary phase and the characteristics of water from the Po river (mean values for stretch through Emilia)

Parameters	Biological plants (secondary treatment)	Plants with tertiary treatment	Po river
pH	7-8	7-7.5	7-8
BOD, mg/L	30-40	5-10	5-15
COD, mg/L	130-160	30-30	15-30
SST, mg/L	40-80	10	70-90
NH_4, mg/L	10-15	0.5	0.7-0.9
NO_3, mg/L	15-20	5	1-10
P, mg/L	2-3	0.5-1	0.5-2
TC No./100 mL	20,000-50,000	1,000-2,000	50,000-500,000

In Italy, a new law n°152 issued on May 11, 1999, by the Ministry of Environment has totally revised the standards concerning wastewater treatment and disposal and the law n°319/76 (called "Merli law") has been repealed. Up to now, reuse of municipal wastewater for irrigation is regulated by Annex 5 of a resolution of the National Interministerial Committee for the Protection of Waters from Pollution. Wastewater reuse is considered as discharge on soil for agricultural purposes and is allowed only if wastewater addition can increase production. Specific restrictions are imposed on wastewater quality. In fact, the upper limit of the sodium adsorption ratio (SAR) is set at 15, but a maximum of 10 is suggested. The presence of TC in wastewater for irrigation is accepted at very low levels depending on the use of agricultural products (Table 2.7). No limits are set for the concentration of toxic, poisonous or bioaccumulable substances but a specific evaluation is required of the annual volume of wastewater, which can be applied depending on soil and crop type (Barbagallo *et al.*, 2001).

The number of WWTPs in operation as function of treatment level (primary, secondary and tertiary) is reported according to their geographical distribution: Northern Italy (Piemonte, Valle d'Aosta, Lombardia-, Trentino-Alto Adige, Friuli Venezia-Giulia, Veneto, Emilia Romagna, Liguria); Central Italy (Toscana, Umbria, Marche and Lazio); Southern Italy (Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria, Sicilia and Sardegna) is presented in Table 2.8. More than 55% of the constructed plants run at least a secondary treatment (generally activated sludges or trickling filters).

Table 2.7

Microbiological standards for irrigation with reclaimed municipal wastewater in Italy; comparison of regional guidelines with national and WHO standards

Organisation or Region	TC (MPN/100 mL)[a]	FC (MPN/100 mL)	Faecal Streptococci (MPN/100 mL)	Nematode eggs (No./L)
WHO	not set	1000[b]	not set	1
Italy	2[b],·20[c]	not set	not set	not set
Sicily	3000	1000[b]	not set	1
Emilia Romagna	2[b],·20[c]	not set	not set	not set
Puglia	2[b],·10[c]	not set	not set	absent

[a]mean value of 7 consecutive sampling days;
[b]unrestricted irrigation.
[c] restricted irrigation.

Table 2.8

WWTPs in operation in Italy in function of treatment level (ISTAT, 1996).

	WWTPs in operation				
	PT	ST	TT	NC	Total
Northern Italy	2,877	2,461	242	60	5,640
Central Italy	488	879	108	20	1,495
Southern Italy	327	985	100	23	1,435
Total Italy	3,692	4,325	450	103	8,570

PT = primary treatment; ST = secondary treatment; TT = tertiary treatment; NC = not classified

Extensive treatment processes such as stabilization ponds are generally not considered among the possible options, despite the fact that these simple and low-cost treatment plants should be particularly attractive to small and medium communities in Southern Italy. In these regions, where the land cost is low (particularly in inland areas) and climatic condition are very favourable, extensive processes should be implemented as an integrative measure for the largest WWTPs (particularly to achieve more stringent microbiological standards) or alternative measures for small and medium communities, generally affected by management problems (The law No. 152/99 suggests, for less than 2,000 p.e., the treatment of municipal wastewater by lagooning or constructed wetlands.)

The number of WWTPs and their p.e. is reported according to the site of disposal. Presently, most public sewers discharge into surface water courses (79.2% WWTPs and 74.4% p.e.); other recipients are the sea (2.1% WWTPs and 16.7% p.e.), lakes (1.3% WWTPs and 2.1% p.e.) or other bodies (17.4% WWTPs and 6.8% p.e.); the latter figure takes into account also discharges into soil and subsoil and thus reused volumes are presented in Table 2.9. Moreover, because of a stream regime with low flows (or no flow at all) which characterize several Italian water courses for most of the year, frequently the "natural" water flow, downstream the discharge point of a treatment plant, is mainly constituted by wastewater (treated or raw).

Table 2.9

WWTPs and p.e. according the site of disposal (ISTAT, 1996)

	River		Sea		Lake		Others	
	WWTPs (%)	p.e. (%)	WWTPs (%)	p.e. (%)	WWTPs (%)	p.e. (%)	WWTPs (%)	p.e. (%)
Northern Italy	81.5	84.3	0.8	6.3	1.5	1.1	16.2	8.3
Central Italy	77.6	90.6	1.8	6.2	1.0	0.2	19.6	3.0
Southern Italy	74.3	49.3	5.9	38.9	1.0	4.7	18.8	7.1
Total Italy	79.2	74.4	2.1	16.7	1.3	2.1	17.4	6.8

WWTPs = Wastewater treatment plants; p.e. = population equivalent

In Southern Italy (particularly Sicilia, Sardegna and Puglia) a significant amount of the wastewater discharged into water courses is already used by farmers especially during the dry season; in some cases they pump percolated wastewater through wells or they divert wastewater from river beds (where the effluent has undergone a limited dilution and natural depuration) or directly from sewage and treatment plant outlets. This wastewater produced during autumn-winter period must be stored and more attention should be addressed to the reuse of wastewater produced in coastal areas (Barbagallo *et al.*, 2001).

The high water demand for irrigation favours the development of municipal wastewater reuse. In Southern regions water resources for irrigation are not sufficient to satisfy water demand, even in years considered "normal" from a hydrological viewpoint. Recent drought periods have caused a significant shifting of water resources from the agricultural to the urban sector (particularly in Sicilia, Sardegna and Puglia). It is estimated that in Southern Italy, out of 780,000 hectares equipped with collective distribution networks, no more than 50% are currently irrigated; the low value of the ratio between the irrigated area and the irrigable area is indicative of the lack of available water resources. The deficient and unreliable supply of irrigation water, besides damaging production in most years, has strongly limited irrigation development. The lack of water resources for irrigation is considered one of the main limiting factors in competitiveness of agriculture in Southern Italy.

Wastewater reuse potential is high in Southern Italy, where, owing to scarcity of stream flows in the irrigation season, water is mainly supplied from large reservoirs. Wastewater could be used in areas already equipped with collective distribution networks or to irrigate fields near developed areas presently served with conventional waters. In Northern Italy, due to the presence of perennial watercourses, the agricultural reuse of municipal wastewater can play a major role mainly in controlling pollution of water bodies. Particularly, Emilia Romagna Region has promoted the wastewater reuse of the coastal towns as a mean to control the Adriatic Sea eutrophication. In Italy wastewater reuse is mainly geared toward agricultural irrigation, even if some projects concern industrial reuse and landscape irrigation. In the last years several wastewater reuse systems have been implemented not only in arid and semi-arid regions of Southern Italy, but also in Northern Italy (Emilia Romagna, Valle d'Aosta, Veneto), where available water resources generally meet water demand for different uses.

Since the 1970s water-planning studies have been carried out for various Italian regions including Sicilia, Calabria and Emilia Romagna. Some of these plans have raised objections because of the relevant works required, the elevated costs of construction and the optimistic forecasts of wastewater availability. Recently, according to a survey carried out by CSEI-Catania in 1998 with the support of the Ministry of Agriculture, 16 wastewater reuse systems for irrigation purposes have been selected for a prompt implementation in Sicilia, Puglia and Sardegna (Barbagallo *et al.*, 2001).

In Valle d'Aosta the municipal wastewater reuse system of St. Cristophe-Aosta-Quart (148,000 p.e.) is operational since 2001. The treated wastewater (32,600 m^3/d) is mainly used for landscape irrigation and fire-protection. In the Autonomous Province of Bolzano, even though water resources availability matches water demand, there is an increasing interest in wastewater reuse. Recently, two small reuse systems have been designed: Appiano (1,250 p.e.) and Verano (1,200 p.e.). In Veneto the wastewater reuse project (wastewater flow rate about 70 L/s) of Rosalina Mare (Province of Rovigo) has been designed for landscape and agricultural irrigation (30% and 70% of available flow, respectively). In Emilia Romagna, mainly in the coastal areas, there are many cases of the programmed utilisation of the municipal treated wastewater for irrigation and environmental protection purposes. The largest wastewater reuse system (Basso Rubicone treatment plant, 1250 m^3/d) covers an area of about 400 ha for orchard irrigation (Angelakis *et al.*, 1999). In Toscana there are two important examples of wastewater reuse for industrial water supply. In Piombino the municipal treated wastewater (10,000 m^3/d) is reused for the cooling process in the steel industry. In Prato, in the textile industrial district, about 1 11,000 m^3/d of municipal treated wastewater is used for industrial processing.

The regional governments of Abruzzo and Basilicata have recently included norms concerning wastewater reuse in their regional regulations regarding water resources management (Abruzzo) and reclamation water plan (Basilicata); however, no reuse systems have yet been designed. In the Sarno area (Campania), within a reclamation project of the river basin, 6 new plants will be constructed for treatment of municipal and industrial (agro-food) wastewater. The treated wastewater will be used for irrigation purposes (mainly tomatoes). In the Salento area (Puglia), where the lack of water resources is coupled with the organic pollution of groundwaters, about 16,000 m^3/d (about 100,000 p.e.) of treated wastewater (biological treatment plus final filtration) are about to be made available for irrigation.

In Sardegna, as a result of the lack of water resources exacerbated by the droughts of 1990 and 1995, a state of emergency was declared in 1995 and the Italian government drew up a programme for financial provision by the State and local government authorities with the aim of reducing, at least in part, the serious water shortage. Amongst others, wastewater reuse was considered one of the key-actions to face the water supply emergency. Within the framework of a local government programme and EU funded actions, a new wastewater reclamation scheme is actually implemented for using directly the effluent produced by the "Is Arenas" plant which serves the city of Cagliari and its suburbs. The treated wastewater volume is 35 Mm^3 per year, with a short-term forecast of 60 Mm^3. The reuse scheme includes both direct reuse for agricultural purposes and intermediate storage in reservoirs with further treatment before agricultural irrigation. In Villasimius (province of Cagliari) wastewater of tertiary treatment plant will be soon available for irrigation of about 200 ha (Barbagallo *et al.*, 2001).

In Sicilia, where the experiences of uncontrolled wastewater reuse are so common, there are some examples of reuse: for several years treated wastewater of Grammichele (about 1,500 m^3/d), a small rural town located in Eastern Sicily (district of Catania), has been used for the irrigation of citrus orchards. Several municipalities (such as Caltagirone, Mineo, S. Michele di Ganzaria, etc.) close to Grammichele have planned to reuse treated municipal wastewater in order to meet the increasing water demand for agricultural purposes. Recently the Sicilian Government has authorized and financed, with the support of the European

Union, the wastewater reuse projects of Palermo (in a first stage about 28,000 m^3/d of treated wastewater will be soon available) and Gela (where the 2 WWTPs will be integrated with storage reservoirs for a total capacity of 5 million m^3). In both cases the treated wastewater will be used for agricultural irrigation of several thousand hectares (Borbagallo *et al*., 2001).

2.3.11 Lebanon

In Lebanon, wastewater treatment and reuse are covered by legislation going back to 1930 (Papadopoulos, 1995). Most of the arid and semi-arid regions of the world are dominated by a scarce and unpredictable water regime that reflects a gap between the demand for water of a steadily increasing population and the supply from the physically limited water resources. In these regions water represents the major factor of development. However, the increased pressure on natural resources has created new environmental and economic problems. Agriculture is therefore challenged to meet present food needs without compromising the ability to sustain the natural renewable resources (Karam, 2002).

In Lebanon, like in any other Mediterranean country, water consumption is rapidly increasing due to the rapid population growth and the consequent increase in water demand. Due to the restrictions on water resources, it had been felt necessary to ban the use of marginal waters with a management plan aiming at providing second-class water, suitable for irrigation. Nowadays, the use of non-conventional water in Lebanon becomes practical, mainly in agriculture, but without any awareness from users about their side effects on human health and crop production. Further, municipal and industrial untreated effluents are dumped into the rivers and water streams and are used, without any control, since no national legislation exists, for irrigating crops eaten raw, where heavy metals and other toxins can accumulate to critical levels in plant tissues and human organs. In the Bekaa Valley, which by itself occupy 45% of the total cultivated lands, ground and surface waters are threatened by industrial and municipal p/olluted effluents, which load directly their pollutants into the Litany River and the lake of Karaoun, threatening thereby aquatic life and agricultural systems (Karam, 2002).

Way back in 1991, the total volume of wastewater generated in the country was 165 million m^3, of which 130 million m^3 from domestic uses and 35 million m^3 from industry. It was therefore evident that this huge potential for wastewater treatment and reuse has been lost. At present, only 4m^3 of waste water are treated, of which 2 m^3 are used for irrigation, and the rest is disposed in the marine environment, or infiltrated by deep seepage to groundwater. Present estimates indicate that 35% to 50% of the untreated urban sewage water are infiltrated to the aquifers due to the lack of adequate discharge networks in some urban and rural areas, and pumped again for irrigation and domestic uses. Further, recent studies show that 89.6% of the industrial and domestic solid waste are untreated and put in natural places as rubbish, and 10.4% are dumped in the rivers. This non-point source of pollution constitutes a direct threat to the vulnerable underground water (Karam, 2002).

Due to this situation, corrective measures are now carried out by the Government, aiming at implementing in different locations sewage treatments plants, with the aim to provide second-class water, suitable for irrigation and industrial use (Karam, 2002).

2.3.12 Libya

At Hadba El Khadra (5 km from Tripoli on sandy soil), reuse of wastewater started in 1971. Wastewater is treated in a conventional treatment plant followed by sand filtration and chlorination (12 mg/L). The reclaimed wastewater is then pumped and stored in tanks with a 3-day storage capacity. Reuse was first conducted over 1,000 ha to irrigate forage crops and windbreaks. An additional area covering 1970 ha: 1,160 ha forage, 290 ha vegetables like potatoes, onions, lettuce, etc. and 230 ha for windbreaks and sand dune stabilization) was also irrigated with reclaimed wastewater. 110,000 m^3/d were applied using sprinkler irrigation (pivots). Reuse is also taking place in Al Marj (north-east of Bengazi: 50,000 inhabitants) after biological treatment, sand filtration, chlorination and storage (Angelakis *et al.*, 1999).

2.3.13 Malta

As it has been referred, the water deficit in Malta is acute. Since agriculture is the main source of income, wastewater reuse for irrigation has been contemplated as early as 1884 in order to preserve freshwater for domestic use.

Since 1983, the effluent of the Sant Antnin sewage treatment plant has been used for irrigation. The current 12,800 m^3/d of effluent are expected to be increased to 25,600 m^3/d after expansion of the plant. The plant uses an activated sludge process followed by rapid sand filters (9 $m^3/m^2 \cdot h$). The effluent is then disinfected with gaseous chlorine (20 mg/L and contact time 30 min) and pumped into irrigation reservoirs with a free chlorine residual of 2 mg/L. Due to low water consumption per inhabitant, the raw sewage in Malta is strong (BOD_5=530 mg/L and SS=445 mg/L) and has a high salinity (sodium and chloride) due to high levels of these ions in the domestic water supply.

The effluent is used to irrigate 600 ha of crops by furrow and spray irrigation. The effluent quality is suitable for unrestricted irrigation and is used to produce potatoes, tomatoes, broad and runner beans, green pepper, cabbages, cauliflower, lettuce, strawberries, clover, etc. Despite the high salinity, there are no problems with crops. This is probably associated with high permeability of the calcareous soil. Soil monitoring has shown a salt accumulation in the top soil during the irrigation season followed by leaching to the groundwater with the winter rains.

In 1986, the possibility of industrial wastewater reuse was considered. There are two large industrial water consumers on Malta: Enemalta, a thermal power plant and Malta Drydocks, a shipyard. In the thermal power plant, 1,150 m^3/d of demineralized water are needed for boiler feed make-up. The water used in the dry-docks is intended for washing ship hulls prior to painting. Besides a high physico-chemical quality, exacting requirements are also set related to hygiene, due to the contact with workers during washing operations and exposure through aerosol inhalation. In order to meet the above requirements, advanced wastewater treatment should be planned for the effluent from Sant Antnin station.

Application of the reverse osmosis process was considered. This process could produce effluent containing 300 mg/L of TDS. By applying suitable membranes, it is possible to reduce by as much as 95% the salts and organic matter and almost totally remove colloids, bacteria, viruses and parasites. Prior colloids removal must be foreseen to protect the membranes against fouling. Therefore, effluent of adequate quality for reuse in industry can be produced after extension of the Sant Antnin treatment plant. The use of the reclaimed water for industrial purposes depends primarily on the economic circumstances, namely on the comparison of the total costs of reclaimed water with other sources of water such as desalinated seawater. At the moment, reclaimed water is in use exclusively in industrial laundry.

2.3.14 Monaco

There is more of less the existing situation in France.

2.3.15 Morroco

Despite the influence of the Atlantic ocean which provides it locally with relatively abundant precipitations. Morocco is considered a semi-arid country. Out of 150 billion m^3 annual rainfall, only 30 billion m^3 are estimated to be usable (22 billion m^3 join surface water and 8 billion m^3 feed the aquifers). These resources are very unevenly distributed: the catchment areas of the Sebou, Bou Regreg and Oum er Rbia wadis alone represent two-thirds of the hydraulic potential of the country (Table 2.10).

Approximately 11.5 billion m^3 of water are used annually; 3.5 billion m^3 from groundwater. 93% of this water is used to irrigate 1.2 million ha, including 850,000 ha irrigated more or less permanently throughout the year. Gravity irrigation predominates with 80% of surfaces irrigated particularly on small farms. On the large farms and in irrigation schemes supplied with groundwater, more modern techniques have been used: sprinklers, mobile ramps, centre pivots and drip irrigation. The water is sold to the farmers at a price between 0.01 and 0.02 €/m^3.

Table 2.10

Estimate of wastewater reuse for irrigation in Morocco
(Conseil Supérieur de l'Eau, 1988 and 1994)

Province or Prefecture	Estimated population in 1994	Estimated volume of reused wastewater in 1988	Estimation of irrigated areas in 1994
	(thousand)	(Mm^3/yr)	(ha)
Marrakech	622	15	2,000
Meknes	294	14	1,400
Oujda	419	Na	1,175
Fes	541	21	800
El Jadida	971	Na	800
Khourigba	481	4	360
Agadir	366	Na	310
Beni-Mellal	870	3	225
City of Benguerir	n.a.	Na	95
Tétouan	537	Na	70
Total	5,101	Na	7,235

na: not available

Most Moroccan towns are equipped with sewerage networks, collecting also industrial effluent. Collected volumes of wastewater were estimated at 546 million m^3 per year in 1999, and are expected to reach 900 million m^3 in 2020. About 58% of the currently generated wastewater is discharged to the Mediterranean and Atlantic coasts and the other 42% are discharged to rivers and flood paths. Most of the wastewater produced in the inland towns is used to irrigate about 7,235 ha of crops (in 1994) after insufficient or even no treatment (Table 2.10). Treated wastewater is considered as a source of water but its contribution to the national water balance will not exceed 4.2% (Aomar and AbdelMajid, 2002). Moreover, this potential of wastewater cannot be totally mobilized since most of it is produced by plants located along the coasts of the Mediterranean Sea and the Atlantic Ocean, away from agricultural lands. The high cost of transferring treated wastewater to irrigated areas constitutes another constraint of wastewater reuse to become operational soon (Bazza, 2002).

Wastewater reuse is not a major issue for the management of water resources in Morocco at the moment. However, the authorities think that the situation may be different in a few years. Due to the increase of the urban population by 500,000 inh./yr a rapid increase in drinking water consumption in towns is expected. This will require the transfer of freshwater resources from one catchment area to another and the replacement of freshwater by wastewater for irrigation. The volume of wastewater available for reuse will increase with the improvement of sewerage networks. Under these conditions the share of treated wastewater in the overall water resource could be several percentage points higher within a few decades, especially if the wastewater of coastal towns is also reclaimed (the figure of 10% sometimes mentioned seems excessive). Even though wastewater only represents a small share of water resources on a national scale, it can help solve local problems. This is particularly true for towns located in arid areas that are isolated from the major supply systems. This is also proven by the high rate of spontaneous wastewater reuse in inland towns. The reused water is mainly raw wastewater sometimes mixed with water from the wadis into which they spill. The irrigated crops are mainly fodder crops (4 harvests of corn per year around Marrakesh), fruit trees, cereals and other crops (growing and selling vegetables to be eaten raw is prohibited).

Morocco does not have yet any specific wastewater reuse regulations. Reference is usually made to the WHO recommendations. While reducing its environmental impact on the conventional receiving waters, the lack of wastewater treatment before reuse in inland cities results in adverse health impacts. Improvement in wastewater reuse methods and in the quality of reused water for irrigation is recognized as essential. In karstic areas, the infiltration of wastewater affects groundwater resources to varying degrees. Lastly, the inadequate sanitation, collection and treatment of wastewater, mostly in small towns, are often a risk to the eutrophication of dams.

The discharge of raw wastewater to the sea without proper outfalls may affect the development of tourism by degrading the sanitary quality of beaches and generating unpleasant odors and aesthetics. Major improvements are needed urgently because of the strong migration of the rural population towards the towns and the very fast demographic expansion. A high incidence of waterborne diseases exists in Morocco (a proportion of 25% of the population infected is sometimes suggested). Studies of sanitation master plans for the main towns are currently in progress and are a first step towards meeting these requirements. The setting-up of a Liquid Sewage National Master Plan is a way of extending this procedure over the whole territory.

2.3.16 Slovenia

As it was referred (Vrhovšek, 2002), in Slovenia they have recently started developing and constructing CW (Constructed Wetlands) for different types of wastewater. One of the priorities of the constructed wetlands is water reuse. Unfortunately, so far the constructed wetlands are only used for small communities and consequently for rather limited amounts of water to be recycled. It is expected, that in the very near future, the constructed wetlands and the water recycling will be used widespread and mainly for touristic facilities. There are some few projects that have already finished.

2.3.17 Spain

The Spanish Balearic and Canary Islands, and the Mediterranean coastline and basins (i.e. the arid and semiarid areas of Spain), like the majority of the Mediterranean basin, are suffering structural or occasional water scarcity. Periodic droughts or excess demand are unbalancing the delicate distribution of water among agriculture, industry, ecology, recreational activities and urban needs. During the last decades, the development of the country has been extremely linked to tourist activities, including so different aspects as mass and golf tourism. During summertime, demand increases so heavily that a strong pressure is exerted on existing resources. Until nowadays, the problem was solved either overexploiting groundwater resources or fully diverting surface waters. Several water transport infrastructures were also created, increasing water holding capacity through dams or reallocating resources diverting rivers into neighbouring basins.

Nevertheless, such solutions reached a limit during nineties, because of increasing demands (tourism, agriculture, industry), heavy droughts and bad distribution systems. Several islands (Canary Islands and Majorca) needed to develop new resources desalting sea and brackish water using reverse osmosis. Numerous attempts of developing a National Hydrologic Plan did not succeed and at present, are being publicised different solutions, which include water diversions from national rivers, the extension of the Rhône river water carrier from Montpellier (France) to Barcelona, an increase of seawater desalination and other minor issues.

Among this entire panorama, planned wastewater reclamation and reuse is not being contemplated as a solution, even partial. Nevertheless, unplanned reuse used to be a classical solution for arid and semi-arid areas all around the Spanish Mediterranean coastline. There are several causes for this illegal circumstance. Perhaps, one of the most important is the lack of regulation at state level. In Spain, the Government issued fourteen years ago one Law and one Decree where wastewater reuse was indicated as a possibility and a minimal statement appeared, indicating the need for an administrative concession and a compulsory report of the Health Authorities. An indication was made that further legal developments would be needed.

In the past, and in some places at present, wastewater was used raw for agricultural irrigation, like all around the Mediterranean areas, but the efforts to develop wastewater treatment according to EU rules are decreasing the amount of raw wastewater available and increasing the amount of treated wastewater to be disposed off. Because of the lack of rain during several months every year, a lot of rivers in the Mediterranean coastline have no running water, except treated or untreated wastewater. If wastewater is reclaimed and reused, some of the rivers will become dry. This circumstance is causing that the “Ecologist” (Greens) movements become active asking for water not being diverted. This will lead to problems when trying to reuse wastewater in the inland of the country. Conversely, the major opinion is that wastewater reuse all along the coastlines is a good solution and needs to be promoted (Salgot, 2002).

Nowadays, the main approved uses for reclaimed wastewater are agriculture and golf courses irrigation, and secondarily groundwater recharge and industrial reuse. It is also a strong pressure for discharging treated wastewater into rivers, which otherwise will not carry any water at all. Reclamation systems are today relying on tertiary classical technologies (coagulation-filtration plus disinfection) and extensive natural technologies (wetlands, lagooning and infiltration-percolation). Mostly used disinfection technologies are UV and chlorination. The areas where reclamation and reuse are most operative at present are Balearic Islands (golf courses, urban parks and groundwater recharge), Canary Islands (golf courses and agriculture) and the entire Mediterranean coastline (agriculture, golf courses and leisure activities other than golf) and Victoria in the Basque country where municipal wastewater is reclaimed and reused for agricultural purposes.

The water suppliers becomes increasingly concerned with wastewater reclamation and reuse, and two of the bigger companies (Agbar and Canal de Isabel II, located in Barcelona and Madrid respectively) support research and development (R&D) activities, in collaboration with the Universities, and already operate a number of reclamation facilities. University research groups on wastewater reuse are spread all around the Mediterranean basin and are mainly devoted to wastewater tertiary treatments (advanced treatments in Catalonia, natural treatments in Catalonia, Valencia and Murcia, rules and regulations in Catalonia and Andalusia).

Despite all the mentioned circumstances, there is a bright future for wastewater reuse in Spain, but at present it is compromised, owing to the fact that the projects are appearing and a lot of difficulties arise because of the need for a more complete legal definition. In Spain, there is a strong tendency to decentralise the Administration and give more power to the “Autonomous Governments” (Regional Governments). The decisions and permissions for wastewater reuse are given now case per case depending on the Regional Administrations.

Since it is difficult to get such approvals without having definite legal health regulations, several Regional Health Authorities have decided to develop their own guidelines for wastewater reuse for irrigation. By 2000, three guidelines (Balearic Islands, Catalonia, and Andalusia) are operative. Draft guidelines for the Spanish national regulation were proposed in 1996, taking an approach similar to the California standards than to the WHO guidelines. However, this draft may never be approved as it is and will not adapt the Californian criteria (Salgot, 2002). So far, a new "White Book" on water was prepared and published in 1998, incorporating wastewater reuse into the recognised available water resources. On that basis, a group of experts jointed by the Ministry of Environment elaborated a proposal of minimal criteria (physico-chemical and microbiological) for wastewater reuse (Angelakis *et al.*, 2001). It has been submitted to the Government for approval and are similar to WHO guidelines.

2.3.18 Syria

The average annual precipitation in Syria is 252 mm or 46,000 million m^3/yr. The total renewable resources are 26,260 million m^3/yr, whereas, the availability and dependency ratio are 1791 m^3/inh.yr and 80.3%, respectively (Angelakis, 2003).

The total volume of industrial and municipal wastewater effluent is estimated at 400, 700 and 1600 million m^3 per year for the years 1990, 2000 and 2025 respectively. The discharge of these wastes in a non-treated form into watercourses and rivers led to the degradation of surface water quality to the point where it became unsuitable for direct use for drinking purposes. The most important results of this noticeable pollution of rivers and other water bodies were the disappearance of living organisms because of the lack of oxygen, the appearance of undesirable plants and weeds that clog water canals in certain regions, hateful odours resulting from decomposition of organic materials and the abundance of insects and rodents. The health conditions of the population living in the areas of intensive use of untreated wastewater also degraded. Diseases such as typhoid and hepatitis spread at a much greater rate in these regions (Angelakis, 2003). Animals were also subjected to several waterborne diseases such as tapeworm and tuberculosis and other infectious diseases (Bazza, 2002). The total area irrigated with wastewater is estimated at around 40000ha, with 20000 in Aleppo (Zulita and Abboud, 2001).

To face this alarming situation and at the same time secure treated water for use in agriculture, the Syrian government launched a programme for constructing several treatments plants two of which are already operational in Damascus and Aleppo. The Damascus plant currently treats 300 m3/d. using activated sludge method. The total area irrigated by treated and untreated water is 18 000 ha. located in the outskirts of the city. With the exception of a large share of wastewater produced in Damascus and Aleppo, the collected raw sewage from the cities, villages and other residential areas is used without any treatment, either for direct irrigation of agricultural crops or disposed to the sea or water bodies that are used for unrestricted irrigation. The use of wastewater is restricted to fodder, industrial crops and fruit trees on smaller areas, but it is uncommon that it is used for other crops as well. The situation is expected to improve when several treatment plants under construction in all large cities of the country. In towns and areas where traditional sewerage systems have been inefficient, people are reluctant to pay wastewater connection fees. The shortage of information and awareness on wastewater risks and benefits is also evident (Bazza, 2002).

Several WWTP have been already implemented, such as Damascus (Adra), Aleppo, Homs, Salamyeh, Ras El Ein, and Haramil Awamid. The treated wastewater potentially available for reuse is estimated in 400 million m^3/yr by which an agricultural area more than 40,000 ha could be irrigated. Several other WWTP are under planning or construction such as Tartus, As Sweida Idleb, Al Raqqua, Al Nabik and Dar'a. Thus, the treated wastewater is expected to increase substantially in the near future.

As treatment and reuse of wastewater is new in Syria, all possible problems and constraints are common including the lack of policy, the absence of standards and regulations, and low technical and managerial capacity. Some of these problems are currently being addressed including through assistance from UNDP and FAO. A strategy for wastewater treatment and reuse is under preparation for the Damascus area and is expected to serve as a model for other cities. National standards as well as a monitoring programme for the Damascus area are also under elaboration (Bazza, 2002).

2.3.19 Tunisia

In Tunisia, wastewater is reclaimed in about 45 treatment plants with a total design capacity of 130 million m^3 per year. Several of them are located along the coast to protect coastal resorts and prevent sea pollution. Municipal wastewater is mainly domestic (about 82% domestic, 12% from industries and 6% from tourism) and goes through secondary biological treatment. No further treatment is provided due to cost. The treatment processes vary depending on wastewater origin and local conditions. Out of 44 treatment plants, 15 are activated sludge (medium and low rate), 2 trickling filters, 6 facultative and 4 aerated ponds and 17 oxidation ditches. Five treatment plants are located in the Tunis area and produce about 60 million m^3/yr of treated wastewater. They account for 57% of the country's reclaimed effluent, estimated at 24 million m^3 in 1995. This means that in 1995 for example, only 21% of the available treated wastewater was reused.

The VIIIth National Plan (1992-1996) has foreseen the annual volume of reclaimed wastewater to reach 147 million m^3, potentially allowing the irrigation of an additional 18,000 ha. By the beginning of 20th century, reclaimed wastewater was approximately 10% of the available groundwater resources. The current projections forecast the production of 266 million m^3 of treated effluents by the year 2011 (Table 2.11). These effluents will be used to avoid excessive groundwater mining causing saltwater intrusion in coastal aquifers. While current reuse projects were implemented after construction of the treatment plants, in new projects treatment and reuse are planned at the design stage. Since treated wastewater discharges remain more or less constant throughout the year and their volume is expected to increase with urban, touristic, and industrial development, wastewater reuse will continue to develop in Tunisia, primarily for agricultural purposes.

Table 2.11

Production of treated wastewater in Tunisia (Turki and Naassaoui, 1996)

Year	Number of MWTP	Volume of collected sewage (Mm^3/yr)	Volume of treated effluent (Mm^3/yr)
1995	49	125	113
2001	80	160	152
2006	100	240	216
2011	120	290	266

Irrigation with reclaimed wastewater is well established in Tunisia. Wastewater from la Cherguia treatment plant, in Tunis, has been used since 1965 to irrigate the 1200 ha of la Soukra (8 km North East of Tunis) and saved citrus fruit orchards as aquifers had become overdrawn and suffered from saline intrusion. The effluents from the treatment plant were used, mainly during spring and summer, either exclusively or as a complement to groundwater. Water from la Cherguia's secondary sewage treatment plant is pumped and discharged into a 5800 m^3 pond before storage in a 3800 m^3 reservoir. The water is then delivered by gravity to farming plots through an underground pipe system. A Regional Department for Agricultural Development (CRDA) supervises the operation and maintenance of the water distribution system and controls the application of the Water Code.

After this experience, a wastewater reuse policy was launched at the beginning of the eighties. The 6,366 ha involved in 1996 will be expanded to 20,000 ha. Wastewater reuse in agriculture is regulated by the 1975 Water Code (law No. 75-16 of 31 March 1975), by the 1989 Decree No. 89-1047 (28 July 1989), by the Tunisian standard for the use of treated wastewater in agriculture (NT 106-003 of 18 May 1989), by the list of crops than can be irrigated with treated wastewater (Decision of the Minister of Agriculture of 21 June 1994) and by the list of requirements for agricultural wastewater reuse projects (Decision of 28 September 1995). They prohibit the irrigation of vegetables that might be consumed raw. Therefore, most of the reclaimed wastewater is used to irrigate vineyards, citrus and other trees (olives, peaches, pears, apples, pomegranates, etc.), fodder crops (alfalfa, sorghum, etc), industrial crops (cotton, tobacco, sugarbeet, etc), cereals, and golf courses (Tunis, Hammamet, Sousse, and Monastir). Some hotel gardens in Jerba and Zarzis are also irrigated with reclaimed wastewater (Bahri, 2002).

The 1989 decree stipulates that the use of reclaimed wastewater must be authorized by the Minister of Agriculture, in agreement with the Minister of Environment and Land Use Planning, and the Minister of Public Health. It sets out the precautions required to protect the health of farmers and consumers, and the environment. Monitoring the physical-chemical and biological quality of reclaimed wastewater and of the irrigated crops is planned: analyses of a set of physical-chemical parameters once a month, of trace elements once every 6 months, and of helminth eggs every two weeks on 24h composite samples, etc. In areas where sprinklers are used, buffer areas must be created. Direct grazing is prohibited on fields irrigated with wastewater. Table 2.12 summarizes the Tunisian standards.

Table 2.12

Tunisian standards for reclaimed wastewater reused in agriculture (Angelakis *et al.*, 1999)

Parameters[a]	Maximum allowed concentration
pH	6.5 - 8.5
EC (dS/m)	7,0
COD	90[b,c]
BOD_5	30 [b,c]
SS	30 [c]
Cl	2,000
F	3
Halogenated hydrocarbons	0.001
As	0.1
B	3
Cd	0.01
Co	0.1
Cr	0.1
Cu	0.5
Fe	5
Mn	0.5
Hg	0.001
Ni	0.2
Pb	1
Se	0.05
Zn	5
Intestinal nematodes (arith. mean No. of eggs/ L)	<1

[a] All units in mg/L unless otherwise specified;
[b] 24 h composite sample;
[c] Except special authorization.

Specifications determining the terms and general conditions of reclaimed wastewater reuse, such as the precautions that must be taken in order to prevent any contamination (workers, residential areas, consumers, etc.), have been published. The Ministries of Interior, Environment and Land Planning, Agriculture, Economy and Public Health are in charge of the implementation and enforcement of this decree.

It is interesting to note that in Tunisia, the farmers pay for the treated wastewater they use to irrigate their fields.

2.3.20 Turkey

Irrigation in agriculture is a significant factor in the economy of Turkey confronted by population growth, with correspondingly increasing demand for food stuffs and agricultural raw materials for inland uses and importing purposes.

In Turkey about 8.5 million hectares of agricultural land are considered to be economically feasible to be irrigated; currently about half of this area is being irrigated. In the southeast of the country, close to 1.7 million ha will be irrigated within the framework of GAP

(The Project of Southeast Anatolia), involving some thirteen major schemes/projects. Despite these costly investments, expected benefit from irrigation projects may not be able to be held in the management phase. Irrigation technique practices and excessive water consumption in irrigation leads to some serious problems as erosion, water-logging, salinity and alkalinity problems etc. and reduces the success of irrigation coverage. These issues also have social, health and environmental aspects regarding the inhabitants in the region (Gorgun, 2002). The increasing need for irrigation system encourage the specialists to focus on the topic and today, it is more evident that reclamation and reuse become an attractive option for conversing and extending available water resources in some cases. Agricultural wastewater reuse is an element of water resources development and management that provides innovative and alternative options for agriculture. Reuse of reclaimed water for irrigation enhances agricultural productivity. However, it requires public health protection, appropriate wastewater treatment technology, water management and public acceptance and participation. It must also be economically and financially viable.

The use of reused water for irrigation is mainly due to the scarcity of water resources and inefficient water resource management, both of which are exacerbated by growing population, economic conditions and increasing urbanization. Sustainability of irrigation in contemporary agricultural practices is being negatively affected by some constraints, which are: (a) Restrictions on soil, water and energy resources, (b) Changes in economic conditions, (c) Growing environmental consciousness and (d) Ineffective decisions in irrigation system management

Although, domestic wastewater should not be used directly without proper treatment, it contains nutrients, which are essential for plant growth and can be used after treatment as a water resource in a more convenient way. Especially in arid summer times in which irrigation activities should be increased for agricultural production, it can be said that wastewater is reused for irrigation in some cases. As a result the concentration of nitrogen, phosphorus, salinity, biodegradable organic materials, trace elements may depict subsequent increases in the agricultural production areas if wastewater not treated properly. Boron is another parameter which should be given special emphasis since, the accumulation of boron in a heavy soil due to irrigation, will lead to sharp decrease in agricultural productivity.

The related technical regulations and the constraints for the use of wastewaters for agricultural purposes are indicated in the Tables 2.13, 2.14 and 2.15, with reference to Water Pollution Control Regulations in Turkey. In addition to the regulations listed below there are other criteria in the regulations regarding the classification of the waters to be used for irrigation, maximum allowable heavy metal and toxic elements concentrations as well as the mass limits for application of these pollutants in terms of unit agricultural areas (Gorgun, 2002).

Table 2.13

Regulations for wastewater reuse in agriculture

Agriculture type	Technical limitations
Fruit and viticulture	- Sprinkler irrigation cannot be practiced - Fruit is not suitable for eating if contacted with soil - FC should be less than 1000/100 mL
Fiberly plant and seed growing	-It is suitable for surface irrigation and springier irrigation -Biologically treated and chlorinated wastewater can be used by sprinkler irrigation

	- FC should be less than 1000/100 mL
Feed plants, oil plants, not suitable to eat without cooking, and flowers	- Free irrigation, mechanically treated wastewater

Table 2.14

Treated domestic wastewater (without being disinfected) to be used for irrigation

	Field		Meadow-Pasture		Vegetable		Fruit growing		Feed plants		Small wood Forested	
	PE	PA	PE	PA	PE	PA	PE	PA	PE	PA	PE	PA
At least two hours settled lagoon or bilogical treatment plant effluent	+	+	+	+	-	-	+	-	-	-	+	
Aerobic stabilization ponds or lagoon effluent	+	-	+	-	-	-	+	-	-	-	+	

PE: Plant Existence, PA: Plant Absence, - : not suitable, and + suitable for irrigation

Table 2.15

Suitability of industrial wastewaters to be used for irrigation

I	II	III
Could be used for irrigation if a suitable field near the plant	Suitable if specific condition is provided	Not suitable for irrigation
Beer, malt, wine, yeast, potatoes, vegetable canned food, prunes for canned food, fruit canned food, milk, potatoes starch factories	Sugar, rice and grain starch, leather glue, bone glue plants, slaughterhouse, meat facility, tannery, margarine plants, paper plants, cartboard plants, textile industry wool washing, fish flower, fish canned food, Mining.	Polish and paint plants, soap plants, inorganic heavy chemical industry, medicine plants, metal plants, sulfide cellulose plant, viscose artificial silk plant, Pirolise institution, coal gas institution generator gas turbine, metallic oil industry, coal washing dynamite industry, wood pyrolysis plants.

2.4 Two Main Approaches for Wastewater Re-use Criteria for Irrigation

The evolution of reuse criteria cannot be understood completely without doing a historic review about what have these standards been since 1918. In this year the legislative fever on wastewater reuse started. A summary of this evolution can be found in Table 2.16.

The first element to be evaluated before reusing wastewater is the quality of water in terms of the presence of potentially toxic substances or of the accumulation of pollutants in soil, ground water, and crops. It is important to perform preliminary toxicological tests and to check microbiological changes in irrigated soil not only to assess the presence of heavy metals, but also that of synthetic chemicals that are normally present in urban wastewater (oils, disinfectants, etc.).

On the basis of surveys and experiments performed, there are grounds to sustain that heavy metals predominantly accumulate in sludge and not in the liquid wastewater, with consequent advantages regarding the latter's use for irrigation purposes.

Another aspect to be assessed to guarantee a correct hygienic use of wastewater is the presence of colibacteria and pathogenic bacteria and viruses in general. There are hotly disputed debates about the applicable microbiological quality standards according to the type of irrigation practiced and the type of crop irrigated (Asano and Levine, 1996). The issues are essentially confined to "unrestricted" irrigation (vegetables that can be consumed raw, sports fields, etc.).

Table 2.16

Historical data of the water quality for unrestricted irrigation (Salgot and Angelakis, 2001)

Year	Data and quality criteria
1918	California State Board of Public Health set up the "First regulations for use of sewage for irrigation purposes in California"
1952	First regulations of Israel
1973	WHO 100 FC/100 mL, 80% of samples
1978	State of California wastewater reclamation regulations: 2.2 TC/100 mL
1978	Israel regulations: 12 FC/100 mL in 80% of samples: 2.2 FC/100 mL in 50% of samples
1983	World Bank Report (Shuval *et al.*, 1986)
1983	Florida State: No *E. coli* detection in 100 mL
1984	Arizona State: Standards for virus (1 virus/40 L) and *Giardia* (1 cyst / 40 L)
1985	Report of Feachem *et al.*, 1983
1985	Engelberg report (IRCWD, 1985)
1989	WHO Recommendations for wastewater reuse: 1000 FC/100 mL and < 1 nematode egg/L
1990	Texas State: 75 FC/100 mL
1991	Sanitary French recommendations; based on WHO
1992	US.EPA Guidelines for water reuse: No FC detection in 100 mL (7 d median. No more of 14 FC/100 mL in any sample)

The alternative regulatory practices governing the use of reclaimed wastewater for irrigation are best illustrated by the major microbiological quality guidelines from the WHO (1989) and the State of California's (1978) current wastewater reclamation criteria, compared in Table 2.17. The providers of technology usually promote very high water quality standards (comparable to drinking water), confident that the most expensive technology provides safe enough water (i.e. free of enteric viruses and parasites) for whoever can afford it. The California criteria stipulate conventional biological wastewater treatment followed by tertiary treatment, filtration and chlorine disinfection to produce effluent that is suitable for irrigation. In support of this approach, Asano and Levine (1996) have reported two major epidemiological studies that were conducted in California during the 1970s and 1980s. These studies scientifically demonstrate that food crops that were irrigated with municipal wastewater reclaimed according to the California approach could be consumed uncooked without adverse health effects. Thus, by applying advanced treatment wastewater substantial nutrients may be lost. However, the nutrients removed by the tertiary treatment are not available for fertilizing.

International organizations such as the World Bank and WHO, on the other hand, call for epidemiological studies to defend the less stringent WHO quality guidelines. In contrast to the California approach, the WHO guidelines point out that the microbiological water quality requirements can be met by a series of stabilization ponds. Microbiological monitoring requirements also vary: the WHO guidelines require monitoring of intestinal nematodes whereas the California criteria rely on the required treatment systems and the sole monitoring of the total coliform count to assess microbiological quality (Asano and Levine, 1996). Similarly, the US.EPA criteria emphasize fecal coliforms removal.

Pathogens are difficult (and expensive) to monitor. Therefore, the WHO guidelines, prepared keeping the needs of developing countries in mind, only prescribe a limit for faecal coliforms (<1000/100 mL) and intestinal nematodes eggs (≤1/L). As a consequence, the whole argument about standards revolves around the validity of such limits as a sufficient guarantee of safety for the water used in irrigation (Marecos do Monte *et al.,* 1996). A large part of the answer lies in the treatment requirements associated to the limit values. One must also realize that in the case where raw wastewater is directly reused, the WHO guidelines, merely by requiring treatment, are already a major step forward. Based on an extensive analysis of existing guidelines worldwide, the need for developing health-related chemical criteria for land application of reclaimed wastewater has been reported by WHO (Chang *et al.*, 1995).

Recently, Blumenthal *et al.* (2000) using empirical epidemiological evidences and studies measuring real exposures that occur over time and don't depend on estimates of mean daily microbial based on experiments data have developed recommendations for revising WHO (1989) guidelines (Table 2.18). Besides, reuse of treated wastewater in agriculture, in the revising WHO guidelines, also urban settings, aquaculture and artificial recharge of groundwater shall be included.

2.5 Legislation and Guidelines on Wastewater Reuse at European Level

So far, no regulation of wastewater reuse exists at European level. The only reference to it is the article 12 of the European Wastewater Directive (91/271/EEC) (EC, 1991) stating: "Treated wastewater shall be reused whenever appropriate". To make this statement reality, common definitions of what is "appropriate" are needed.

In conclusion, in the EU it is in force a new framework directive encompassing all existing European regulations dealing with water. This work aims at providing a coherent regulatory approach compatible with the concept of "Integrated Pollution Prevention and Control" and promotes the application of BAT.

The Communication of the EU on the European Community Water Policy (EU, 1996) does not specifically mention the desirability of wastewater reuse, but it introduces a quantitative dimension to water management, on top of the usual qualitative dimension, which may stimulate the consideration of wastewater reuse. It also states "water resources should be of sufficient quality and quantity to meet other economic requirements". For wastewater reuse being a water resource often mobilized for economic reasons, such a statement does have economic implications (Angelakis *et al.*, 1999). In parallel, a "Task Force Environment-Water" has been set up by the EU, largely with an advisory role, in order to set R&D priorities and improve the coordination of the various actions of the European institutions in the domain of water research. One of its declared areas of concern is the promotion of the reuse and recycling of water in the various branches of agriculture and industry (irrigation and cooling in particular), through the development of standards for reuse, the development of techniques for on-site treatment and storage of wastewater, and awareness campaigns.

WHO (1989) guidelines are currently under revision. WHO were reviewing the epidemiological evidence on pathogens since 1984, updating and confirming its approach of microbiological risk assessment and collaborating closely with other scientific researchers. According to Carr (2000) some of the recommended standards of the 1989 guidelines needed to be tightened, for example nematodes where there was a high rate of infection (40 million cases annually of trematode infections world-wide). Arsenic was being revisited because of problems in Bangladesh, etc. and the lack of data about it. Special guidelines were needed for sprouts and similar crops where bacterial re-growth (notably *E. coli* 0157) was a problem. *Facioliasis* spp., cyanobacterial toxins, endocrine disrupters and *Cyclospora* spp. were being explored. WHO wastewater reclamation and reuse initiatives are towards of including 4 categories: (a) agriculture, (b) aquaculture (shell-fisheries, etc.), (c) artificial recharge exclusively for potable supply, and (d) urban settings. It was hoped to finalise guidelines by the end of 2002. The new guidelines would cover the various options for health protection such as treatment of wastewater, crop restrictions, application controls, and control of human exposures. A multi-barrier approach throughout the water cycle was important.

2.6 Guidelines and/or Regulations for Wastewater Recycling and Reuse in the USA

Total coliform and faecal coliform organisms are often used in conjunction with specified requirements for treating wastewater, and in such cases it is assumed that the need for expensive and time-consuming monitoring of treated water for pathogenic microorganisms is eliminated. In practice, however, this approach has led to guidelines that require zero faecal coliform bacteria/100 mL for water used to irrigate crops that are eaten raw in addition to a requirement for secondary treatment, filtration and disinfection. The US.EPA and the US Agency for International Development have taken this approach, and consequently have recommended strict guidelines for wastewater use (US.EPA, 1992). For unrestricted irrigation (that is, for uses that include crops likely to be eaten uncooked), no detectable faecal coliform bacteria are allowed in 100 mL (compared with the 1989 WHO guidelines of $\leq$ 1000 faecal coliform bacteria/100 mL), and for irrigation of commercially processed and fodder crops the guideline limit is $\leq$ 200 faecal coliform bacteria/100 mL (for which only a guideline limit on the presence of nematode eggs is set by WHO). In the USA, the setting of actual standards is the responsibility of individual states, and different states take different approaches (some specify treatment processes, others specify water quality standards) and a range of standards is in use (Blumenthal *et al.*, 2000).

As it is referred above, the well-known California criteria as California Code Regulations, Title 22, Division 4 (Dept. of Health Services, 1978) stipulate conventional biological wastewater treatment by tertiary treatment, filtration and chlorine disinfection to produce effluent that is suitable for irrigation. In support of this approach, Asano and Levine (1996) have reported two major epidemiological studies that were conducted in California during the 1970s and 1980s. These studies scientifically demonstrate that food crops that were irrigated with municipal wastewater reclaimed according to the California approach could be consumed uncooked without adverse health effects. However, the nutrients removed by the tertiary treatment are not available for fertilizing.

Table 2.17

Comparison of the microbiological quality guidelines and criteria for irrigation by the World Health Organization (1989), the US.EPA (1992) and the State of California (1978) (adapted from Asano and Levine, 1996)

Agent	Reuse conditions	Intestinal nematodes[a]	Fecal or total coliforms[b]	Wastewater treatment requirements
WHO	Irrigation of cereal crops, industrial crops, fodder crops, pasture, and trees	<1/L	No standard recommended	Stabilization ponds with 8-10 d retention or equivalent removal
WHO	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	<1/L	<1,000/100 mL	A series of stabilization ponds or equivalent treatment
US.EPA	Irrigation of pasture for milking animals; fodder, fiber and seed crops and landscape improvement	No standard recommended	200/100 mL[d]	Secondary treatment followed by disinfection
CA	Irrigation of pasture for milking animals, landscape impoundment	No standard recommended	<23/100 mL[b]	Secondary treatment followed by disinfection
WHO	Landscape irrigation where there is public access, such as hotels	<1/L	<200/100 mL	Secondary treatment followed by disinfection.
US.EPA	Surface or spray irrigation of any food crop including crops eaten raw	No standard recommended	not detectable[c]	Secondary treatment followed by filtration (with prior coagulant and/or polymer addition and disinfection)
CA	Spray and surface irrigation of food crops, high exposure landscape irrigation such as parks	No standard recommended	<2.2/100 mL[b]	Secondary treatment followed by filtration and disinfection

[a] *Ascaris* and *Trichuris* species and hookworms; expressed as the arithmetic mean number of eggs/L during the irrigation period.
[b] The California Wastewater Reclamation Criteria are expressed as the median number of TC per 100 cm^3, as determined from the bacteriological results of the last 7 d for which analyses have been completed.
[c] The number of FC should not exceed 14/100 mL in any sample
[d] The number of FC should not exceed 800/100 mL in any sample

Table 2.18

Recommended revised microbiological WHO guidelines for treated wastewater use in agriculture[a]

Category	Reuse conditions	Exposed group	Irrigation technique	Intestinal nematodes[b] (arithmetic mean no. of eggs/L[c])	Faecal coliforms (geometric mean no./100 mL[d])	Wastewater treatment expected to achieve required microbiological quality
A	Unrestricted irrigation					Well-designed series of waste stabilization ponds (WSP), sequential batch-fed wastewater storage and treatment reservoirs (WSTR) or equivalent treatment (e.g., conventional secondary treatment supplemented by either polishing ponds or filtration and disinfection)
	A1 For vegetable and salad crops eaten uncooked, sports fields, public parks[e]	Workers, consumers, public	Any	≤ 0.I[f]	$\le 10^3$	
B	Restricted irrigation					
	Cereal cops, industrial crops, fodder crops, pasture and trees[g]	B1 Workers (but no children < 15 years), nearby communities	Spray or sprinkler	≤ 1	$\le 10^5$	Retention in WSP series including one maturation pond or in sequential WSTR or equivalent treatment (e.g., conventional secondary treatment supplemented by either polishing ponds or filtration)
		B2 as B1	Flood/furrow	≤ 1	$\le 10^3$	As for Category A
		B3 Workers including children < 15 years, nearby communities	Any	≤ 0.1	$\le 10^3$	As for Category A

C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Trickle, drip or bubbler	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] *Ascaris and Trichuris* species and hookworms; the guideline limit is also intended to protect against risks from parasitic protozoa.

[c] During the irrigation season (if the wastewater is treated in WSP or WSTR which have been designed to achieve these egg numbers, then routine effluent quality monitoring is not required).

[d] During the irrigation season (faecal coliform counts should preferably be done weekly, but at least monthly).

[e] A more stringent guideline limit (≤ 200 faecal coliforms/100 mL) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

[f] This guideline limit can be increased to ≤ 1 egg/L if (i) conditions are hot and dry and surface irrigation is not used or (ii) if wastewater treatment is supplemented with anthelmintic chemotherapy campaigns in areas of wastewater reuse.

[g] In the case of fruit trees, irrigation should stop two weeks before fruit is picked, and no fruit should be picked off the ground. Spray/sprinkler irrigation should not be used.

2.7 Necessity for Establishing Regional Guidelines Among Mediterranean Countries

Most Mediterranean countries are arid or semi-arid with mostly seasonal and unevenly distributed precipitations. Due to the rapid development of irrigation and domestic water supplies, conventional water resources have been seriously depleted. As a result, wastewater reclamation and reuse is increasingly being integrated in the planning and development of water resources in the Mediterranean region, particularly for irrigation.

Cyprus, France, Israel, Italy, and Tunisia are the only Mediterranean countries to have established national guidelines for the use of reclaimed wastewater. A preliminary comparison of such criteria with those of California, US.EPA, and WHO are presented in Table 2.19. Regional guidelines exist in Spain. The existence of guidelines is necessary for the planning and safe implementation of treated wastewater reuse for irrigation. It also contributes to a sustainable development of landscape and agricultural irrigation. Guidelines must also clearly promote the development of best practices. This does not need to be defined in great detail but must take into account important specific local conditions, such as the quality of reclaimed wastewater, the type of soil, the climate, the relevant crops and the local agricultural practices. However, the need for sharing a common rationale for developing wastewater reclamation and reuse standards on both sides of the Mediterranean is obvious.

Table 2.19

Comparison of criteria (max. limits) for the irrigation of crops consumed by humans with reused wastewater by WHO, US.EPA, the State of California and some Mediterranean countries (national guidelines)

Parameters	California[1] T-22 (1978)	US.EPA (1992)	WHO (1989)	Israel (1978)	Tunisia (1975)	Cyprus (1997)	France (1991)	Italy (2001)
Type of regulation	Law	Guidelines	Guidelines	Law	Law	Provis. std.	Guidelines	Law
Minimum treatment required	Advanced treatment	Advanced treatment	Stabilisation Ponds[2]	Secondary treatment[3]	Stabilisation ponds	Tertiary treatment		Secondary treatment
Total BOD_5 (mg/L)		10		15	30	10		
Dissolved BOD_5 (mg/L)				10				
SS (mg/L)		5[4]		15	30	10		
Turbidity (NTU)	2	2		-				
PH					6.5-8.5		as WHO	
Conductivity (dS/m)					7.0			
DO (mg/L)	Present			0.5				
TC (MPN/100 mL)	2.2 (50%)[5]	0[6]		2.2(50%); 12(80%)				2.2
FC (MPN/100 mL)			1000		?	50		
Helminths (eggs/100 mL)[7]	-	-	1		<1	0		
Resid. avail. Cl (mg/L)	Present	1.0		0.5				
Salinity								
Metals								Yes
Main treat. Processes	Oxid., Clarif., Filt., Disinf.	Filt., Disinf.	Stabil. Ponds or equival.	Long stor., Disinf.	Stabil. Ponds or equival.	Filt., Disinf.		

[1] Spray irrigation;
[2] Stabilization ponds in series with proper retention time;
[3] Seasonal storage may constitute an equivalent to tertiary treatment;
[4] If SS are used instead of turbidity;
[5] Not to exceed 23/100 mL in a single monthly test;
[6] Not to exceed 14/100 mL at all times;
[7] Nematodes such as *Ascaris*, *Trichuris* and hookworms.

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ANNEXES

A1
DEFINITION OF TERMS

A1.1. Introduction

The following terms, used frequently in the field of wastewater reclamation and reuse, are important in understanding the concepts discussed in this report. EU advocates the use of those of a positive inclination, such as water reuse or water recycling.

A1.2. Types of Water and their Uses

Beneficial uses are the many ways water can be used, either directly by people or for their overall benefit. Examples include municipal water supply, agricultural and industrial applications, navigation, and water contact recreation.

Blackwater is any water that combines into a property's foul downpipe and enters the sewer system –includes mainly wastewater from toilets and bidets.

Direct potable reuse is a form of reuse that involves the incorporation of reclaimed water directly into a potable water supply system, often implying the blending of reclaimed water. Otherwise, it involves pipe-to-pipe systems.

Direct reuse is the use of reclaimed water that has been transported from a water reclamation plant to the water reuse site without intervening discharge to a natural body of water. It includes such uses as agricultural and landscape irrigation.

Effluent is sewage or industrial/trade wastewaters that are discharged, normally after partial or full treatment.

Greywater is the domestic wastewater from baths, showers, and handbasins. It may include dishwater and washing machine wastewater. It does not include toilet flushings.

Ground water is the water contained in the soil or rocks below the water table
Indirect potable reuse is the potable reuse by incorporation of reclaimed water after appropriate treatment into a raw water supply. It allows mixing and assimilation by discharge into an impoundment or natural body of water, such as domestic water supply reservoir or groundwater.

Indirect reuse is the use of water reclaimed indirectly by passing it through a natural body of water or use of groundwater that has been recharged with reclaimed water.

Non-potable reuse is the form of reuse that involves non-potable purposes, such as irrigation, street cleaning, and golf course watering.

Planned reuse is the deliberate direct or indirect use of reclaimed water.

Potable water is water intended and suitable for human consumption.

Potable water reuse is a direct or indirect augmentation of drinking water with reclaimed water that is highly treated to protect public health/or is the use of reclaimed water for potable water supply.

Rainwater is water from atmospheric precipitation collected and stored from hard surfaces on and around buildings and in water butts.

Reclaimed (waste) water is wastewater that, through reclamation, is suitable for a direct beneficial use or a controlled use that would not otherwise occur.

Surface water is the maintained water on the soil surface.

Unplanned reuse is the unintentional use of wastewater, without a system designed or constructed for reuse purposes.

Waste waters are those waters that have already been used.

(Waste)water reclamation (*re-purification*, *recovery*, *reuse*, *renovation*, and *recycling*) is the treatment or processing of wastewater to make it usable. These terms are also often used to include delivery of reclaimed water to its place of use and its actual use. In the past the term *recycling* was often referred to the use of water that is captured and redirected back into the same water-use scheme, i.e. industries. Today the term recycling appears to be more predominant.

(Waste)water reuse is the use of treated wastewater, for a beneficial use such as agricultural irrigation or industrial cooling.

A1.3. Quality

Absorption is the process by which a substance is taken into and included within another material, for example the uptake of water by soil.

Adsorption is the addition of molecules or ions at an interface.

E. coli (Escherichia coli) is an organism of the coliform group, which inhabits the human and animal intestine. *E. coli* is an indicator of faecal contamination.

Environmental assessment is the comprehensive appraisal of the likely effects of a planned development that has not taken place.

Hazard identification involves assessing the inherent properties of a substance or circumstance that could have adverse effects

Infiltration is the downward entry of water into soil.

Ion exchange capacity is the total quantity of ions that a soil can absorb by exchange (from water), usually expressed as milliequivalents per 100 g.

Pathogens are microorganisms including bacteria, protozoa, parasites, prions and viruses, that are capable of producing diseases.

Pollutant is any undesirable solid, liquid, or gaseous matter in a gaseous, liquid, or solid medium.

Risk assessment is an analysis of the probability that an event will occur. It is a combination of hazard, exposure, and control.

Potassium adsorption ratio (PAR) is the ratio for soil extracts and irrigation waters used to express the relative activity of potassium ions in exchange reactions with soil, derived from the Equation A2.1:

$$PAR = \frac{K^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}} \qquad (A2.1)$$

with ionic concentrations expressed in milliequivalents per litre (meq/L).

Saline soil A soil containing soluble (sodium) salts in such quantities that they interfere with the growth of most plants.

Sodium adsorption ratio (SAR). An index of the sodium hazard of irrigation water defined by the Equation A2.2:

$$SAR = \frac{Na}{\sqrt{(Ca^{++} + Mg^{++})/2}} \qquad (A2.2)$$

with ionic concentrations expressed in meq/L

Total maximum daily load (TMDL). A water basin budget for pollutant influx to watercourse.
Water Table is the level below which the soil or rocks are saturated with water.

A2
ABBREVIATIONS

BAT	: Best available techniques
BOD	: Biochemical oxygen demand
COD	: Chemical oxygen demand
CRDA	: Regional Department for Agricultural Development
CSHPF	: Conseil Supérieur d' Hygiène Publique de France
CSEI	: Centro studi di economia applicata all' Ingegneria
EC	: Electrical Conductivity
EEC	: European Economic Community
p.e.	: Equivalent population
EPA	: Environment Protection Agency
EUREAU	: Union of National Associations of Water Services
EFTA	: European Free Trade Associations
EU	: European Union
FC	: Faecal coliforms
Ha	: hectares
MAP	: Mediterranean Action Plan
MENA	: Middle East and North Africa
MF	: Microfiltration
MPN	: Most probable number
MWTP	: Municipal wastewater treatment plants
N/A	: not available
NAGREF	: Hellenic National Agricultural Research Foundation
NASA	: National Aeronautics and Space Administration, USA
NC	: not classified
NF	: nanofiltration
NTSW	: natural treatment systems of wastewater
NTU	: nephelometric turbidity units
PA	: plant absence
PA	: Polyamide
PE	: plant existence
p.e.	: population equivalent
PT	: primary treatment
R&D	: research and development
RO	: reverse osmosis
SAR	: sodium adsorption ratio
SAT	: soil-aquifer-treatment
SS	: suspended solids
ST	: secondary treatment
TC	: total coliform
TDS	: Total dissolved solids
TF	: Trickling filter
TMDL	: total maximum daily load
TN	: total nitrogen
TOC	: total organic carbon
TP	: total phosphorus
TSS	: total suspended solids
TT	: tertiary treatment
UF	: ultrafiltration
UK	: United Kingdom

USA	: United States of America
UV	: Ultra violet
WHO	: World Health Organization
WPCF	: Water pollution Control Federation
WWTP	: Wastewater treatment plant