EP

United Nations Environment Programme

UNEP(DEC)/MED WG.231/Inf.6
16 May 2003

ENGLISH

MEDITERRANEAN ACTION PLAN

Meeting of the MED POL National Coordinators

Sangemini, Italy, 27 - 30 May 2003

STRATEGIC ACTION PROGRAMME

GUIDELINES

MUNICIPAL WASTEWATER REUSE

FOR THE MEDITERRANEAN REGION

In cooperation with

WHO

UNEP
Athens, 2003

FOREWORD

The MED POL Programme for the Assessment and Control of Marine Pollution in the Mediterranean is, among other, responsible to follow up the implementation of the provisions of the Protocol related to the control of pollution from land-based activities (LBS Protocol). In 1996 a Strategic Action Programme (SAP) to Address Pollution from Land-based Activities was formulated and one year after was adopted by the Contracting Parties in the framework of the implementation of the LBS Protocol.

An activity included in the SAP is referred to the development at regional level of programmes for sharing and exchanging technical information and advice regarding environmentally sound sewage treatment, including the use of treated wastewater.

The 12th Ordinary Meeting of the Contracting Parties, held in Monaco, in 2001, recommended that a set of guidelines for municipal wastewater reuse be developed for the Mediterranean countries. The implementation of this task was entrusted to WHO/MED POL. The first draft of the guidelines was prepared by two Mediterranean experts that took into consideration all the recent work in preparing such guidelines and particularly those initiatives by the Mediterranean Water Institute and other Mediterranean Agencies, discussed in the Barcelona and Rabat meetings. Within the framework of he Regional Symposium on Water Recycling in the Mediterranean Region, held in Iraclio, in September 2002, the draft guidelines were also presented and discussed during a workshop on water recycling and reuse practices in Mediterranean countries.

The comments made at the workshop were incorporated and the second draft was presented to the Meeting of Government designated experts, held in Athens, from 81-0 April 2003. The present document includes the comments and suggestions as proposed by the participants during the above Meeting and reflects the opinion of the experts on the matter.

EXECUTIVE SUMMARY

Wastewater reuse is a widespread practice in most Mediterranean countries. The main reuse projects in the region are dedicated to agricultural irrigation, landscape irrigation, and groundwater recharge. Industrial reuse is very seldom practised.

The management of wastewater in the Mediterranean varies from country to country, as do the standards and their enforcement. Some countries have no wastewater treatment facilities and direct reuse of raw wastewater is occurring with serious health hazards and environmental problems. Others have a well-established national reuse policy. Moreover, wastewater treatment and reuse standards differ from one country to another and even within a given country such as in Italy or Spain.

Some of the main discrepancies in the standards are, in part, due to differences in approaches to public health and environmental protection. For example, some countries have taken the approach of minimising any risk and have elaborated regulations close to the California's Title 22 effluent reuse standards, whereas the approach of other countries is essentially a reasonable anticipation of adverse effects resulting in the adoption of a set of water quality criteria based on the WHO guidelines (1989). This has led to substantial differences in the standards adopted by Mediterranean countries.

The WHO and the Californian approaches are actually challenged by scientific and management questions and uncertainties which should be addressed in order to establish Mediterranean and worldwide standards.

How were the existing guidelines and standards derived?

It was found the absence of comprehensive international guidelines and a lack of scientific data and knowledge. The rationale behind the guidelines is not always scientifically based: in the conservative approaches, the pathogen standards are not risk-based concentration limits for individual pathogens but are technologically based requirements aimed at reducing the presence of pathogens and potential exposures to them by treatment or a combination of treatment and use restrictions. Existing water reuse criteria are not based on either comprehensive epidemiological studies or risk assessment modelling data. These inconsistencies in the existing guidelines or standards may have led to too conservative or too liberal standards.

There are few studies related to environmental microbiological health risks. Literature data on epidemiological studies are rather limited and mainly evoked for microbiological contamination of bathing or drinking waters. Very few epidemiological studies were conducted on non-potable reuse: Jerusalem and Mexico studies are exceptional.

To evaluate the safety of wastewater reclamation and reuse applications, potable water and bathing standards were used as benchmarks. Should bathing or drinking water quality criteria be adopted as reference for unrestricted irrigation and urban uses (crops eaten raw, golf courses, public parks, sprinkling of orchards,...)? Not all non potable uses, if any, require drinking water quality, nor all bathing water quality. However, infection risks considered as acceptable when related to bathing or drinking potable water can serve as references for reuse guidelines.

Draft proposal for Mediterranean water reuse guidelines

Health risks include microbiological and chemical risks. As non potable reuse will long remain the goal of the large majority of the reuse projects, these draft guidelines for municipal water reuse for the Mediterranean Region are focused on the microbiological hazards. In preparing guidelines for municipal water reuse for the Mediterranean Region, some principles were considered. Wastewater quality guidelines or standards should reflect the potential for regional variations in climate, water flow and wastewater characteristics and should be designed to protect individuals against realistic maximum exposures. They should be:

- realistic in relation to local conditions (epidemiological, socio-cultural and environmental factors),
- affordable, and
- enforceable.

Five categories of reclaimed water uses are considered (Table 1):

I. urban and residential reuses, landscape and recreational impoundments,
II. unrestricted irrigation, landscape impoundments (contact with water not allowed), and industrial reuses,
III. restricted agricultural irrigation,
IV. irrigation with reclaimed water application systems or methods (drip, subsurface, …) providing a high degree of protection against contamination and using water more efficiently,
V. groundwater recharge.

Water quality criteria are proposed for non potable water reuse categories I to IV. Groundwater recharge guidelines depend on whether the aquifer water is potable or not, the intended use of non potable recharged aquifer, the technique of recharge and the hydrogeological context.

Wastewater treatments expected to meet the criteria were defined for each water category.

Research needs

There is no documented scientific evidence that the WHO guidelines failed to protect public health. But, within the context of uncertainties concerning the potential impacts on human health and the environment of the various disposal and recycling options, additional research is needed to reduce persistent uncertainty about the potential for adverse human health effects from exposure to reclaimed water and to increase confidence in water reuse. To assure the public and protect the public health, there is a need to update the scientific basis of the regulations to ensure that the chemical and pathogen standards are supported by current scientific data and risk assessment methods and to validate the effectiveness of reclaimed water management practices. There is a need to address scientific and management questions and uncertainties that challenge the existing reclaimed water guidelines and standards.

Table 1

Recommended guidelines for water reuse in the Mediterranean Region

<table>
<tr><th rowspan="3">Water Category</th><th colspan="3">Quality criteria</th><th rowspan="3">Wastewater treatment expected to meet the criteria</th></tr>
<tr><th colspan="2">Microbiological</th><th>Physical-chemical</th></tr>
<tr><th>Intestinal nematode[a] (No. eggs per liter)</th><th>FC or E. coli [b] (cfu/100 mL)</th><th>SS [c] (mg/L)</th></tr>
<tr><td colspan="5">Category I</td></tr>
<tr><td>a) Residential reuse: private garden watering, toilet flushing, vehicle washing.</td><td rowspan="3">≤ 0.1[h]</td><td rowspan="3">≤ 200 [d]</td><td rowspan="3">≤ 10</td><td rowspan="3">Secondary treatment + filtration + disinfection</td></tr>
<tr><td>b) Urban reuse: irrigation of areas with free admittance (greenbelts, parks, golf courses, sport fields), street cleaning, fire-fighting, fountains, and other recreational places.</td></tr>
<tr><td>c) Landscape and recreational impoundments: ponds, water bodies and streams for recreational purposes, where incidental contact is allowed (except for bathing purposes).</td></tr>
<tr><td colspan="5">Category II</td></tr>
<tr><td>a) Irrigation of vegetables (surface or sprinkler irrigated), green fodder and pasture for direct grazing, sprinkler-irrigated fruit trees</td><td rowspan="2">≤ 0.1[h]</td><td rowspan="3">≤ 1000 [d]</td><td rowspan="3">≤ 20
≤ 150 [f]</td><td rowspan="3">Secondary treatment or equivalent [g] + filtration + disinfection
or
Secondary treatment or equivalent [g] + either storage or well-designed series of maturation ponds or infiltration percolation</td></tr>
<tr><td>b) Landscape impoundments: ponds, water bodies and ornamental streams, where public contact with water is not allowed.</td></tr>
<tr><td>c) Industrial reuse (except for food, beverage and pharmaceutical industry).</td><td>-</td></tr>
<tr><td colspan="5">Category III</td></tr>
<tr><td>Irrigation of cereals and oleaginous seeds, fiber, & seed crops, dry fodder, green fodder without direct grazing, crops for canning industry, industrial crops, fruit trees (except sprinkler-irrigated)[e], plant nurseries, ornamental nurseries, wooden areas, green areas with no access to the public.</td><td>≤ 1</td><td>None required</td><td>≤ 35
≤ 150 [f]</td><td>Secondary treatment or equivalent [g] + a few days storage
or
Oxidation pond systems</td></tr>
</table>

Category IV				
a) Irrigation of vegetables (except tuber, roots, etc.) with surface and subsurface trickle systems (except micro-sprinklers) using practices (such as plastic mulching, support, etc.) guaranteeing absence of contact between reclaimed water and edible part of vegetables.	None required	None required	Pretreatment as required by the irrigation technology, but not less than primary sedimentation	
b) Irrigation of crops in category III with trickle irrigation systems (such as drip, bubbler, micro-sprinkler and subsurface).				
c) Irrigation with surface trickle irrigation systems of greenbelts and green areas with no access to the public.				
d) Irrigation of parks, golf courses, sport fields with sub-surface irrigation systems.				
Category V: groundwater recharge				
a) Surface spreading into nonpotable aquifers	-	None required	≤ 35	Secondary treatment or equivalent (g)
b) Surface spreading into potable aquifers	-	≤ 1000(d)	≤ 20	Secondary treatment or equivalent (g) + filtration + disinfection
c)Direct injection	No detectable	No detectable	< 5	Advanced wastewater treatment processes in order to meet drinking water maximum contaminant levels

(a) *Ascaris and Trichuris* species and hookworms; the guideline limit is also intended to protect against risks from parasitic protozoa.
(b) FC or *E. coli* (cfu/100mL): faecal coliforms or *Escherichia coli* (cfu: colony forming unit/100 mL).
(c) SS: Suspended solids.
(d) Values must be conformed at the 80% of the samples per month, minimum number of samples 5.
(e) In the case of fruit trees, irrigation should stop two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
(f) Stabilization ponds.
(g) such as advanced primary treatment (APT) (Jimenez *et al*., 1999 and 2001).
(h) As very few investigations, if any, have been carried out on how to reach < 0.1 nematode egg /L, this criterion is considered a medium term objective and is provisionally replaced by <1 nematode egg /L.

Table of Contents

Scope of the document

The document focuses on the health impact of wastewater reuse on human beings, i.e. users, consumers, workers and neighbors of wastewater reuse projects. Potential health risks offered by wastewater reuse are related to the micro-organisms and chemicals conveyed by the reused wastewater.

- Chemicals constituents are a major health concern for indirect potable reuse but not for non potable reuses, apart some exceptional situations such as reuse of untreated wastewater or massive non controlled input of industrial effluents. In this report, indirect potable reuse is addressed only as a groundwater recharge application and appropriate recommendations are provided in order to ensure that the aquifer water remains potable, according to current related standards. Non potable reuses are and will long be the virtually only applications in the Mediterranean; therefore, health impacts of chemical constituents are not considered hereafter. Chemicals (Cl, Na, salinity, B, heavy metals, …) may also have detrimental effects on irrigated plants and soils; this very important issue is addressed in several manuals and particularly in FAO reports. The potential build up of nitrates in aquifers used for potable water production, which may result from irrigation with reused water, is a major concern that should be carefully considered at the planning stage; as it highly depends on the natural context, this issue cannot be properly addressed through regulations or guidelines.

- Possible transmission of infectious disease by waterborne pathogens is the most common concern associated with wastewater reuse. The reports aims at addressing this very sensitive and controversial issue.

Benchmark standards in the World and current standards for water reuse in the Mediterranean and the methodologies used for developing guidelines or standards for water reuse have been reviewed, seeking how the existing approaches and state of art could be used to propose Mediterranean guidelines based on as much scientific basis as possible. A number of knowledge gaps were identified.

The present document comprises two main parts. The first one summarizes the California and WHO approaches and gives and overview of the current water reuse standards and guidelines in the Mediterranean region. A proposal of Mediterranean water reuse guidelines is presented in the second part, together with the methodology used for working out this proposal and implementation recommendations. Comments related to the limits and future evolutions of these guidelines and research needs will be found in the conclusion.

The proposed guidelines do not exempt from abiding by local, regional or national regulations related to water quality and environment protection.

In this document, the terms *wastewater reuse* or *water reuse* are employed indifferently, the current trend being to replace the former and its waste connotation by the latter viewed as more acceptable by the public.

1. INTRODUCTION

In the Mediterranean basin, wastewater reclamation and reuse are practiced since the Greek and Roman times (Angelakis and Spyridakis, 1996). Land application of reclaimed water is an old and common practice, which has gone through different development stages with time, knowledge of the processes, treatment technology, and regulation evolution. Wastewater has also been used by the European (Great Britain, Germany, France, Poland, etc.) and the Mediterranean civilizations (wastewater was reused in the XIV and XV century in the Milanese Marcites and in the Valencian huertas, respectively (Soulié and Tréméa, 1992)).

Raw or partially treated wastewater has been applied in many locations all over the world not without causing serious public health consequences and negative environmental impacts. This generated the existence of endemic, and quite epidemic diseases.

Water reuse for irrigation raises issues both as potential resources of nutrients and source of pollution. Wastewater content in organic matter, nitrogen, phosphorus, and potassium may improve soil fertility and enhance plant development. However, contents in mineral and organic trace substances and pathogens represent a risk for human health and the environment. Wastewater microbial composition imposes crop restrictions and constraints for the users. Content in micro-organisms is of essential concern for residential, urban and recreational uses, as far as humans may be in contact, directly or indirectly, with wastewater. Ingestion or inhalation of pathogens may result in infection and disease. Organic and inorganic trace elements may present an environmental concern because of their potential harmful effects on biota. They may accumulate in the surface soil layers, be transported to underlying groundwater systems or be removed through plant uptake. They may then induce metabolism problems in plants and animals and consequently contaminate the food chains. These elements may be transferred to animals or humans through different pathways and cause human health effects depending on their concentration. Therefore, wastewater must be treated and used in such a way as to ensure only acceptable risks for users, workers, consumers (human and/or animal), and the environment.

Several water reuse guidelines and manuals have been published. The Californian standards for agricultural reuse were the first to be issued in 1918. In 1985, Pettygrove and Asano published their document entitled “Irrigation with reclaimed municipal wastewater - A guidance manual”. In 1989, the World Health Organization developed microbiological quality guidelines for wastewater use in agriculture, the "Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture", which were aimed at encouraging water reuse in a controlled and sanitary acceptable way. In the same year, UNEP and WHO jointly published the "Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture", with emphasis on environmental and public health protection. In 1991, UNEP and FAO jointly published the "Environmental guidelines for water reuse in the Mediterranean region". These were followed, in 1992, by an FAO publication on "Wastewater Treatment and Use in Agriculture" and by the U.S. Environmental Protection Agency document “Guidelines for Water Reuse” published the same year. The development of human health-related chemical guidelines for irrigating crops with reclaimed water and using sewage sludge as fertilizer has also been considered by the World Health Organization (Chang *et al*., 1995). These guidelines have been supporting many countries to implement or upgrade environmentally sound and safe wastewater reclamation and reuse systems adapted to their own technical, socio-economic and cultural conditions. Some countries have also implemented water reuse strategies and issued standards for pathogens, and organic and inorganic pollutants.

In the Mediterranean region, the volume of wastewater is increasing. Large areas may be supplied with reclaimed water which may also be used for different other purposes depending on the demand, the water characteristics, its suitability, etc. Consequently, there is a major potential use of reclaimed water in the region. It is, however, essential that the development of water reuse in agriculture and other sectors be based on scientific evidences of its effects on environment and public health. Although several studies have been conducted on wastewater quality and for different purposes, at this time, there are no regulations of water reuse at a Mediterranean level. With the development of tourism and Mediterranean food market, there is a need for sharing a common rationale for developing water reuse standards on both sides of the Mediterranean.

1.1 Background

The Mediterranean region is characterized by common issues related to environmental and development problems, in particular, concerning water resources management, their development and pollution control. However, the two shores (North/East and South) of the basin are strongly contrasted and face differently the arising issues.

Hot and dry summers and mild winters receiving the major part of the annual precipitation characterize the «Mediterranean» climate. Rainfall is unevenly distributed (in space and time). Moreover, the whole basin or parts of it are experiencing drought episodes in a more or less regular pattern with unpredictable successions of dry years which may seriously worsen the situation.

According to the Blue Plan (Margat and Vallée, 2000), renewable water resources are very unequally shared across the Mediterranean basin with around 72% located in the North (Spain, France and Monaco, Italy, Malta, Bosnia-Herzegovina, Croatia, Slovenia, R.F. of Yugoslavia, Albania, and Greece), 23% in the East (Turkey, Cyprus, Syria, Lebanon, Israel, Palestinian Territories of Gaza and the West Bank, and Jordan), and 5% in the South (Egypt, Libya, Tunisia, Algeria, and Morocco). Besides, available water resources are becoming increasingly scarce, vulnerable and threatened by over-exploitation and different pollution sources (Table 2). Countries of the Southern Mediterranean and Middle East region are facing increasingly more serious water shortage problems. Some of them have few naturally available fresh water resources and rely mainly on groundwater. Surface waters are already in most cases utilized to their maximum capacity. Groundwater aquifers are often over-drafted and sea and brackish water intrusion in coastal areas has reached threshold limits in some locations. Non-renewable deep or fossil aquifers are being tapped to varying degrees. Exploitation of non-renewable resources of Saharan aquifers is intensive in Libya, Egypt, Tunisia and Algeria. Desalination of brackish and seawater is already under implementation or planned in some countries despite its high cost. National exploitation ratios over 50%, or even nearing 100% in several Mediterranean countries (Egypt, Gaza, Israel, Libya, Malta, Tunisia) show that actual water consumption already exceeds the renewable conventional water resources. As a consequence, several problems appear all around the basin such as water and soil salinization, desertification, increasing water pollution, and unsustainable land and water use.

Total population of the region is actually around 427 million inhabitants with 145 million living near the sea and an additional 180 million tourists each year. By 2025, the population is expected to increase by 17-19% and the tourist population by 40%. The demographic evolution of population is fundamentally different in Eastern and Southern countries (intensively growing) compared to the Northern ones (stabilizing or decreasing). It is aggravated by a very intensive urbanization often along the coastal areas.

Table 2

Current pressures on water resources in Mediterranean countries
(after Margat and Vallée, 2000)

Countries and territories	Date of value	Indexes of quantitative pressure (%) on natural renewable resources		Resources available in average year 10^9 m^3/year (5)	Urban and industrial waste water discharged and returned to continental water 10^9 m^3/year (1)	Index of potential depletion % (2)
		Exploitation index (3)	Final consumption index (4)			
SPAIN	1997	31,6	20,6	89,0	3,22	3,6
FRANCE	1994	21,5	4,9	172,0	5.3	3,1
ITALY	1993	23,5	14,5	143,0	7,7	5,4
MALTA	1995	167,0 (6)	≅ 27 (7)		≅ 0,007	-
SLOVENIA CROATIA BOSNIA-HERZEGOVINA F.R. of YUGOSLAVIA F.Y.R MACEDONIA	1990	6,5	~ 1	262,0	~ 7	2,3
ALBANIA	1995	3,3	2,1	41,7	~ 0,3	0,7
GREECE	1990	10,1	8,6	63,0	~ 0,1	~ 0,2
TURKEY	1997	15,2	12,6	171,0	5,5	3,2
CYPRUS	1994	27,6	24,0	0,6		
SYRIA	1993	47,7 (8)	31,6	24,5	0,35	1,4
LEBANON	1994	26	21,2	3,9	0,0	0,4
ISRAEL	1996	92,4	87,5	0,17		
GAZA THE WEST BANK	1994 1994	217,0 24,0	132,0 14,3	-0,018 0,52	0,06 0,05	 ~ 9
EGYPT	1993	91,4 (9)	83 (9)	~16,0	6,5	39
LIBYA	1995	477,0	475,0	-3		-
TUNISIA	1995	62	59,9	1,5	0,05	3,2
ALGERIA	1990	27,8	21,5	11,3	0,8	~ 7,0
MOROCCO	1991	47	31,7	20,5	0,3	~ 1,5

1 Not including cooling waters discharged from thermal-electric power stations.
2 Ratio : return of urban and industrial wastewater to continental waters / flows of natural renewable resources decreased by final consumption (= availability), in %. These depletion indexes are naturally much higher if they are compared to low water flow levels.
3 Exploitation index : annual water withdrawn / average annual flow of total resources (natural, renewable), in %.
4 Consumption index : annual final consumption of water withdrawn (= net consumption per water use + wastewater not returned to continental waters, discharged at sea) compared to the annual average flow of total renewable natural resources, in %.
5 Balance : average annual flow of total renewable natural resources– final consumption (this balance includes non-returned wastewater).
6 Compared to exploitable resources with no fresh water / saltwater imbalance.
7 Malta : taking into consideration the return of water losses and non conventional wastewater (desalination).
8 Syria : compared to the real water resources (25.11) with reduced external resources, the exploitation index would be 55%, the final consumption index 45% and the availability would be around 13.8 10^9 m^3/year.
9 Egypt: indexes compared to real renewable resources (58 109 m3/year) and accounting for remobilisation and reusage.

Due to rapid population growth, the average annual per capita renewable water is rapidly decreasing since 1950. It varies across a wide range – from a little over 100 to more than 3000 cubic meters per year (Margat and Vallée, 2000). All the Mediterranean countries of the EU are expected to maintain themselves at or above 3000 m^3/inh./yr when in the major part of the other Mediterranean countries, the projected water availability is below the level of "chronic water scarcity" (< 1000 m^3/inh./yr), due mainly to very high population growth. Some countries, such as Tunisia, Israel and Malta, experience "absolute water stress" with per capita water availability of less than 500 m^3/inh./yr. In Malta, 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.

These problems of water scarcity will intensify because of population growth, rise in living standards, and accelerated urbanization which threaten the water supply in general and agriculture in particular and lead to both an increase in water consumption and pollution of water resources. Continuing increase in demand by the urban sector has led to increased utilization of fresh water for domestic, industrial and tourism purposes, on the one hand, and generation of greater volumes of wastewater, on the other.

The Mediterranean basin is nowadays depending for its' economic and social development on the agriculture (largest water use share reaching 61% on average, 42% to 84% of total demands) and tourism and, secondarily, on industry and other economic activities. Irrigated agriculture in competition with other sectors will face increasing problems of water quantity and quality considering increasingly limited conventional water resources and growing future requirements and a decrease in the volume of fresh water available for agriculture. Around the cities of the region, competition with other sectors often makes water the main factor that limits agricultural development. Policy makers have then been compelled to develop additional water resources as well as to preserve the existing ones. Reclaiming and recycling water is, among various measures, designed to encourage integrated and efficient management and use of water resources and is therefore becoming an important component of the national resources policy.

The agricultural sector is influenced in the Northern part by the common agricultural policy and in the Southern and Eastern parts by the agreements of agricultural exchange, and the future free trade area. Expansion of the irrigated area will continue in the Southern and Eastern countries with increasing demand for food and from the development of agricultural production for export markets. On the other hand, the irrigated sector will have to face major challenges with the future scenario of agricultural trade liberalization; a part of the water resources may be reallocated to high added-value export products instead of basic production or to industrial activities, tourism, and domestic water supply. Providing water quantities and qualities in compliance with the needs is one of the challenges facing the region.

A main problem in effluent ruse is progressive damage to soil and water resources contamination by toxic micro-elements and other chemical agents, present in effluent water.

Therefore, in order to encourage extensive reuse of effluent and secure its sustainable reuse in the Mediterranean region, complementary guidelines addressing additional physical and chemical parameters are required. Major threats to soil and water resources include:

a) Organic matter (BOD, COD), which are abundantly present in urban wastewater. Dissolved organic matter fraction can cause dispersion of clays in soils resulting in a gradual decrease in soil hydraulic conductivity and blockage/scaling of soils. Organic matter contains metal complexants (e.g. EDTA) , which might influence heavy metal mobilization. in soil and their migration towards …….).

b) Nutrients such a nitrate, nitrite and amonia are abundantly present in domestic and agro-ecological waste effluent. Increased concentration will cause leakage/seepage of nitrates and nitrites, through the soil and will contaminate underlying groundwater. Washout of nutrients to surface waters including marine could result in over-fertilization of algal bloom (eutrophication). Certain nutrient levels can be maintained in effluent as a substitute of artificially added fertilizer.

c) Boron is essential to plant growth at a few tenths mg/L. Boron is toxic to many sensitive plants, depending on the tolerance level of various plants. Phosphorus, potassium, sodium (SAR), chlorides (and TDS), above certain levels can adversely effect soils and many crops and therefore careful management practices should be followed.

d) Toxicants in effluents such as metals (mercury, cadmium, zinc, etc.) are harmful to plants once exceeding required levels. Their migration to groundwater and surface water can pose human health hazards (with acute and chronic effects).

1.2 The current state of water reuse in the Mediterranean region and selected countries

1.2.1. Significance of water reuse

The significance of water reuse may be evaluated through the comparison of water reuse potential with total water use. Water reclamation and reuse is generally small compared with total water use but it is expected to increase significantly. It is and will become more significant in water scarce regions. In the United States, it was estimated that municipal water reuse accounted for 1.5% of total freshwater withdrawals in the year 2000. In Tunisia, reclaimed water accounted for 4.3% of available water resources in the year 1996, and may reach 11% in the year 2030. In Israel, it accounted for 15% of available water resources in the year 2000, and may reach 20% in the year 2010. The volume of treated wastewater compared to the irrigation water resources is actually about 7% in Tunisia, 8% in Jordan, 24% in Israel, and 32% in Kuwait. Approximately 10% of the treated effluent is being reused in Kuwait, 20-30% in Tunisia, 85% in Jordan, and 62% in Israel. In California, where the largest number of water reuse facilities existing in the United States is found, there is around 434 million cubic meters of municipal wastewater currently reused with, in 1999, water reuse for agricultural irrigation amounting to 68% of the total reclaimed water used (Asano *et al*., 2000). In Japan, water reuse is mainly directed toward non-potable urban applications such as toilet flushing, urban environmental water, and industrial reuse (Asano *et al*., 2000). In Tunisia, the expected amount of reclaimed water in the year 2020 is expected to be approximately 18% of the available groundwater resources and could be used to replace groundwater currently used for irrigation in areas where excessive groundwater mining is causing salt water intrusion in coastal aquifers.

1.2.2. Driving forces, benefits and concerns of water reuse

The driving forces for water reuse development in the Mediterranean region are related to different issues such as water resources (water scarce environment threatened by pollution), economical (cost-effectiveness of reclaimed water), or environmental issues (gradually more stringent water quality discharge regulations).

The benefits, potential health risks and environmental impacts resulting from water reuse and the management measures aimed at using wastewater within acceptable levels of risk for the public health and the environment are acknowledged in several documents (Shuval *et al*., 1986; Mara and Cairncross, 1989; Asano, 1998; Crites and Tchobanoglous, 1998; Angelakis *et al*., 1999; Blumenthal *et al.*, 2000; Angelakis and Bontoux, 2001).

Water reuse is meant to help close the water cycle and therefore enable sustainable reuse of available water resources. When integrated to water resources management, water reuse may be considered as an integral part of the environmental pollution control and water management strategy. It may present benefits to public health, the environment, and economic development. Reclaimed water may provide significant additional renewable, reliable amounts of water and contribute to the conservation of fresh water resources. It may be considered as a valuable source of water and nutrients in agriculture schemes and therefore contributes to reducing chemical fertilizers' utilization and to increasing agricultural productivity. Reuse of reclaimed water, if properly managed, may alleviate pollution of water resources and sensitive receiving bodies. It may also contribute to desertification control and desert reclamation. Saline water intrusion may be controlled in coastal aquifers through groundwater recharge operations. Other social and economic benefits may result from such schemes such as employment and products for export markets. It is, however, essential that the development of reuse prevents negative effects on environment and public health since wastewater content in mineral and organic trace substances and pathogens represents a risk for human health. Adequate treatment has therefore to be provided for the intended reuse.

1.2.3. Water reuse in the Mediterranean region

In most of the countries of the Mediterranean region, wastewater is widely reused at different extents within planned or unplanned systems. In many cases, raw or insufficiently treated wastewater is applied. In other cases, wastewater treatment plants are often not functioning or overloaded and thus discharge effluents not suitable for reuse applications. This leads to the existence of health risks and environment impacts and to the prevalence of water-related diseases. In some other situations where conditions for reuse are met, wastewater is then submitted to adequate reclamation systems and treated effluents are being reused for different purposes without presenting any risk for human health. In these cases, reclaimed water is an important alternative resource for sustainable development and food production.

However, only few Mediterranean countries (Cyprus, Israel, Tunisia, Syria) have included water reuse in their water resources planning and have official policies calling for water reuse. A wide variety of approaches to water reuse policy may be found because of the difference in the capacity to implement such policies and depending on the socio-economic, institutional, and technological conditions. Differences between countries occur in their environmental and public health policies. They also occur in existing wastewater collection, treatment and disposal facilities, in human capacities, and in equipment, material, and financial resources (USEPA, 1992).

A large range of situations may also be found with different treatment levels and reuse operations. In most of the cases, conventional technology has been adopted for treating wastewater independently of the type of reuse. The general approach adopted up to now is based on producing an effluent in compliance with water quality discharge requirements.

The main reuse operations in the region are for agricultural irrigation, landscape irrigation, and groundwater recharge. Industrial reuse is very seldom practiced. It should also be noticed that several research and pilot studies have been conducted in the region. The information gained from such studies has allowed the development of treatment and reuse for the specific conditions of the region. The implementation of large-scale reuse schemes has resulted in significant technical and operational experience in reclaimed water reuse. However, up to now, there are no specific Mediterranean guidelines regulating water reuse. The EU-Mediterranean countries have to comply with the European Directive (91/271/EEC), which specifies that "treated wastewater shall be reused whenever appropriate".

2. EXISTING WATER REUSE REGULATIONS

2.1 WHO and California approaches

Different approaches might be adopted for establishing water reuse regulations. The two benchmark standards, the California water reuse standards (1978) and the World Health Organization guidelines (1989), result from different historical processes and do not have the same objectives. They are presented in the following.

2.1.1. California water reuse standards

The first water reuse regulations were established in 1918 by the State of California. At that time, the only application considered was irrigation. In 1933, the first microbial effluent standards for the "irrigation of garden truck produce eaten raw" were set up by the California State Board of Health at a coliform concentration of ≤ 2.2 MPN/100 mL (Ongerth and Jopling, 1977). The coliform concentration was equivalent to that required for drinking water and based on the concept of "zero risk". Since then, standards were continuously revised to address new reclaimed water applications and to take into account advances in wastewater treatment technology and updated knowledge in public health protection (Crook, 1998).

Several investigations, beginning in the late 1960s, helped to develop comprehensive water reuse regulations addressing a broad variety of uses in several states of the U.S.A.. Florida and especially California were leader in this process. In 1978, the California Wastewater Reclamation Criteria were issued by the California Department of Health Services (DHS). They have been recently revised (State of California Title 22 Water Recycling Criteria, 2000). These standards, which apply to the wastewater reclamation, include water quality standards, treatment process requirements, operational and treatment reliability requirements. Water quality criteria and treatment requirements are as follows (Table 3):

1. For agricultural reuse restricted to the irrigation of fodder, fibre, seed crops, orchards* and vineyards*, processed food crops, non food-bearing trees, ornamental nursery stock*, and sod farms* and to the flushing of sanitary sewers, no bacterial limit is set and a secondary treatment is required.

2. For the irrigation of pasture for milking animals, landscape areas - with restricted or controlled access - ornamental nursery stock and sod farms where public access is not restricted; landscape impoundments, for industrial or commercial cooling water where no mist is created, for non structural fire fighting, industrial boiler feed, soil compaction, dust control, for cleaning roads, sidewalks and outdoor areas, the total coliforms content limit is 23/100 mL. The required reclamation is a secondary treatment plus disinfection.

3. For the other applications - irrigation of food crops and open access landscape areas, supply of impoundments; fish hatcheries, toilet and urinal flushing; industrial process water; decorative fountains; commercial laundries and car washes; snow-making; structural fire fighting; industrial or commercial cooling where mist is created -, the bacterial quality criteria is 2.2 TC/100 mL. The treatment required depends on the applications and turbidity values; it ranges from secondary treatment followed by disinfection to secondary treatment followed by coagulation, clarification, filtration and disinfection.

---

* with the restrictions mentioned in Table 3.

Table 3

California water recycling criteria: treatment and quality requirements for nonpotable uses of reclaimed water (State of California Title 22 Water Recycling Criteria (2000)).

Type of use	**Total coliform limits**[a]	**Treatment required**
Irrigation of fodder, fiber, & seed crops, orchards[b] and vineyards[b], processed food crops, nonfood-bearing trees, ornamental nursery stock[c], and sod farms[c]; flushing sanitary sewers	• None required	• Secondary
Irrigation of pasture for milking animals, landscape areas[d], ornamental nursery stock and sod farms where public access is not restricted; landscape impoundments; industrial or commercial cooling water where no mist is created; nonstructural fire fighting; industrial boiler feed; soil compaction; dust control; cleaning roads, sidewalks, and outdoor areas	• ≤23/100 mL • ≤240/100 mL in more than one sample in any 30-day period	• Secondary • Disinfection
Irrigation of food crops[b]; restricted recreational impoundments; fish hatcheries	• ≤2.2/100 mL • ≤23/100 mL in more than one sample in any 30-day period	• Secondary • Disinfection
Irrigation of food crops[e] and open access landscape areas[f]; toilet and urinal flushing; industrial process water; decorative fountains; commercial laundries and car washes; snow-making; structural fire fighting; industrial or commercial cooling where mist is created	• ≤2.2/100 mL • ≤23/100 mL in more than one sample in any 30-day period • 240/100 mL (maximum)	• Secondary • Coagulation[g] • Filtration[h] • Disinfection
Non restricted recreational impoundments	• ≤2.2/100 mL • ≤23/100 mL in more than one sample in any 30-day period • 240/100 mL (maximum)	• Secondary • Coagulation • Clarification[i] • Filtration[h] • Disinfection

[a]Based on running 7-day median.
[b]No contact between reclaimed water and edible portion of crop.
[c]No irrigation for at least 14 days prior to harvesting, sale, or allowing public access.
[d]Cemeteries, freeway landscaping, restricted access golf courses, and other controlled access areas.
[e]Contact between reclaimed water and edible portion of crop; includes edible root crops.
[f]Parks, playgrounds, schoolyards, residential landscaping, unrestricted access golf courses, and other uncontrolled access irrigation areas.
[g]Not required if the turbidity of the influent to the filters is continuously measured, does not exceed 5 NTU for more than 15 minutes and never exceeds 10 NTU, and there is capability to automatically activate chemical addition or divert the wastewater if the filter influent turbidity exceeds 5 NTU for more than 15 minutes.
[h]The turbidity after filtration through filter media cannot exceed 2 nephelometric turbidity units (NTU) within any 24-hour period, 5 NTU more than 5% of the time within a 24-hour period, and 10 NTU at any time. The turbidity after filtration through a membrane process cannot exceed 0.2 NTU more than 5% of the time within any 24-hour period and 0.5 NTU at any time.
[i] Not required if reclaimed water is monitored for enteric viruses, *Giardia*, and *Cryptosporidium*.

The standards are based on a microbiological quality, which is expected to guarantee that infectious risks are reduced to an acceptable level, and on treatment requirements, which determine the reliability of the process in the achievement of this microbiological quality. As a result, different treatment requirements may correspond to the same microbiological quality, depending on the evaluation of the risks related to the respective types of use: the higher the risks, the higher the required reliability.

When direct or indirect human contact is likely to happen, reclaimed water should be essentially free of pathogens, particularly enteroviruses, because very low virus contents can initiate human infection. This microbiological quality is characterised by a total coliform 7-day median value of less than 2.2/100 mL, no more than 23 TC/100 mL in more than one sample in any 30-day period and a maximum value of 240 TC/100 mL in any sample Furthermore, the turbidity should not exceed 2 NTU after filtration on a continuous monitoring base. This criterion has been shown to determine the virus removal capability of the treatment process. It is assumed that treatment processes controlling viruses provide a water free of parasites, particularly *Giardia lamblia* and *Cryptosporidium parvum*.

For all types of uses resulting in a possible direct or indirect human contact, California is promoting stringent water quality standards. However, as coliforms have proved to be unadaquate indicators for those pathogens that are more resistant to disinfection and less readily removed by physical treatments, more reliance is placed on the pre-determined ability of a process to reduce all types of pathogens (Cooper and Olivieri, 1998). Confident that advanced technologies provide a safe water quality (i.e. free of enteric viruses), technologically based requirements to reduce the presence of pathogens by treatment or a combination of treatment and use restrictions were established.

The criticisms addressed to the California's water reuse criteria are that they are too conservative and that they are not based on sound scientific data. California health services have chosen not to use epidemiological studies as a basis for determining water quality standards, mainly because at low exposure epidemiological studies are not sensitive. No risk assessments modelling data were used to establish the pathogen standards (Crook, 2001).

To evaluate the safety of wastewater reclamation and reuse applications, the U.S. EPA's Surface Water Treatment Rule (SWTR) for domestic water supply was used as a point of reference. Acceptable risks for this evaluation were defined as meeting the 10^{-4} infection risk criterion (probability of one infection per 10,000 population in one year) at least 90 and 95% of time, (Asano *et al.*, 1992; Tanaka *et al.*, 1998). The calculation used data from the monitoring of the virus content of unchlorinated secondary effluents from 4 wastewater treatment plants of California.

Table 4

Expectation of the annual risk of infection for the upper 95% confidence limit using Monte Carlo simulation

Treatment	Application	Annual risk of infection
Full treatment (5.2 log removal of enterovirus)	Golf course irrigation	$1.1\ 10^{-7} – 6\ 10^{-6}$
	Food crop irrigation	$3.7\ 10^{-10} – 2.1\ 10^{-8}$
	Recreational impoundment	$1.3\ 10^{-5} – 6.8\ 10^{-4}$
Direct chlorination of secondary effluents (3.9 log removal of enterovirus)	Golf course irrigation	$2.2\ 10^{-6} – 1.2\ 10^{-4}$
	Food crop irrigation	$7.5\ 10^{-9} – 4.1\ 10^{-7}$
	Recreational impoundment	$2.6\ 10^{-4} – 1.3\ 10^{-2}$
Unchlorinated effluents	Golf course irrigation	$1.7\ 10^{-2} – 5.3\ 10^{-1}$

(0 log removal of enterovirus)	Food crop irrigation	$5.9\ 10^{-5} – 3.3\ 10^{-3}$
	Recreational impoundment	$6.2\ 10^{-1} – 1\ 10^{0}$

Adapted from Tanaka *et al*., 1998.

As can be seen in Table 4, all applications of unchlorinated effluents lead to unacceptable risks. Direct chlorination of secondary effluents means annual risks lower or much lower than acceptable, at the exception of recreational impoundments where the risks to the swimmers are higher than acceptable. A full treatment as required by California standards (secondary treatment plus coagulation, flocculation, sedimentation, filtration and disinfection) reduces the risks far below those that are acceptable, except for recreational impoundments where bathing is allowed and the risks are about acceptable. Though some assumptions of this work might be questioned, the results of Tanaka *et al.* (1998) provide some ground to the critics addressed to the California's water reuse criteria, putting that they are too conservative and not based on sound scientific data. For instance, if the full treatment required by these standards allows lowering the risks encountered by swimmers - supposed to drink 100 mL/day - to an acceptable level, as defined by EPA SWTR, is it worth investing for the same high level treatment to irrigate food crops or for other applications where exposure is several order of magnitude lower? The cost of wastewater treatment to comply with such high standards may be unnecessarily prohibitive in many cases. Several experts believe that stringent water quality standards are not justified (Barcelona, 27-28 January 2000 and Rabat, 8-10 October 2001).

2.1.2. WHO water reuse guidelines

In 1973, the World Health Organization (WHO) proposed health criteria and treatment processes for reuse applications ranging all the way from irrigation of crops not intended for human consumption up to potable reuse. Relatively stringent guidelines were recommended for the quality of the effluent to irrigate crops to be consumed raw: a guideline value of 100 coliforms/100 mL was set for unrestricted irrigation. These recommendations were based on the concept of "zero risk". The guidelines made recommendations on treatment: secondary treatment (activated sludge, trickling filtration or waste stabilization ponds (WSP)) followed by chlorination or filtration + chlorination. Implementation of such treatment technologies (except WSP) remained unattainable for most developing countries, and led, in some circumstances, authorities tolerating the indirect reuse of untreated wastewater. Few countries have developed reuse projects in compliance with these guidelines.

WHO water reuse guidelines (1973) recognized that (1) applying drinking water-type standards (2.2 coliforms/100 ml) for water reuse was unrealistic and lacked an epidemiological basis, (2) few if any rivers worldwide used for unrestricted irrigation of vegetables eaten uncooked carry water of such quality, (3) few if any developing countries could meet such standards for water reuse.In 1985, the guidelines were reviewed and the nature of health risks associated with agriculture and aquaculture were revised. The epidemiological evidence on pathogens was reconsidered, updated and the approach of microbiological risk assessment was confirmed (Feachem *et al*., 1983; Shuval *et al*., 1986; Strauss and Blumenthal, 1989).

The epidemiological approach for health risks assessment allowed an evolution of the water reuse guidelines; the goal remaining no actual risk of infection to the exposed population that can be attributed to water reuse. In 1989, WHO issued a new set of microbiological quality guidelines for water use in agriculture and aquaculture (Table 5). Other non potable uses were not considered. The guidelines set ≤ 1000 FC/100mL and ≤ 1 intestinal nematode egg/L for unrestricted irrigation, and only ≤ 1 intestinal nematode egg/L for restricted irrigation. These guidelines aimed at encouraging water reuse in a controlled and sanitary acceptable way.

Table 5

WHO guidelines for the safe use of wastewater in agriculture (WHO, 1989).

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

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

The WHO recommendations take into account the wastewater treatment process, the irrigation system, the exposed group, and the crops to be irrigated. They 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 combining different measures is considered as important element. Other precautions such as wearing protective clothing and increased levels of hygiene, cooking, provision of adequate washing facilities, human exposure control, promotion of hygiene, etc., are also recommended.

WHO guidelines (1989) have allowed a real development of water reuse and enhanced the acceptance of water reuse among decision-makers, engineers, health authorities, and the public in several countries. They have been adopted by a number of developing as well developed countries. They are, however, a matter of controversy, particularly on the FC geometric mean ≤ 1000 /100mL criterion for unrestricted irrigation; they are questioned on the ability of the faecal coliforms limit to protect against viruses and on the nematode eggs limit to protect against protozoan parasites since viruses and protozoa are not easily removed by conventional treatment processes and disinfection (Blumenthal *et al*., 2000). Finally, they are considered as too liberal and not ensuring public safety (Crook and Surampalli, 1996).

Even though there is no documented scientific evidence that they failed to protect public health, WHO guidelines (1989) are currently under revision. Review is based on risk assessment, epidemiological studies supplemented by microbiological investigations and model-based quantitative microbiological risk assessment (QMRA) for selected pathogens (Blumenthal *et al*., 2000). New epidemiological data mainly based on Mexico's investigations are considered as well as QMRA data for low level exposures for areas where enteric disease is not highly. This revision has allowed:

- the validation of bacteriological guidelines for unrestricted irrigation,
- the reinforcement of parasitological standards, and
- the reinforcement of microbial guidelines for restricted reuses, depending on the irrigation method.

2.1.3. Comments

Major differences between the WHO and Californian approaches are illustrated by some examples.

- Concerning wastewater treatment, the WHO guidelines recommend a series of stabilization ponds or an equivalent treatment to meet the microbial water quality requirements for irrigation of food crops eaten raw, when the California criteria stipulate secondary conventional biological wastewater treatment followed by coagulation, filtration and chlorine disinfection.

- The WHO guidelines require the monitoring of intestinal nematodes and faecal coliforms, whereas the California criteria rely on treatment systems and the monitoring of the total coliforms density for assessment of microbiological quality; total coliforms being a more conservative measurement of disinfection effectiveness in reclaimed water compared to faecal coliforms. For most applications, the WHO requirements are less stringent than the California ones: for unrestricted irrigation, the WHO guidelines is ≤ 1000 FC/100 mL compared to the California criteria with ≤ 2.2 TC/100 mL, and for irrigation of pasture and commercially processed and fodder crops only a guideline limit on the presence of nematode eggs is set by WHO when the California guideline requires ≤ 23 TC/100 mL.

- California water reuse criteria are neither based on epidemiological investigations, nor on mathematical risk assessment modeling data, (Crook *et al*., 2001), when the WHO guidelines are based on the epidemiological and technological evidence available concerning health risks associated with wastewater irrigation.

The WHO and the California approaches are then challenged by scientific and management questions and uncertainties which should be addressed in order to establish worldwide standards.

2.2 Existing Mediterranean water reuse regulations

The management of wastewater in the Mediterranean varies from country to country, as do the standards applied, their derivation, and their enforcement. Countries where reuse is developing on a rational basis, within an organized institutional setting, have elaborated and implemented their own regulations and precise standards. In other countries, it is just referred to health standards. Some of the significant differences in the standards are, in part, due to differences in approaches to public health and environmental protection. For example, some countries have taken the approach of minimizing any risk, whereas other ones have adopted a protective approach of reasonably anticipated adverse effects. This has led to significantly different standards (set of physical-chemical and microbiological criteria) between countries (Table 6) and even within a given country such as in Italy or Spain. The differences are also in the general requirements, management practices, operational standards, frequency of monitoring requirements, etc.

A variety of approaches have been taken by different agencies to regulate water quality for water reuse systems. These differences pertain mostly to the existing irrigation practices, local soil conditions, desire to protect public health, choice of irrigation or wastewater treatment technologies and needs to keep costs down.

At this time, no regulation of water reuse exists at a European level. The only reference to it is the article 12 of the European Wastewater Directive (91/271/EEC, EU, 1991) stating: “Treated wastewater shall be reused whenever appropriate”.

Concerning the national regulations, three groups of countries may be distinguished:

1. Those with no guidelines or standards: Albania, Algeria, Bosnia and Herzegovina, Croatia, Egypt, Greece, Lebanon, Libya, Malta, Monaco, Morocco, Slovenia, Syria, and Turkey.
2. Those which have adopted a set of public health water quality criteria based on the WHO guidelines (1989), that means that reuse is practiced with a low level of risk: France, Tunisia, Spain (Andalusia, Balearic Islands, …), Italy (Sicily).
3. Those which elaborated regulations close to the California’s Title 22 effluent reuse standards (1978) with minimum risk levels: Cyprus, Italy, Israel.

Standards issued in Cyprus, France, Israel, Italy, Spain and Tunisia are provided in the annexes of this report.

Table 6

Comparison of criteria and maximum limits for raw and cooked crops irrigated with reclaimed water set up by WHO, US.EPA, the State of California and some Mediterranean countries (adapted from Angelakis *et al.*, 2001).

Parameters	California[1] T-22 (1978)	US.EPA (1992)		WHO (1989)		Cyprus (1997)		France (1991)		Israel (1999)		Italy (1977)		Spain (1995)		Tunisia (1989)
Type of regulation	Law	Guidelines		Guidelines		Provis. std.		Guidelines		Guidelines		Law		Guidelines		Law
Type of irrigation	Unrestrict.	Unrestr.	Restric.	Unrestr.	Restrict.	Unrestr.	Restrict.	Unrestr.	Restrict.	Unrestr.	Restrict.	Unrestr.	Restrict.	Unrestr.	Restrict.	Restrict.
Minimum treatment required	Advanced treatment	Advanced treatment		Mechanized treatment or stabilisation ponds[2]		Mechanized treatment or stabilisation ponds		Mechanized treatment or stabilisation ponds		Secondary treatment		Secondary treatment		Secondary treatment		Secondary treatment
Main treatment processes	Oxid., Clarif., Filt., Disinf.	Sec., Filt., Disinf.	Sec., Disinf.	Stabil. ponds or equival.		Sec., Ter., Disinf.	Sec., stor. or Stabil. ponds	Stabil. ponds >10 d or equiv.	Stabil. ponds >30 d or equiv.	Sand filtration or equiv. + Disinf.	Quality and multiple barriers requirements (cf Annexes)			Sec., filt. or equiv.+ disinf.	Sec., Disinf.	Secondary treatment
Total BOD_5 (mg/L)	-	10	30	-	-	10-15	20-	-	-	20		-	-	-	-	30
Dissolved BOD_5 (mg/L)	-	-	-	-	-	-	-	-	-			-	-	-	-	-
COD (mg/L)	-	-	-	-	-	-	-	-	-	-		-	-	-	-	90
SS (mg/L)		5[4]	30	-	-	10-15	30-	-	-	30		-	-	-	-	30
Turbidity (NTU)	2	2	-	-	-	-	-	-	-	-		-	-	-	-	-
DO (mg/L)	Present	-	-	-	-	-	-	-	-	0.5		-	-	-	-	-
TC (MPN/100 mL)	2.2 (50%)[5]	-	-	-	-	-	-	-	-			2	20	<10	<200	-
FC (MPN/100 mL)	-	0[6]	≤200	1000	-	5-100	200-1000	1000	-	10		-	-	“	“	-
Helminths (eggs/100 mL)[7]	-	-	-	≤1	≤1	0	0	≤1	≤1	-		-	-	<1	<1	<1
Resid. avail. Cl_2 (mg/L)	Present	1.0	1	-	-	-	-	-	-	1.0		-	-	-	-	-
pH	-	6-9	6-9	-	-	-	-	-	-	-		-	-	-	-	6.5-8.5
EC (dS/m)	-	-	-	-	-	-	-	-	-	-		-	-	-	-	7
SAR	-	-	-	-	-	-	-	-	-	-		SAR<15[8]	SAR<15[8]	-	-	
Trace elements	-	-	-	-	-	Yes	Yes	-	-	-		Yes	-	-	-	Yes

[1] Spray irrigation;
[2] Stabilization ponds in series with proper retention time;
[4] If SS are used instead of turbidity;
[5] Not to exceed 23/100 cm^3 in a single monthly test;
[6] Not to exceed 14/100 cm^3 at all times;
[7] Nematodes such as *Ascaris*, *Trichuris* and hookworms.
[8] $SAR = Na/[(Ca+Mg)/2]^{1/2}$

3. DRAFT PROPOSAL FOR MEDITERRANEAN WATER REUSE GUIDELINES TO SUPPORT THE IMPLEMENTATION OF THE STRATEGIC ACTION PROGRAMME

3.1 Introduction

Previous meetings in Barcelona (27-28 January, 2000) and Rabat (8-10 October, 2001) have shown that establishing Mediterranean guidelines for urban wastewater reuse is not an easy task. Unfortunately, in this small part of the World, existing guidelines and regulations, that should have been the basis of a well shared consensus, result from at least two very different approaches, leading to large discrepancies between regulations and guidelines in the region.

3.2 Principles

It was found the absence of comprehensive international guidelines and a lack of scientific data and knowledge. The rationale behind the guidelines is not always scientifically based : in the conservative approaches, the pathogen standards are not risk-based concentration limits for individual pathogens but are technologically based requirements aimed at reducing the presence of pathogens and potential exposures to them by treatment or a combination of treatment and use restrictions. Existing water reuse criteria are not based on either comprehensive epidemiological studies or risk assessment modelling data. These inconsistencies in the existing guidelines or standards may have led to too conservative or too liberal standards.

There are few studies related to environmental microbiological health risks. Literature data on epidemiological studies are rather limited and mainly evoked for microbiological contamination of bathing or drinking waters. Very few epidemiological studies were conducted on non-potable reuse: Jerusalem and Mexico studies are exceptional.

To evaluate the safety of wastewater reclamation and reuse applications, potable water and bathing standards were used as benchmarks. Should bathing or drinking water quality criteria be adopted as reference for unrestricted irrigation and urban uses (crops eaten raw, golf courses, public parks, sprinkling of orchards,...)? Not all non potable uses, if any, require drinking water quality, nor all bathing water quality. However, infection risks considered as acceptable when related to bathing or drinking potable water can serve as references for reuse guidelines.

To be useful and efficiently contribute to the improvement of human health and the alleviation of water resource shortages, guidelines must take the local conditions into account. If, taken as a whole, countries of the North bank are developed, industrialised, more and more equipped with wastewater treatment plants complying with the EU Directive on wastewater disposal (EU, 1991), the economy of the South bank - some countries excepted - lags far behind, with poor wastewater management policy, virtually no wastewater treatment plant and endemic diseases linked to the weaknesses of public hygiene. Farmers of both banks are not always used to pay for water; when they do, the fees cover only a small part of the costs and farmers are more than reluctant to pay more. Therefore, the proposed guidelines should provide an efficient protection to the populations of both banks, including the tourists of one bank travelling to the other bank and the consumers of exported vegetables and fruits, but without requiring unaffordable treatments. Too stringent regulations can not be enforced and are eventually ignored.

These views are shared by several experts, particularly by these who have recently assessed the WHO guidelines (Blumenthal *et al*., 2000). Their work was based on risk assessment using epidemiological studies supplemented by microbiological investigations and model based QMRA. A large use of their results was made adding some QMRA data and taking the acceptable annual risks related to bathing and potable water drinking as benchmarks.

3.3 Foremost health risks

Potential health risks offered by wastewater reuse are related to the microbial and chemical composition of the reclaimed water:

- Possible transmission of infectious disease by waterborne pathogens is the most common concern associated with non potable reuse. The majority of documented disease outbreaks have been related to contamination by bacteria and parasites (Crook, 1998).
- Chemical constituents are a major health concern for indirect potable reuse but not for urban uses of reclaimed water; they also may affect agricultural and industrial applications. Toxic chemicals may present adverse health effects when adsorbed or inhaled or where there is contact with water. Heavy metals accumulate in the environment and may be toxic to plants; cadmium, copper, molybdenum, nickel and zinc can affect animals and humans. Heavy metal contents in secondary treated effluents are generally within acceptable levels for most non potable reuses. Attention must be paid to the effect of organics and heavy metals in reclaimed water used for crop irrigation when industrial effluents are a significant fraction of wastewater. The main impact of nutrients is the potential build up of nitrates in aquifers.

Indirect potable reuse is likely to be on the agenda of some Mediterranean countries. This issue can be joined with aquifer recharge of potable aquifers. Specific guidelines will be recommended for this application.

Non potable applications are and will long remain the large majority of reclaimed water reuse projects in the Mediterranean. Therefore, the proposed health guidelines will focus on the microbiological criteria. Providing guidelines on toxic elements is beyond the scope of this work. Guidelines values for the chemical quality of irrigation water are available in Ayers and Westcot (1985) and Chang *et al*., (1998). The impact of eventual stable toxic organic constituents on crops should be considered on a case by case basis when harmful discharge of industrial effluents in public sewer is suspected.

3.4 Criteria

Three water quality criteria are proposed, nematode eggs, faecal coliforms or *Escherichia coli* and suspended solids (SS). Treatments likely to achieve the required water quality are also suggested (Table 7).

Due to uneven levels of development, health risks related to waterborne parasites remain an important concern in several Mediterranean countries. Therefore, nematode egg limits still have to be included in Mediterranean guidelines.

Faecal coliforms or *E. coli* are, together with total coliforms, the indicator bacteria most commonly used in water quality standards, particularly for water reuse, bathing water and drinking water. Faecal coliforms is a widely used indicator of treatment performances.

Faecal coliforms contents are currently monitored in many Mediterranean countries. Faecal coliforms content is the bacterial criterion of the WHO guidelines.

SS (instead of NTU): turbidity is a criterion used in several reuse standards, particularly in conservative regulations; for instance, California standards state that where direct or indirect contact with reclaimed water is likely, the turbidity shall not exceed a daily average of 2 NTU (nephelometric turbidity units). Turbidity standards are linked to the virus removal capability of tertiary treatment processes. Though turbidity measurement offers the advantage of allowing a continuous monitoring and thus would be preferred, SS control would be considered a minimum requirement in the Mediterranean. It is a widespread measurement. It allows establishing links between reuse guidelines and the EU Directive on wastewater disposal (EU, 1991) meaning that secondary treatment is required.

3.5 Categories of reuse applications and water quality

Only five categories of reclaimed water uses are considered, in order to facilitate the implementation of the guidelines. Water reuse cost-effectiveness was also taken into account in the sense that a reclaimed water supply network must serve as many reuse applications as possible in the same area. The categories are the following (Table 7):

- ***Category I : urban and residential reuses, landscape and recreational impoundments***
  a) Residential reuse: private garden watering, toilet flushing, vehicle washing.
  b) Urban reuse: irrigation of areas with free admittance (greenbelts, parks, golf courses, sport fields), street cleaning, fire-fighting, fountains, and other recreational places.
  c) Landscape and recreational impoundments: ponds, water bodies and streams for recreational purposes, where incidental contact is allowed (bathing is excluded).

- ***Category II : unrestricted irrigation, landscape impoundments (contact with water not allowed), and industrial reuses***
  a) Irrigation of vegetables (surface or spray irrigated), green fodder and pasture for direct grazing, sprinkler-irrigated fruit trees.
  b) Landscape impoundments: ponds, water bodies and ornamental streams, where public contact with water is not allowed.
  c) Industrial reuse (except for food, beverage and pharmaceutical industry).

- ***Category III : restricted agricultural irrigation***
  a) Irrigation of cereals and oleaginous seeds, fibre, & seed crops, dry fodder, green fodder without direct grazing, crops for canning industry, industrial crops, fruit trees (except sprinkler-irrigated), plant nurseries, ornamental nurseries.
  b) Landscape irrigation: wooden areas, green areas with no access to the public.

- ***Category IV : irrigation with reclaimed water application systems or methods providing a high degree of protection against contamination***
  a) Irrigation of vegetables (except tuber, roots, etc.) with surface and subsurface trickle systems (except micro-sprinklers) and/or using practices (such as plastic mulching, support, etc.) guaranteeing absence of contact between reclaimed water and edible part of vegetables.
  b) Irrigation of crops in category III with trickle irrigation systems (such as drip, bubbler, micro-sprinkler or subsurface).
  c) Irrigation with surface trickle systems of greenbelts and green areas with no access to the public.

d) Irrigation of parks, golf courses, sport fields with subsurface irrigation systems.

- ***Category V: groundwater recharge***
  a) Surface spreading into non potable aquifers.
  b) Surface spreading into potable aquifers.
  c) Direct injection.

Categories I to IV are non potable water reuses, for which water quality criteria are proposed. The quality of reclaimed water has often been reported to evolve during conveyance and storage; it may be degraded or improved, depending on the initial water quality, the residence times, the conveyance and storage systems characteristics and the environment. This evolution raises the question of where the reclaimed water quality should be monitored. As no specific measures, such as chlorination, are recommended to preserve the degradation of the microbial quality along the supply and storage systems, the microbial quality should be monitored at the outlet of the treatment system (treatment plant + storage, if this storage is included in the treatment process) and at the point of use in order to evaluate eventual improvements or degradation of the water quality.

Wastewater treatments expected to meet the criteria were defined for each water category. In the case of agricultural reuse, the capacity of reclaimed water application systems or methods, such as surface trickle or subsurface irrigation, to provide a high degree of protection against contamination (and to use water more efficiently) was taken into account.

Groundwater recharge guidelines depend on whether the aquifer water is potable or not, the intended use of non potable recharged aquifer, the technique of recharge and the hydrogeological context (cf § 3.6.5).

3.6 Guidelines

3.6.1. Water Category I

A unique water category is proposed for residential, urban and landscape reuses and for recreational impoundments and stream augmentation. The reasons are comparable levels of risk and, also, to facilitate the implementation of dual water supply systems in Mediterranean towns. Developing urban and landscape reuses, a major challenge for the next years, should allow to dramatically increase the rate of wastewater that is reused. To be cost-effective, a reclaimed water supply network must serve as many non potable applications as possible in the same area.

The non potable reclaimed water applications which entail the highest health risks are listed in this section. Therefore, water category I should comply with the most stringent criteria.

Bacterial criterion

In the WHO guidelines, irrigation of sports fields and public parks has been classified in category A irrigation, together with irrigation of vegetables to be eaten raw; the recommended bacterial guideline being a geometric mean of 1000 FC/100 mL (WHO, 1989). A more stringent guideline (≤ 200 FC/100 mL) was recommended for public lawns with which the public may come in direct contact. Actually, the Scientific Group which established these guidelines considered that where the public has direct access to lawns and parks, the potential risk may be higher than that associated with irrigation of vegetables eaten raw.

Therefore, a guideline of 200 FC/100 mL was adopted, as recommended by Durand *et al*. (1986), who performed an epidemiological investigation on health effects of landscape irrigation with reclaimed water at Colorado Springs. This guideline was not questioned in Blumenthal *et al*. (2000).

Because bathing is associated with the inevitable absorption of an important amount of water, bathing water regulations and guidelines deserve a special consideration. The mean oral absorbed bathing water is hypothesised 100 mL per day (Tanaka *et al*., 1998; López-Pila and Szewzyk, 2000), which represents the highest daily water ingestion after drinking consumption (1 to 2 L/d). Bathing water quality has been subjected to regulations or guidelines in many countries. The European Directive 76/160/EEC on bathing water quality set guideline maximum contents of 500 TC/100 mL, 100 FC/100 mL and 100 faecal streptococci (FS)/100 mL, the mandatory limit values being 10,000 TC/100 mL and 2,000 FC/100 mL (EU, 1976). As acknowledged by the European Commission, the implementation of the Directive has led to a significant and constant improvement of bathing water quality (COM, 2000). However, due to a lack of epidemiological investigations, very little is known about the improvement of swimmers health. Mariño *et al*. (1995) found skin infections, but not enteric and respiratory attacks, to be associated to seawater pathogen levels, which could be related to faecal contamination. In a study by Medema *et al*. (1995), triathletes having swum in 170 *E. coli* /100 mL and 13 FS/100 mL water reported illness symptoms during the week after the event which were higher, but not significantly higher, than those reported by run-bike runners. The European Commission has considered a revision of the Bathing Water Directive. The microbiological standards of its final proposal will reflect the recommendations of the new guidelines for recreational waters prepared by the WHO. The WHO recommendations were revised on the basis of a review of the available scientific literature and of an epidemiological study carried out by Kay *et al*. (1994). This work has been criticised by Mugglestone *et al*. (2001) for resulting in an overestimation of the health risks undergone by swimmers. The limit values envisaged by the Commission are 50 Enterococci/100 mL in coastal waters and 400 *E. coli*/100 mL in freshwater (COM, 2000).

A 200 FC/100 mL limit value (as a geometric mean) has been recommended by US EPA (1976) for recreational (bathing) waters. Though an investigation of US EPA has calculated for such a content an added seasonal gastro-intestinal illness rate of 8 per 1000 swimmers in freshwater and 19 per 1000 swimmers in seawater (such figures can also be derived from López-Pila and Szewzyk, 2000), this standard is currently enforced in many states of the USA (USEPA, 1998). In Florida, the standard is also 200 FC/100 mL, but no more than 10% samples may exceed 400 FC/100 mL and a content ≥ 800 FC/100 mL must not be reached on any one day.

In 1986, US EPA recommendations were revised:

- -in freshwater, bacterial density should not exceed one or the other of the following: 126 *E. coli* per 100 mL or 33 Enterococci per 100 mL.
- in seawater, the geometric mean of Enterococci content should not exceed 35 per 100 mL (USEPA, 1986).

In California, standards vary between 20 and 2000 FC/100 mL; limits were also set for Enterococci, in the range of 12 to 50 CFU/100 mL. New Zealand has adopted a limit value of 126 *E. coli* /100 ML in freshwater standard and a seasonal median of 35 Enterococci/100 mL in seawater.

Though a general trend at strengthening bathing water guidelines can be noticed, contents of 100-200 FC or *E. coli* per 100 mL seem to be a widely accepted standard for freshwaters. These regulations are reported to be related to a seasonal gastro-intestinal illness rate of 1 to 2%, considered as an acceptable risk. That this risk seems to be accepted world-wide is somewhat surprising but can be explained by the high annual risk of gastro-intestinal disease in the global population.

Drinking water standards constitute another key reference. Several authors have assessed the safety of reuse applications using the US EPA Surface Water Treatment Rule for domestic water supply, according to which an annual risk equal or less than 10^{-4} per person from enteric virus infection was considered as acceptable (Tanaka *et al*., 1998, Blumenthal *et al*., 2000). This benchmark has been reported as being too stringent and a guideline one order of magnitude higher being appropriated (Haas, 1996).

While disputed by Crook (1998), the argument that the microbial standard for bathing water can be valid for non potable reclaimed water may be indirectly used. The applications itemized in Category I entail limited or occasional contacts with the reclaimed water (bathing in recreational impoundments has been excluded) and possible ingestion of no more than 1 mL of reclaimed water in one exposure. Following the hyphothesis of López-Pila and Szewzyk, (2000) and assuming a geometric mean content of 200 FC or *E. coli* /100 mL and no reduction of the pathogens in the environment, a rough risk assessment results in an annual infection risk evaluated between 3.2 10^{-3} and 3.2 10^{-4} for 100 and 10 exposure frequencies respectively. These figures are one order of magnitude higher or of the order of magnitude of the acceptable annual risk for potable water drinking. They are one or two orders of magnitude less than the risk considered as acceptable when bathing. Despite the actual large uncertainties and approximations attached to epidemiological investigations and QMRA, it is concluded that the 200 FC or *E. coli* /100 mL guideline limit offers an appropriate protection to the users and the public.

It is proposed to include toilet flushing in this category of applications, while some countries have adopted much more conservative standards or guidelines for this application. It should be noticed that the criterion which is enforced in Japan, the country where this application is the most developed, is TC content ≤ 1000 CFU/100 mL (Ogoshi *et al*., 2001), which is considered close to *E. coli*. ≤ 200/100 mL.

Nematode egg criterion

Most of reclaimed water uses listed in Category I imply incidental direct contact and possible absorption of reclaimed water. Therefore, the strictest Nematode egg criterion is recommended. Investigations reviewed by Blumenthal *et al.* (2000) showed that a guideline limit of 0.1 egg/L is required for efficient protection of exposed populations. Detecting such low nematode egg content requires sampling a volume of 20 to 50 L according to the turbidity, an on site minimum sedimentation time of 8 hours, and a careful removal and discard of the supernatant. The pellet (90 to 95% of the initial volume) is then recovered and transported to the laboratory for centrifugation and analysis according to either OMS (1989) or EPA (1992) procedures (Schwarzbrod, 2002). However few investigations, if any, have been carried out on the treatments allowing to reach ≤ 0.1 nematode egg /L at a reasonable cost. Therefore, this criterion should be considered as a medium term objective and provisionally replaced by ≤ 1 nematode egg /L.

SS criterion

Whatever the process, a low SS content is required for disinfection effectiveness. Therefore, a guideline of 10 mg/L is proposed, that will imply filtration prior to disinfection in most reuse projects.

Minimum treatment recommended

Though the 200 FC/100 mL guideline does not greatly differ from the 1000 FC/100 mL standard applying to Category II in terms of bacterial water quality, it implies an important difference in the treatments required. Extensive treatments, such as lagoons, stabilisation reservoirs and infiltration percolation, aimed at polishing secondary effluents, often cannot guarantee that the 200 FC/100 mL guideline is reliably met. This limitation is linked to the processes, their implementation and also to recontamination in open storage and the environment. Therefore, more conventional disinfection treatments and more secured storage have to be used, which means more costly water reuse projects (Xu and Brissaud, 2002).

Treatments recommended to reach 200 FC/100 mL should allow meeting 0.1 nematode egg/L guideline.

3.6.2. Water category II

The applications listed in Category II do not imply direct contact of humans with reclaimed water. However, the irrigation of vegetables, including those likely to be eaten raw, and pasture for direct grazing, aspersion of fruit trees are applications that require high quality water. It is the unrestricted irrigation category, which has been the subject of so intense controversies among the experts. Vegetables to be eaten cooked, such as potatoes, leeks, beans, etc. and not exclusively grown for the canning industry, are included in the same category as vegetables to be eaten raw, for they are often grown in the same fields, irrigated with the same water. The same quality criteria are proposed for landscape impoundments and water bodies where public contact with water is not allowed because, though forbidden, direct contact of people, mainly young children, with water may occur.

Industrial reuse : The water quality required for industrial purposes is site-specific and depends on the particular use. As the use of reclaimed water for cooling is frequent and presents potential hazards from aerosols and windblown spray, it is proposed to apply unrestricted irrigation criteria as a minimum quality requirement to industrial reuses.

Bacterial criterion

The most recent investigations which can be related to the validity of the WHO guideline limit of 1000 FC/100 mL have been reviewed by Blumenthal *et al*. (2000). The results of epidemiological studies performed in Mexico suggest that the risk of enteric infection due to the consumption of vegetables is significant but low when the guideline limit is exceeded by a factor 10 in the irrigation water. Tests performed in Portugal showed that:

- lettuces sprinkler irrigated with low quality secondary effluents were initially highly contaminated but fell within the quality recommended by the International Commission on Microbiological Specifications for Food (ICMSF) 5 days after the irrigation ceased (Vaz da Costa-Vargas *et al*., 1991);
- the microbiological quality of crops irrigated with water just exceeding the WHO guideline complied with the ICMSF standard.

In dry weather, the microbiological quality of radish and lettuce drip and furrow irrigated with water slightly exceeding the WHO guideline was well below the ICMSF standard and of better quality than that of locally sold lettuce; however rainy weather deteriorated the microbiological quality of lettuce (Bastos and Mara, 1995). Shuval *et al*. (1997) found that the annual risk to be contaminated from eating lettuce irrigated with reclaimed water meeting the WHO guideline ranged from 10^{-5} to 10^{-7} for hepatitis A, from 10^{-5} to 10^{-6} for rotavirus and was about 10^{-6} for cholera. Asano *et al*. (1992) calculated an annual risk associated with the consumption of spray irrigated food crops between 10^{-6} and 10^{-9} for a 1 virus unit/100 L and between 10^{-4} and 10^{-7} for a 100 times higher virus content; however, the assumption that the irrigation is stopped two weeks before harvesting is not always realistic. Despite uneven knowledge on the relationships between enteric viruses and faecal coliforms or *E. coli*, Blumenthal *et al.* (2000) concluded that these data comfort the WHO guideline limit of 1000 FC/100 mL as being likely to produce an annual risk of viral infection inferior to 10^{-4}.

Assuming an amount of ingested water of 1 mL and an exposure frequency of 10 days, the annual risk of rotavirus infection resulting of contacts with 1000 *E. coli*/100 mL reclaimed water of landscape impoundments where public contact with wastewater is not allowed is estimated to be < 2.10^{-4}. The daily risk when falling into such reclaimed water and swallowing 100 mL is estimated around 5.10^{-3}.

Nematode egg criterion

Blumenthal *et al*. (2000) inferred from experimental studies in North-east Brazil and Leeds (Ayres *et al*., 1992) and epidemiological studies in central Mexico, that it would be wise to adopt a guideline limit of ≤ 0.1 egg/L. This guideline will allow protecting vegetable consumers, particularly when climatic conditions favour the survival of helminth eggs, and farm workers.

SS criterion

A SS guideline limit of 20 mg /L (150 mg/L for stabilisation ponds) is proposed in order to ensure that the microbial limits are reliably met when conventional treatments are used.

Minimum treatment recommended

Secondary treatment can be performed in conventional or extensive low technology facilities. Advanced primary treatment may achieve sufficient performances. The limit of 1000 FC/100 mL allows using extensive technologies, such as maturation ponds, reservoirs and infiltration percolation, to polish wastewater in order to reach the microbial guidelines. The possibility of using low technology and O&M cost techniques is regarded as a key factor of the development of planned water reuse in many Mediterranean countries. As mentioned in the recommendations of Blumenthal *et al.* (2000), a special attention should be paid to the design and operation of reservoirs, stabilisation and maturation ponds, as their performances are highly depending of the climate and the feeding/withdrawal schedule. Conventional disinfection techniques might be preferred in densely populated areas.

3.6.3. Water category III

The applications listed in category III (restricted irrigation) exclude direct contact of humans and animals with reclaimed water (at the exception of incidental contacts with workers). Crops cultivated for the canning industry will be disinfected in the canning process. No direct grazing of green fodder will be allowed. Other crops, cereals, fibre, industrials, seeds, dry fodder,… are harvested a long time after the irrigation has ceased. Therefore health related risks are considerably reduced.

Bacterial criterion

It is proposed not to include any bacterial limit for restricted irrigation. Essential eventual health risks are not related to crop consumption but to workers and neighbours contamination in case of sprinkler irrigation. Therefore, in case of aspersion, setback distances between irrigation sites and residential areas, roadways, sports fields, … must be established. This measure is preferred to setting a bacterial limit of 10^5 FC/100 mL as suggested by Blumenthal *et al*. (2000), though such a quality would be reached after the minimum treatment required to meet the SS guideline limit. Including a distinction between sprinkler irrigation and flood and furrow irrigation, with a limit of 10^3 FC/100 mL for the latter does not look relevant in Mediterranean countries. However, where frequent contact of children or workers with wastewater is observed and cannot be avoided, such a limit should be set and enforced; thus, setback distances would not be relevant, as shown by the review of Blumenthal *et al*., (2000).

Nursery plants should not be irrigated with water category III for at least two weeks before being sold.

Nematode egg criterion

As for the bacterial criterion, no sufficient reason is found to shift from the limit of 1 nematode egg /L to a more stringent guideline, whatever the irrigation technique (sprinkler, furrow and flood irrigation). However, in countries where frequent contact of children and workers with wastewater is observed and can not be avoided, the limit of 0.1 egg/L would be recommended when technologies allowing to reach this limit will be available.

SS criterion

The guideline limit of 35 mg SS/L (150 mg/L for stabilisation ponds) is proposed so that the wastewater has to go through a secondary, or an advanced primary treatment, before being reused.

Minimum treatment recommended

As mentioned above, a secondary treatment, or an advanced primary treatment is required, followed by a few days storage, in order to meet the nematode egg limit. Oxidation ponds or a secondary treatment followed by maturation ponds may also be used to reach the same figures.

3.6.4. Water category IV

A water category IV is proposed when the combination of the irrigation technique and the agricultural practice results in very low microbiological health risks. The applications include:

- irrigation and cultivation practices which guarantee the absence of contact of vegetables and fruits with wastewater and the absence of aerosols and run off ;
- irrigation with techniques able to prevent aerosols and run off of crops listed in category III and of green areas where the public has no access;
- irrigation of green areas open to the public and sports fields which guarantee the absence of contact of the public with the irrigation water.

Microbial criteria

Given the very low level of health risks related to the applications listed in category IV, none microbial guideline is set.

SS criterion and treatment recommended

No SS guideline is proposed. However, trickle irrigation techniques (drip, bubbler, micro-sprinkler and subsurface) require a treatment of wastewater in order to avoid the clogging of the distribution network and the emitters. A primary sedimentation is highly recommended as a minimum; primary effluents should go through a filtration process appropriate to the irrigation technology which has been selected.

3.6.5. Category V: groundwater recharge

Aquifers constitute natural reservoirs, replenished during rainy periods, where a big quantity of water is stored and can be extracted to meet the dry period needs. However, over the years, aquifers have been overexploited, leading to severe depletion and salt water encroachment in coastal aquifers. In many places, aquifer water supply is no more sustainable. On the other hand, reclaimed water is available all the year long. In rainy season, conventional water sources meet the demand and reusing water would be unnecessary and costly. Then, storing reclaimed water in aquifers when water demand is low allows getting provision of water that will be available to meet dry season needs. Artificial recharge of aquifers with reclaimed water is also used to control sea water intrusion in coastal areas.

When better sources are not available, groundwater recovered from aquifers recharged with reclaimed water can be an option for potable supply. This practice, even after a series of treatments have brought reclaimed water quality up to the most stringent potable water standards, might not be easily accepted by the public. Injecting this water then recovering it a few months later, blended with natural groundwater, is more likely to be accepted by consumers. The aquifer serves as a storage and, also, as a psychological and aesthetic facilitator.

Aquifer recharge is direct or indirect. Direct recharge means that the recharge water is introduced directly in the aquifer through injection wells. The injected water is treated so as to avoid clogging of the aquifer around the injection wells. Indirect recharge is feasible only for unconfined aquifers; the recharge water is spread on the land - over-irrigation - or in infiltration basins and infiltrates through the vadose zone down to the water table. The unsaturated layer behaves as a filter and a natural reactor, providing an additional treatment and allowing the percolating water quality to greatly improve.

A major issue is the health risks encountered when using the water withdrawn from aquifers recharged with reclaimed water. Contaminants of concern are micro-organisms, nutrients, heavy metals, trace organic pollutants, pharmaceutical and endocrine disrupters. Related risks are depending on the use of the recovered water.

Recharge for indirect potable reuse

Artificial recharge for indirect potable reuse is an attractive option that has been considered for years and is implemented in the United States (West Basin and Orange County in California, Mesa and Tucson in Arizona, etc.). The recharge should not degrade the quality of the groundwater nor impose any additional treatment after pumping. Most existing regulations do not rely on the capability of the aquifer to remove pollutants to meet the water quality required within the aquifer. Therefore, the recharge water reaching the saturated zone of the aquifer should have previously acquired the quality admitted for drinking water.

If the recharge is direct, then the injected water should be potable, abiding, as a minimum requirement, by the regulations enforced in the country or by the WHO Guidelines for Drinking Water Quality. Moreover, the injected water should also be treated in order to prevent clogging around the injection wells, long term health risks linked to mineral and organic trace elements and the degradation of water quality in the aquifer. The capacity of the aquifer to remove pollutants provides an additional barrier protecting the abstracted water quality.

Setting requirements for indirect recharge is not an easy task. The quality of infiltrated water may be dramatically improved when percolating through the vadose zone, thanks to retention and oxidation processes. These processes affect organic matter, nutrients, micro-organisms, heavy metals and trace organic pollutants. However, though much has been learned on these processes during the past years (Bouwer, 1996, Drewes and Jekel, 1996), on paper forecasting of the efficiency of the treatment provided by infiltration through a vadose zone and a lateral transfer in the saturated zone is hardly feasible. Performances depend on a number of factors: depth of the unsaturated zone, physical and mineralogical characteristics of the soil layers, soil heterogeneity, hydraulic load, infiltration schedule, infiltrated water quality. Therefore, when transfer through the unsaturated zone is part of the treatment to bring injected water up to potable water quality, a case by case approach is highly recommended. For each project, pollutant removal tests should be performed, at the laboratory and on site. Every pollutant of concern should be considered. The example of the Dan Project - Israel shows that submitting secondary effluents to a Soil Aquifer Treatment (SAT) system in a dune sand aquifer can result in the production of a nearly potable water (Sack *et al*., 2001). However recharging potable water aquifer with secondary effluents through SAT would not be recommended; further treated water including microbiological decontamination is suitable to reliably obtain potable quality in the aquifer.

Physical characteristics of the soil layers housing the unsaturated zone are a key feasibility factor of indirect recharge. Low permeability limits the infiltration rate and the oxidation of residual organic pollution while very high permeability results in high infiltration velocities and reduced elimination of most chemical and microbiological pollutants. Karsts are a typical example of high permeability medium; the recharge through karstic layers requires a previous treatment that puts the water up to potable quality.

Recharge of non potable aquifers

The quality of the water extracted from the aquifer should meet the most stringent standards related to the intended water applications : irrigation, urban and industrial uses. Health related standards are those applying to wastewater reuse; micro-organisms are the main concern. Limits can also be set for other parameters such as organic matter and heavy metal contents – when irrigation is considered. Trace organic elements are not likely to present major harmful impact. As mentioned for the case of potable aquifer recharge, it would not be recommended to rely on the saturated zone of aquifers for the improvement of the recharged water quality, even if there is no doubt that filtration effects do exist. The saturated zone should only be considered as an additional barrier.

Indirect recharge requires a less treated injectant and is less easy to implement. SAT is an appropriate treatment to meet the required water quality, provided it is properly designed and managed. Prediction of the quality of the percolating water when it reaches the saturated zone is generally uneasy. The main reason is the high heterogeneity of soil layers. Therefore, a detailed investigation of the hydraulic characteristics of the soil layers below the infiltration site is of the utmost usefulness. On site performance tests are necessary. Dune sand layers, often homogeneous, are an exception. When highly permeable or heterogeneous on-site soils are not able to provide the required treatment, infiltration percolation through calibrated sand beds filling pits excavated at the soil surface can be used as a treatment before infiltration through on site soil layers (Brissaud *et al*., 1999).

The quality required of the reclaimed water applied in infiltration facilities should depend on the site, the hydraulic load, the infiltration schedule and the quality to be reached in the aquifer. A secondary treatment or equivalent (such as advanced primary treatment) is a minimum. Each project must be tailored according to the local context and the water quality to be reached.

3.7 Management requirements

Management requirements are meant to public health preservation. They focus on the operational practices of both the reclaimed water producer and the reclaimed water user. Since complete elimination of pathogens is not possible, multiple barriers between pathogens and humans that may be exposed to the reclaimed water are required to minimizing public health risk. Barriers such as detention time in storage systems, selected irrigation systems, setback distances from the application site, entry restrictions, warning signs, avoiding or preventing cross-connections with potable water distribution systems/backflow prevention, and coded distribution systems, would minimize the direct contact of potentially contaminated water.

3.7.1. Water quality monitoring requirements

Reclaimed water quality monitoring establishes the performance of treatment operations. Water quality indicators should be monitored analysing 24-hour composite or grab samples. Sampling frequency for the different water quality criteria is specified in Table 8 for a medium size project (20,000 – 80,000 p.e.). The sampling frequency should be decided taking into account health risks related to the reclaimed water applications and the size of the project, in other words the population exposed. Results are checked against the numerical limits set for different reuse applications. In addition, periodical monitoring of the soil should also be established for irrigation and agricultural purposes.

Two control points should be considered: (i) the point where reclaimed water leaves the reclamation system (treatment plant plus storage, if the storage is included in the treatment process) and (ii) the final point of use where the only bacteriological criterion will be considered. An approved laboratory should analyse the samples and the results submitted to the regulatory agency.

When a potable unconfined aquifer lays below agricultural sites irrigated with reclaimed water, a groundwater monitoring program should be conducted. The monitoring based on a set of wells and piezometers has to be defined on a case by case basis depending on the reclaimed water quality and the hydrogeological context.

Table 7

Recommended guidelines for water reuse in the Mediterranean Region

<table>
<tr><th rowspan="3">Water Category</th><th colspan="3">Quality criteria</th><th rowspan="3">Wastewater treatment expected to meet the criteria</th></tr>
<tr><th colspan="2">Microbiological</th><th>Physical</th></tr>
<tr><th>Intestinal nematode[a] (No. eggs per liter)</th><th>FC or E. coli[b] (cfu/100 mL)</th><th>SS[c] (mg/L)</th></tr>
<tr><td colspan="5">Category I</td></tr>
<tr><td>a) Residential reuse: private garden watering, toilet flushing, vehicle washing.</td><td rowspan="3">≤ 0.1[h]</td><td rowspan="3">≤ 200[d]</td><td rowspan="3">≤ 10</td><td rowspan="3">Secondary treatment + filtration + disinfection</td></tr>
<tr><td>b) Urban reuse: irrigation of areas with free admittance (greenbelts, parks, golf courses, sport fields), street cleaning, fire-fighting, fountains, and other recreational places.</td></tr>
<tr><td>c) Landscape and recreational impoundments: ponds, water bodies and streams for recreational purposes, where incidental contact is allowed (except for bathing purposes).</td></tr>
<tr><td colspan="5">Category II</td></tr>
<tr><td>a) Irrigation of vegetables (surface or sprinkler irrigated), green fodder and pasture for direct grazing, sprinkler-irrigated fruit trees</td><td rowspan="2">≤ 0.1[h]</td><td rowspan="3">≤ 1000[d]</td><td rowspan="3">≤ 20
≤ 150[f]</td><td rowspan="3">Secondary treatment or equivalent[g] + filtration + disinfection
or
Secondary treatment or equivalent[g] + either storage or well-designed series of maturation ponds or infiltration percolation</td></tr>
<tr><td>b) Landscape impoundments: ponds, water bodies and ornamental streams, where public contact with water is not allowed.</td></tr>
<tr><td>c) Industrial reuse (except for food, beverage and pharmaceutical industry).</td><td>-</td></tr>
<tr><td colspan="5">Category III</td></tr>
<tr><td>Irrigation of cereals and oleaginous seeds, fiber, & seed crops, dry fodder, green fodder without direct grazing, crops for canning industry, industrial crops, fruit trees (except sprinkler-irrigated)[e], plant nurseries, ornamental nurseries, wooden areas, green areas with no access to the public.</td><td>≤ 1</td><td>None required</td><td>≤ 35
≤ 150[f]</td><td>Secondary treatment or equivalent[g] + a few days storage
or
Oxidation pond systems</td></tr>
</table>

Water Category	Quality criteria			Wastewater treatment expected to meet the criteria
	Microbiological		Physical	
	Intestinal nematode[(a)] (No. eggs per liter)	FC or *E. coli* [(b)] (cfu/100 mL)	SS [(c)] (mg/L)	
Category IV				
a) Irrigation of vegetables (except tuber, roots, etc.) with surface and subsurface trickle systems (except micro-sprinklers) using practices (such as plastic mulching, support, etc.) guaranteeing absence of contact between reclaimed water and edible part of vegetables.	None required	None required	Pretreatment as required by the irrigation technology, but not less than primary sedimentation	
b) Irrigation of crops in category III with trickle irrigation systems (such as drip, bubbler, micro-sprinkler and subsurface).				
c) Irrigation with surface trickle irrigation systems of greenbelts and green areas with no access to the public.				
d) Irrigation of parks, golf courses, sport fields with sub-surface irrigation systems.				
Category V: groundwater recharge				
a) Surface spreading into nonpotable aquifers	-	None required	≤ 35	Secondary treatment or equivalent [(g)]
b) Surface spreading into potable aquifers	-	≤ 1000[(d)]	≤ 20	Secondary treatment or equivalent [(g)] + filtration + disinfection
c) Direct injection	No detectable	No detectable	< 5	Advanced wastewater treatment processes in order to meet drinking water maximum contaminant levels

(a) *Ascaris and Trichuris* species and hookworms; the guideline limit is also intended to protect against risks from parasitic protozoa.
(b) FC or *E. coli* (cfu/100mL): faecal coliforms or *Escherichia coli* (cfu: colony forming unit/100 mL).
(c) SS: Suspended Solids
(d) Values must be conformed at the 80% of the samples per month, minimum number of samples 5.
(e) In the case of fruit trees, irrigation should stop two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
(f) Stabilization ponds
(g) such as advanced primary treatment (APT) (Jimenez *et al*., 1999 and 2001)
(h) As very few investigations, if any, have been carried out on how to reach < 0.1 nematode egg /L, this criterion is considered a medium term objective and is provisionally replaced by <1 nematode egg /L.

Table 8

Water quality monitoring requirements

Water Category	Sampling frequency / Number of samples per year		
	Quality criteria		
	Microbiological		Physical
	Intestinal nematode (No. eggs per liter)	FC or *E. coli* [(a)] (cfu/100 mL)	SS [(b)] (mg/L)
Category I			
a) Residential reuse: private garden watering, toilet flushing, vehicle washing.	Fortnighly	Twice weekly	Weekly
b) Urban reuse: irrigation of areas with free admittance (greenbelts, parks, golf courses, sport fields), street cleaning, fire-fighting, fountains, and other recreational places.			
c) Landscape and recreational impoundments: ponds, water bodies and streams for recreational purposes, where incidental contact is allowed (except for bathing purposes).			
Category II			
a) Irrigation of vegetables (surface or sprinkler irrigated), green fodder and pasture for direct grazing, sprinkler-irrigated fruit trees.	Fortnightly [(c)]	Weekly	Weekly (where affordable also check BOD for efficiency o treatment reasons)
b) Landscape impoundments: ponds, water bodies and ornamental streams, where public contact with water is not allowed.			
c) Industrial reuse (except for food industry).	-		
Category III			
Irrigation of cereals and oleaginous seeds, fiber, & seed crops, dry fodder, green fodder without direct grazing, crops for canning industry, industrial crops, fruit trees (except sprinkler-irrigated), plant nurseries, ornamental nurseries, wooden areas, green areas with no access to the public.	Monthly[(c)]	-	Monthly

Category IV			
a) Irrigation of vegetables (except tuber, roots, etc.) with surface and subsurface trickle systems (except micro-sprinklers) using practices (such as plastic mulching, support, etc.) guaranteeing absence of contact between reclaimed water and edible part of vegetables	-	-	-
b) Irrigation of crops in category III with trickle irrigation systems (such as drip, bubbler, micro-sprinkler and subsurface).			
c) Irrigation with surface trickle irrigation systems of greenbelts and green areas with no access to the public.			
d) Irrigation of parks, golf courses, sport fields with sub-surface irrigation systems.			
Groundwater recharge			
a) Surface spreading into non potable aquifers	-	Monthly	Monthly
b) Surface spreading into potable aquifers	-	Weekly	Weekly
c) Direct injection	Weekly	Daily	Daily

(a) FC or *E. coli* (cfu/100mL): faecal coliforms or *Escherichia coli* (cfu: colony forming unit/100 mL).
(b) SS: Suspended solids. When affordable, continuous recording of NTU should be preferred.
(c) Routine effluent quality monitoring not required if the wastewater is treated in WSP or WSTR designed to achieve these egg numbers.

3.7.2. Soil monitoring

The accumulation of pollutants threatening the agronomic quality of irrigated soils should be monitored. The frequency of soil sampling should be adapted to the long term process of the accumulation of pollutants of concern.

3.7.3. Treatment reliability requirements

In order to eliminating public health risks, it is essential that the plant meets the standards set for the treated wastewater quality, otherwise the reuse of the treated wastewater should be discontinued. Therefore, treatment facility reliability features should be incorporated into the system design via alarms, alternative power supply, and, when appropriate, backup or multiple unit processes. When unit process failures occur, backup/multiple units, standby replacement equipments, chemical storage and supply ensure that there is an alternative process to keep the flow continuous or shorten the duration of repair.

As a precautionary measure and in order to remove pathogens such as viruses and parasites, disinfection methods other than chlorination (e.g. ozonation, UV) to avoid harmful disinfection by products, should be considered when the final effluent contains significant amounts of organic carbon (BOD>40 mg/L) and ammonia (NH_3 > 20 mg/L).

Reliability enhancement involves pre-treatment of industrial wastewater and enforcement of sewer discharge regulations to prevent hazardous wastes dumping into the collection system.

3.7.4. Emergency storage or disposal

In case the treatment process fails to comply with health related requirements, emergency storage or disposal provisions of untreated or partially treated wastewater should be available.

3.7.5. Reclaimed water storage

Reclaimed water storage is essential for ensuring the continuity of reclaimed water supply in case the treatment plant fails to supply the water needed or to meet the water quality criteria. When an alternative source is not available, a reclaimed water storage should be included in the distribution system. The recommended capacity is the one week highest demand in a year. Storage facilities may also be designed in order to participate in the treatment and seized accordingly.

3.7.6. Cross-connection and backflow prevention

When dual-distribution systems are present, cross-connections are a concern because of the possibility of contaminating the potable water supply. Cross-connection control can be achieved through installing protective devices such as double check valve assembly, reduced pressure principle backflow prevention device and an air gap separation.. Documentation of cross-connection control inspections is usually required for all water reuse facilities. The following information should also be provided such as pipe locations of both the recycled and potable systems, type and location of the outlets and plumbing fixtures that will be accessible to the public.

3.7.7. Other considerations regarding reclaimed water systems

All reclaimed water pipes and outlets should be colour-coded or taped preferably a characteristic color (purple usually) to identify that reclaimed water is being used.

Outlet fittings should be of a special type to prevent misuse. Authorized personnel should secure reclaimed water valves and outlets.

Signposting to advise the public about the use of reclaimed water and to provide effective written notification to the end users of reclaimed water concerning the origin, nature, and proper use of reclaimed water should be provided. Warning notices (using symbols) should be posted at water valves. Measures should also be taken as to prevent contact of domestic animals with reused water.

3.7.8. Setback distances

Setback distances provide buffer zones between facilities using reclaimed water and areas where the public (or a potable water supply) may be exposed to the reclaimed water. The setback distance required depends mainly on the quality of the reclaimed water, the method of irrigation (e.g. sprinkling, sub-surface trickling, drip, bubbler etc.), the radius of wetted area, climatology and hydro-geological aspects of the site. Setback distances have to be set accordingly to regulations applying to potable supply wells and water travel times in the aquifer. In the case of sprinkler irrigation, minimum distances to inhabited areas and public ways should be fixed and sprinklers should not be used within specific distances to houses or roads.

3.7.9. Crop restriction

Crop restriction is meant to protect consumers. It is related to crops not allowed to be irrigated with Category III water , mainly vegetables, and tuber and roots in Category IV. Limitation of crops has to be completed by controlled application of effluent and human exposure. A strong institutional framework and the capacity to monitor and control compliance with regulations and to enforce them are also required when adopting crop restriction as a means of health protection.

3.7.10. Irrigation management and time of application restrictions

Appropriate reclaimed water application methods, water application rate limitations, waiting periods before harvesting and animal grazing are practices that minimize contamination of crops and soils.

Specification of the most appropriate time period for application is meant to minimize potential direct human contact with spray water and aerosols. Public parks, golf courses, and public and private landscaping receiving reclaimed water are required to irrigate during the off-hours, for instance between 9 p.m. and 6 a.m., in order to reduce the potential for contact with the general public and contribute to the risk management programme.

Spray/sprinkler irrigation should not be used on vegetables and fruit unless the effluent meets the guidelines. Trickle and subsurface irrigation, particularly when the soil surface is covered with plastic sheeting, can give a high degree of health protection, besides using water more efficiently. A good filtration system to remove suspended solids from irrigation water is required to prevent emitters clogging.

Low range sprinklers are recommended. Sprinkler irrigation is not recommended under windy conditions since there is a potential for the pathogens to be carried away in the formed aerosols and cause health hazards to the workers, farm population and nearby residents. No water should be applied on saturated soils to avoid runoff and surface ponding.

When fruit trees are irrigated with Category III water, no fruit should be picked off the ground.

3.7.11. Greenhouses

Irrigation using surface and subsurface trickle systems (except micro-sprinklers) is highly recommended in greenhouses. If micro-sprinklers are used, irrigation should take place in the absence of workers.

3.7.12. Control of human exposure and hygiene

Farm workers should be aware of the risk of exposure associated with reclaimed water application and handle reclaimed water with care. Preventive measures to protect agricultural field workers and crop handlers include the wearing of protective clothing (use of appropriate footwear in the field), increased levels of hygiene, and possible immunization (against certain diseases such as typhoid and hepatitis A). Worker health controls should be scheduled on a regular basis.

Educational programs should be provided for the public, schools, and other agencies concerning the need for water conservation and reuse, reuse activities, health education campaigns and environmentally sound wastewater management reuse practices.

3.7.13. Soil and groundwater protection

When irrigation is practised, even though the water quality and conveyance requirements are met, chemical constituents in reclaimed water should not result in any soil or groundwater quality degradation. Attention should be paid to salinity and nitrate leaching, to pharmaceutically active chemicals, endocrine disrupters, etc. Scheduling of irrigation based on crop water requirements, soil water holding capacity and reclaimed water quality will prevent groundwater contamination. Selection of crops with high N requirements will reduce aquifer contamination by nitrates.

3.7.14. Potable groundwater recharge

Reclaimed water used for groundwater recharge of domestic water supply aquifers by surface spreading shall be at all times of a quality that fully protects public health. If the recycled water being used for recharge does not meet the criteria, the groundwater recharge operation should be suspended until the criteria are met; and the concerned departments should be notified.

Attention should be paid to the nitrogen content of the water used for recharge. It should not exceed the limit accepted for potable water.

For a surface spreading project, all the recharge water shall be retained underground for a minimum of six months prior to extraction for use as a drinking water supply, and shall not be extracted within 150 m of a point of recharge.

For a direct or subsurface injection project, all the recharge water shall be retained underground for a minimum of nine months prior to extraction for use as a drinking water supply, and shall not be extracted within 500 m of a point of recharge.

A groundwater monitoring program with a set of monitoring wells has to be conducted.

4. CONCLUSION

Establishing Mediterranean guidelines for municipal water reuse is a challenge because of the absence of comprehensive international guidelines, and of a scientific consensus on the approach that should be adopted to issue such guidelines. This has led to inconsistencies between the guidelines that are already implemented in Mediterranean countries. However, a number of potential benefits may be gained in providing minimum requirements which should constitute the basis of water reuse regulations in every country of this region threatened by water scarcity and where food exchanges and tourism are increasingly developing.

These guidelines have been prepared making a large use of the results of the recent assessment of the WHO guidelines by Blumenthal *et al*., (2000). Their work was based on risk assessment using epidemiological studies supplemented by microbiological investigations and model based QMRA. Some QMRA data have been added, taking the acceptable annual risks related to bathing and potable water drinking as benchmarks.

Five water categories based on comparable levels of risk have been distinguished. Water reuse cost-effectiveness was also taken into account in the sense that a reclaimed water supply network must serve as many reuse applications as possible in the same area. The following reclaimed water uses were considered: agriculture, landscape irrigation, urban and residential reuse, landscape and recreational impoundments-excepting those where bathing is allowed-, groundwater recharge and industrial uses. Wastewater treatments expected to meet the criteria were defined for each water category. In the case of agricultural reuse, the capacity of the reclaimed water application system or method to reduce health risks was taken into account.

5. RECOMMENDATIONS

Mediterranean countries are unequally developed, several being already equipped with wastewater treatment plants while others have virtually no equipment. Therefore, all countries can not be expected to be able to meet the reuse guidelines in the same time.

A regional committee should be established with internationally-recognized water reuse experts, practitioners and regulators from Mediterranean countries to periodically re-evaluate and update the guidelines in order to ensure that they are supported by the best available scientific data and risk-assessment methods, and to validate the effectiveness of reclaimed water management practices.

International organizations should foster efforts for more consistency between the different regulations and guidelines related to water quality. For the sake of integrated water management and to gain public understanding and acceptance, water reuse regulations should be part of a set of consistent water regulations applying to drinking water, bathing water, irrigation water, discharge.

There is no documented scientific evidence that the WHO guidelines failed to protect public health. But, within the context of uncertainties concerning the potential impacts on human health and the environment of the various disposal and recycling options, additional research is needed to reduce persistent uncertainty about the potential for adverse human health effects from exposure to reclaimed water and to increase confidence in water reuse. To assure the public and protect the public health, there is a need to update the scientific basis of the regulations to ensure that the chemical and pathogen standards are supported by current scientific data and risk assessment methods and to validate the effectiveness of reclaimed water management practices. There is a need to address scientific and management questions and uncertainties that challenge the existing reclaimed water guidelines and standards:

- National and regional surveys on chemicals and pathogens in raw and treated wastewater, and sewage sludge, using relevant sampling programs, statistical and analytical methods, should be carried out in the Mediterranean Region. Short and long term changes of water quality have to be analyzed to identify possible trends.
- Monitoring programs of water quality at the point of use should be undertaken, together with the control of the quality of irrigated agricultural products. More investigations are still needed on the changes of reclaimed water quality in storage and distribution systems.
- An extensive review of disinfection technique effectiveness, drawbacks and costs would strongly help water reuse designers.
- Techniques allowing to reliably meet the criterion of < 0.1 nematode egg / L at an acceptable cost should be sought after.
- More knowledge is needed on the elimination of pathogens in extensive low cost techniques.
- More investigation on irrigation systems, such as drip and sub-surface systems, which can provide the best health protection and water conservation at the same time, is strongly hoped.There is a growing demand for the introduction of a viral indicator that can be used in water reuse regulations. This demand should urge further investigation and the development of detection methods sensitive, reliable and cost-effective.
- Carefully well-designed epidemiological investigations that examine exposure and health impacts to exposed populations (reclaimed water appliers, reclaimed water users, farmers, communities near land application sites, etc.) would help assessing the risks related to water reuse in the Mediterranean region. Epidemiological studies on illnesses related to bathing in Mediterranean countries should also be performed.
- More research should be performed in order to increase the effectiveness of QMRA. Several issues should be particularly considered :
  - dose-response relationships,
  - environmental persistence of pathogens on soil and crops after application of reclaimed water,
  - exposure assessment,
  - relationships between pathogen and microbial indicators.
- The concept of *acceptable risk* should be assessed, with the view of reducing inconsistencies between the different uses of water; the meaning of this concept should be clarified.
- In the case of potable reuse, new studies are needed on trace organics, endocrine disrupters, pharmaceutical products and associated health risks.Risk assessment investigations addressing interactions between pathogen and chemical components should be undertaken. Such interactions may result in inhibition or enhancement of adverse effects of individual exposures. Existing information on potential interaction of chemicals and pathogens that might be associated with reclaimed water exposures should be synthesized
- A rationale for the setting of setback distances (cf § 3.7.8) should be established.

The aim of this report is to address public health aspects of water reuse. Other important aspects of this practice, such as crop production, soil conservation and environmental impact, must be taken into account in order to enable engineers, farmers, municipalities and the competent authorities to properly plan and design sustainable wastewater reuse. Material provided by FAO should help every country in its decision making process.

6. REFERENCES

Angelakis, A.N., and S.V. Spyridakis. (1996). The status of water resources in Minoan times - A preliminary study. In: Diachronic Climatic Impacts on Water Resources with Emphasis on Mediterranean Region (A. Angelakis and A. Issar, Eds.). Springer-Verlag, Heidelberg, Germany, pp. 161-191.

Angelakis, A.N., M.H. Marecos do Monte, L. Bontoux, and T. Asano. (1999). The status of wastewater reuse practice in the Mediterranean basin. Water Res.: **33**(10): 2201-2217, 1999.

Angelakis, A.N. and L. Bontoux (2001). Wastewater Reclamation and Reuse in Eureau Countries. Water Policy 3: 47-59.

Asano, T., Leong, L.Y.C., Rigby, M.G. and Sakaji, R.H. (1992). Evolution of the California wastewater reclamation criteria using enteric virus monitoring data. *Wat. Sci. Tech*., **26** (7-8), 1513-1524.

Asano, T. (1998). Wastewater Reclamation and Reuse. Water Quality Management Library Vol. 10. Technomic Publishing Inc., Lancaster, Pennsylvania, USA.

Asano, T., Ogoshi, M., and Suzuki, Y., (2000). Lessons Learned from the Japanese Water Reuse Experiences, Water Reuse 2000 Conference, San Antonio, Texas, January 30-February 2, 2000.

Asano, T. and Cotruvo, J. (2002). Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations – Draft document, WHO Chapter, March 25, 2002, 30 p.

Ayers R. S. and Westcot D. W. (1985). *Water quality for agriculture*, Food and Agriculture Organization of the United Nations, FAO Irrigation and Drainage, Paper 29, Rome. Italy.

Ayres, R.M. et al. (1992). Contamination of lettuces with nematode eggs by spray irrigation with treated and untreated wastewater. *Wat. Sci. Tech*. **26**(7-8), 1615-1623.

Bastos, R.K.X. and Mara, D.D. (1995). The bacteriological quality of salad crops drip and furrow irrigated with waste stabilization pond effluent: an evaluation of the WHO guidelines. *Wat. Sci. Tech*. **31**(12), 425-430.

Blumenthal, U.J., Mara, D.D., Peasey, A., Ruiz-Palacios, G. and Scott, R. (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bulletin of the WHO* **78** (9), 1104-1116.

Bouwer, H. (1996) Issues in artificial recharge. *Water Science and Technology*, **33**(10-11), 381-390.

Brissaud, F., M. Salgot, A. Bancolé, C. Campos & M. Folch, (1999). Residence time distribution and disinfection of secondary effluents by infiltration percolation. *Wat. Sci. Tech*. **40**(4/5) :215-222.

Chang A. C., Page A. L. and Asano T. (1995). *Developing human health-related chemical guidelines for reclaimed water and sewage sludge applications in agriculture*, World Health Organization, Geneva, Switzerland.

Chang, C., Page, A.L. and Asano, T. (1998). Evaluating methods of establishing human health-related chemical guidelines or cropland application of municipal wastewater. In Asano T. ed. *Wastewater Reclamation and Reuse*. Lancaster, PA, Technomic Publishing, 581-626.

COM (2000). Developing a new bathing water policy. http://www.europa.eu.int/comm/environment/docum/00860_en.htm

Conseil Supérieur d'Hygiène Publique de France. 1991. Recommandations sanitaires concernant l'utilisation, après épuration, des eaux résiduaires urbaines pour l'irrigation des cultures et des espaces verts, DGS/SD1.D./91/Nº 51, Paris, Ministère de la Santé, 40 p.

Cooper, R.C. and Olivieri, A.W. (1998). Infection disease concerns in wastewater reuse. In Asano T. ed. *Wastewater Reclamation and Reuse*. Lancaster, PA, Technomic Publishing, 489-520.

Crites, R. and G. Tchobanoglous (1998). Small and Decentralized Wastewater Management Systems, WCB and McGraw-Hill, New York, USA.

Crook, J. and Surampalli, R.Y. (1996). Water reclamation and reuse criteria in the USA. *Wat. Sci. Tech*., **33**(10-11): 475-486.

Crook, J. (1998). Water reclamation and reuse criteria. In Asano T. ed. *Wastewater Reclamation and Reuse*. Lancaster, PA, Technomic Publishing, 627-703.

Crook, J., Johnson, L.J. and Thompson, K. (2001). California's new water recycling criteria and their effect on operating agencies.

Drewes, J.E. and Jekel, M. (1996). Simulation of groundwater recharge with advanced treated wastewater. *Water Science and Technology*, 33(10-11), 409-418.

Durand, R.E. *et al*., (1986). Epidemiological investigation of community health effects of landscape irrigation with reclaimed water: the Colorado Springs study. Colorado Springs, Wastewater Division of the City of Colorado Springs.

European Union (1976). Bathing water quality directive 76/160/EEC. http://www.europa.eu.int/water/water-bathing/directive.html

European Union (1991). *Council Directive Concerning Urban Wastewater Treatment*. 91/271 EEC of May 21, 1991, OJ NO L135/40 of May 30, 1991.

Feachem, R.G., Bradley, D.H., Garelick, H. and Mara, D.D. (1983). Sanitation and Disease: Health Aspects of Excreta and Wastewater Management. John Wiley and Sons, New York.

Haas, C.N. (1996). Acceptable health risk. Viewpoint. *J. Am. Water Works Assoc*., **18**, 8.

Jiménez B., Chávez A., and Hernández C. (1999). Alternative wastewater treatment intended for agricultural use in Mexico. *Wat. Sci. Tech.,* 40, No. 4-5, pp. 355-362.

Jiménez B., Chávez A., Maya, C. and Jardines, L., (2001). Removal of microorganisms in different stages of wastewater treatment for Mexico City. *Wat. Sci. Tech.,* 43, No. 10, pp. 155-162.

Kay, D., Fleisher, J.M., Salmon, R.L., Jones, F., Wyer, M.D., Godfree, A.F., Zelenauch-Jacquotte, Z. and Shore, R. (1994). Predicting likelihood of gastroenteritis from sea bathing: results from randomised exposure. *Lancet* **344**, 905-909.

López-Pila, J. and Szewzyk, R. (2000). Estimating the infection risk in recreational waters from the faecal indicator concentration and from the ratio between pathogens and indicators. *Wat. Res*. **34** (17), 4195-4200.

Mara, D. and Cairncross, S. (1989). Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture, Measures for public health protection, WHO, Geneva, Switzerland.

Margat, J. and D. Vallée (2000). Mediterranean Vision on Water, Population and the Environment for the 21st Century. Blue Plan. Mediterranean Action Plan/UNEP, GWP/MEDTAC, Montpellier, France.

Mariño, F.J., Moriñigo, M.A., Martinez-Manzanares, E. and Borrego, J.J. (1995). Microbiological-epidemiological study of selected marine beaches in Malaga (Spain). *Wat. Sci. Tech.* **31**(5-6), 5-9.

Medema, G.J., Van Asperen, I.A., Klokman-Houweling, J.M., Nooitgedagt, A., Van de Laar M.J.W. and Havelaar, A.H. (1995). The relationship between health effects in triathletes and microbiological quality of freshwater. *Wat. Sci. Tech.* **31**(5-6), 19-26.

Mugglestone, M.A., Stutt, E.D. and Rushton, L. (2001). Setting microbiological water quality standrds for sea bathing – a critical evaluation. *Wat. Sci. Tech*. **43**(12), 9-18.

Ongerth, H. and Jopling, W.F. (1977). Water reuse in California. In “Water Renovation and Reuse” edt. By Shuval H.I., Academic Press, New York, 219-256.

Ogoshi, M., Suzuki, Y. and Asano, T. (2001). Water reuse in Japan. *Wat. Sci. Tech*. 43(10), 17-23.

Pettygrove, G.S., and Asano, T., (ed.). (1985). Irrigation with reclaimed municipal wastewater - A guidance manual. Lewis Publishers, Inc., Chelsea, Mississipi.

Pescod, M.B. (1992). Wastewater treatment and use in agriculture. FAO Irrigation and Drainage Paper 47. Food and Agriculture Organization of the United Nations, Rome. 125 p.

Sack, J., Icekson-Tal, N., and H. Cikurel (2001). Soil aquifer treatment: evaluation of water quality and treatment reliability in Dan Region – Israel. In EU project ENV4-CT98-0790 CATCHWATER final report, 390-426.

Schwarzbrod, J. (2002). Personal communication.

Shuval, H., Adin, A., Fattal, B., Rawitz, E. and Yekutiel P. (1986). Wastewater irrigation in developing countries: Health effects and technical solutions. World Bank Technical paper 51, The World Bank, Washington, D.C.

Shuval, H., Lampert, Y. and Fattal, B. (1997). Development of a risk assessment approach for evaluating wastewater reuse standards for agriculture. *Wat. Sci. Tech*. **35**(11-12), 15-20.

Soulié, M. and Tréméa, L., (1992). Technologie pour le traitement et la réutilisation des eaux usées dans le bassin méditerranéen, Actes des 3èmes Rencontres de l'Agence Régionale pour l'Environnement, Provence - Alpes - Côte d'Azur, 24-27 September 1991, 171-255.

State of California. (1978). Wastewater Reclamation Criteria, An Excerpt from the California Code of Regulations, Title 22, Division 4, Environmental Health, Dept. of Health Services, Sacramento, California.

State of California (2000). Title 22, Code of regulations, 24 p. November 2000.

Strauss, M. and Blumenthal, U.J. (1989). Health Aspects of Human Waste Use in Agriculture and Aquaculture –utilisation Practices and Health Perspectives. International Reference Center for Waste Disposal, Dubendorf (Report N° 08/88).

Tanaka, H., Asano, T., Schroeder, E. D. and Tchobanoglous, G. (1998). Estimating the safety of wastewater reclamation and reuse using enteric virus monitoring data. *Wat. Environ. Res*. **70** (1), 39-50.

United Nations Environment Programme (1991). Environmental guidelines for municipal water reuse in the Mediterranean Region. Mediterranean Action Plan, Priority Actions Programme, United Nations Environment Programme in cooperation with Food and Agriculture Organization of the United Nations, PAP-3/G.1.

U.S. Environmental Protection Agency (1976). *Quality Criteria for Water. EPA-R3-73-033.* A report of the National Academy of Science – National Academy of Engineering Committee on Water Quality Criteria. US Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (1992). Guidelines for Water Reuse. EPA/625/r-92/004, U. S. Environmental Protection Agency, Washington D.C. 247 pp.

U.S. Environmental Protection Agency (1998). *Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters).* 4305 EPA-823-R-98-003. Office for Water. U S Environmental Protection Agency. http://www.epa.gov/waterscience/beaches/local/sum2.html

Vaz da Costa-Vargas, S.M., Mara, D.D. and Vargas-Lopez, C.E. (1991). Residual faecal contamination on effluent-irrigated lettuces. *Wat. Sci. Tech*. **24**(9), 89-94.

World Health Organization (1973). *Reuse of effluents: Methods of wastewater treatment and health safeguards*, Tech. Bull. Ser. 51, WHO, Geneva, Switzerland.

World Health Organization (1989). Health guidelines for the use of wastewater in agriculture and aquaculture, Tech. Bull. Ser. 77, WHO, Geneva, Switzerland.

Xu, P. and Brissaud, F. (2002). Evaluating water reuse guidelines : technical-economic impact and risk assessment *(submitted to Water Research).*

7. ANNEXES

<u>Table 1</u>

Provisional quality criteria for irrigation with reclaimed water in Cyprus (1989)

Irrigation of		**BOD_5 (mg/L)**	**SS (mg/L)**	**Faecal coliforms (MPN/100 mL)**	**Intestinal nematodes (No./L)**	**Treatment required**
All crops (*)	A	10[a]	10[a]	5[a] 15[b]	Nil	Secondary, tertiary and disinfection
Vegetables eaten cooked (**) Amenity areas of unlimited public access	A	10[a] 15[b]	10[a] 15[b	50[a] 100[b]	Nil	Secondary, tertiary and disinfection
Crops for human consumption. Amenity areas of limited public access	A	20[a] 30[b]	30[a] 45[b]	200[a] 1 000[b]	Nil	Secondary, storage >1 week and disinfection or tertiary and disinfection
	B	-	-	200[a] 1 000[b]	Nil	Stabilization-maturation ponds total retention time >30 days or secondary and storage >30 days
Fodder crops	A	20[a] 30[b]	30[a] 45[b]	1 000[a] 5 000[b]	Nil	Secondary and storage >1 week or tertiary and disinfection
	B	-	-	1 000[a]	Nil	Stabilization-maturation ponds total retention time >30 days or secondary and storage >30 days
Industrial crops	A	50[a] 70[b]	- -	3 000[a] 10 000[b]	- -	Secondary and disinfection
	B	-	-	3 000[a] 10 000[b]	- -	Stabilization-maturation ponds with total retention time >30 days or secondary and storage >30 days

A: Mechanized methods of treatment.
B: stabilization ponds.
[a] These values must not be exceeded in 80% of samples per month, minimum number of samples 5.
[b] Maximum value allowed.
(*) Irrigation of leaved vegetables, bulbs and corms eaten uncooked is not allowed.
(**) Potatoes, beetroots, colocasia.
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 effluent.

Table 2

Water reuse recommendations in France (1991)

WATER QUALITY	CRITERIA	IRRIGATION TYPE	TYPE OF VEGETATION	TREATMENT
A	None	On-surface or subsurface trickle irrigation	Cereals, industrial crops, fodder Fruit trees Forest and green areas with restricted access	-
B	≤ 1 helminth egg/L (Taenia, Ascaris)	Surface or furrow irrigation Spray irrigation if aerosol propagation limited: setback distances from residential areas > 100 m, hedges, etc.	Fruit trees, cereals and fodder, nurseries and food crops eaten cooked Sport fields if irrigation is stopped several weeks before access	Stabilization ponds >10 days retention time or equivalent
C	≤ 1 helminth egg/L (Taenia, Ascaris) ≤ 10^3 FC/100 mL	Irrigation methods with limited contact with crops: low pressure sprinklers, surface irrigation, furrows Setback distances from residential areas > 100 m	Fruit trees, pasture, food crops eaten raw, etc. Sport fields, golf courses, green areas with open access	Stabilization ponds >30 days retention time or equivalent

Note that the new French draft 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 *Taenia* egg.
(b) Setback distances (from roads, houses, ...) ≥ 50 m.
(c) Spray irrigation during off-hours. Low range sprinklers are recommended.
(d) Sub-surface irrigation was not taken into account.

The Israeli Ministry of Health – Principles for giving permits for irrigation with treated wastewater – R. Halperin (August 1999)

Table 3a

Number and type of barriers for different crops and effluent qualities

Un-limited irrigation	High quality effluents.	Oxidation pond effluents ****	Medium quality effluents	Crop	Sand filtration or long retention or 10% effluents.	Effluent disinfection *		Distance from drip-irrigation. **	Plastic ground cover-up.	Subsurface irrigation.	Inedible pill or shell.	Eaten cooked only..
The number or barriers required.					One of the 3	Obligatory	Voluntarily.					
0	2	***	***	Fresh eaten vegetables grown above ground (pepper, tomato, cucumber, paprika, and zucchini).	+	+			+	++		
0	2	***	***	Cooked vegetables with shell (eggplant, pumpkin).	+		+		+	++	+	+
0	2	***	***	Cooked vegetables grown in the ground (potatoes).	+		+					+
0	2	***	***	Peanuts.	+		+				+	
0	2	***	***	Fresh eaten vegetables grown in the ground (carrot, onion, radish).	+	+						
0	2	***	***	Beans.	+	+			+	++		+
0	2	***	***	Vegetables with shell (watermelon, melon, peas).	+	+			+	++	+	
0	2	3-2	3	Artichokes.	+		+	++	+	++		+
0	2	3-2	3	Corn (edible).	+		+	++	+	++	+	
0	2	3-2	3	Citrus.	+		+	++		++	+	
0	2	3-2	3	Citrus, irrigated with pulsators or under leave sprinklers.	+		+	+			+	
0	2	3-2	3	Citrus with edible shell (Chinese orange).	+		+	++		++		
0	2	3-2	3	Nuts, almonds, pomegranate, pistachios.	+		+	++		++	+	
0	2	3-2	3	Deciduous trees (apple, prune, plum, pear, peaches, apricot) and cherry.	+		+	++		++		
0	2	3-2	3	Tropical fruits (mango, avocado, persimmon).	+		+	+	+	++	+	
0	2	3-2	3	Tropical fruit with cutting of the lowest leaves.	+		+	++	+	++	+	
0	2	3-2	3	Grapes with high trellis.	+		+	++		++		
0	2	3-2	3	Grapes with regular trellis.	+		+	+	+	++		
0	2	***	***	Grape with no trellis.	+	+			+	++		
0	2	3-2	3	Sabras (cactus fruits).	+		+	++	+	++	+	
0	2	3-2	3	Dates.	+		+	+++	+	++		
0	2	3-2	3	Olives.	+		+	++	+	++		+
0	2	3-2	3	Flowers.	+		+	+	+	++	+	
0				Public gardening.								

The total amount of barriers needed is dependent on the basic quality of the effluent that is used for irrigation, as follows.

1. Effluents of very high quality (that are suitable to unlimited irrigation) do not require barriers at all.
   The quality of biological-mechanical treatment works' effluents, with 20/30 BOD_5 /Suspended Solids (SS) ("baseline quality"), or an equal quality, where afterwards the effluents are put through a depth granular filter (or a same value filter) and a disinfection process of at least half an hour, where at the end of this disinfection process the effluent contains at least a total residual chlorine content of 1 mg/l.
   These effluents shall contain no more than 10 E.Coli/100 ml of effluent water.

2. Effluents of high quality require 2 barriers in order to be approved for agricultural irrigation.
   These effluents include: effluents from a biological-mechanical treatment work or an equal value treatment work (if authorized) that produces effluents of "baseline quality" (20/30 BOD_5/SS).
   (Comment: an equal value treatment work is for example the treatment work in the city of Arad, which has a reproduction of algae. In this case it should be noted that the values of SS and BOD_5 should be subtracted by the load of SS and BOD_5 caused by the concentration of the algae.)

3. Effluents of medium quality require 3 barriers and are not suitable to irrigate vegetables.
   Effluents from treatment works that are not intensive (like aerated ponds) and also effluents from biological-mechanical treatment work, with too much load, that produce worse effluents than the baseline (20/30), in the condition that they contain no more than 60 mg/l BOD_5 and 90 mg/l SS

4. Oxidation pond effluents
   - For effluents from a small treatment work - an oxidation pond that accept only sanitary sewage, with 15 days of retention time, that cannot be minimized, it would be possible to approve the irrigation of fruits, or crops with the same (or lower) sensitivity, with two barriers.
   - In oxidation ponds that accept sanitary sewage, with at least 10 days of retention time, 3 barriers are required to irrigate fruits.
   - In oxidation ponds that accept sewage with a BOD_5 that is more than 400 mg/l, an additional day of retention is required for every 50 mg/l BOD_5 in excess of the primary 400 mg/l BOD_5.

Table 3b
Effluent qualities

Type of effluent / Treatment	Unlimited irrigation	High quality	Oxidation ponds	Medium quality
Biological-mechanical treatment works with an effluent quality of 20/30 BOD_5/SS.	Obligatory	+		
Sand filtration.	One of the three			
Long-term retention.				
Pond with 10% effluent.				
Disinfection with half an hour contact time and 1 mg/l free residual chlorine after the disinfection.	Obligatory			
Oxidation ponds with at least 15 days retention time.		+		
Secondary treatment effluents up to 60 mg/l BOD_5 and 90mg/l SS.				+
Oxidation ponds with at least 10 days retention time.			+	

Table 4

Microbiological standards for irrigation with reclaimed water in Italy (1977)

Region	Water quality criteria	
	Microbiological quality	**Physical-chemical**
National standards: • Unrestricted irrigation[(b)] • Restricted irrigation[(c)]	 2 TC/100 mL[(a)] 20 TC/100 mL[(a)]	 SAR≤15
Emilia Romagna: • Unrestricted irrigation • Restricted irrigation	 2 TC/100 mL[(a)] 20 TC/100 mL[(a)]	 -
Puglia: • Unrestricted irrigation • Restricted irrigation	 2 TC/100 mL[(a)] 20 TC/100 mL[(a)]	15 mg/L BOD_5; 40 mg/L COD; 10 mg/L TSS; 0.2 mg/L residual Cl_2; pH: 6.5-8.5
Sicily: • Restricted irrigation • Irrigation is prohibited for crops that are in direct contact with the reclaimed water	 3000 TC/100 mL[(a)] 1000 FC/100 mL 1 helminth egg/L ND salmonella	 40 mg/L BOD_5; 160 mg/L COD; 30 mg/L TSS; pH: 6.5-8.5

(a) mean value of 7 consecutive sampling days.
(b) unrestricted irrigation: crops that can be eaten raw.
(c) restricted irrigation: pasture

Table 5

Draft microbiological guidelines and criteria for irrigation in Spain (1995)

Reuse application	Intestinal nematodes	TC or FC	Wastewater treatment requirements, treatment and disinfection
Crops that can be eaten raw[(a)]	<1/L	<10/100 mL	Secondary treatment, filtration or equivalent treatment and disinfection
Fruit trees and crops that are eaten cooked	<1/L	<200/100 mL	Secondary treatment and disinfection
Industrial crops; cereals, fodder crops and pastures	<1/L	<500/100 mL	Secondary treatment and disinfection
Lawns, wooded areas, and other areas with limited public access	<1/L	<200/100 mL	Secondary treatment and disinfection
Parks, public gardens, lawns, golf courses and other areas with direct public exposure	<1/L	<10/100 mL	Secondary treatment, filtration or equivalent treatment and disinfection

(a) In the case of spray irrigation, minimum distances to inhabited areas and public ways will be fixed.

Table 6

Draft of wastewater quality standards proposed by CEDEX in 1999 (Spain)

Use of the reclaimed wastewater		Quality Criteria				
		Biological		Physical-chemical		Other Criteria
		Intestinal Nematode Eggs	*Escherichia coli*	Suspended solids	Turbidity	
1	Residential uses: Private garden irrigation, toilet flushing, home air conditioning systems, car washing	< 1 egg/10 L	0 cfu/100 mL	< 10 mg/L	< 2 NTU	
2	Urban uses and facilities: Irrigation of open access landscape areas (parks, golf courses, sport fields, ...). Street cleaning, fire-fighting, ornamental impoundments and decorative fountains	< 1 egg/L	< 200 cfu/100 mL	< 20 mg/L	< 5 NTU	
3	Greenhouse crops irrigation	< 1 egg/L	< 200 cfu/100 mL	< 20 mg/L	< 5 NTU	*Legionella pneumophila* 0 cfu/100 ml
4	Irrigation of raw consumed food crops. Fruit trees sprinkler irrigated	< 1 egg/L	< 200 cfu/100 mL	< 20 mg/L	< 5 NTU	
5	Irrigation of pasture for milking or meat animals	< 1 egg/L	< 1.000 cfu/100 mL	< 35 mg/L	No limit is established	*Taenia saginata and solemn* < 1 egg/L

Use of the reclaimed wastewater		Quality Criteria				
		Biological		Physical-chemical		Other Criteria
		Intestinal Nematode Eggs	*Escherichia coli*	Suspended solids	Turbidity	
6	Irrigation of crops for canning industry and crops not raw-consumed. Irrigation of fruit trees except by sprinkling	< 1 egg/L	< 1.000 cfu/100 mL	< 35 mg/L	No limit is established	
7	Irrigation of industrial crops, nurseries, fodder, cereals and oleaginous seeds	< 1 egg/L	< 10.000 cfu/100 mL	< 35 mg/L	No limit is established	
8	Irrigation of forested areas, landscape areas and restricted access areas. Forestry	<1 egg/L	No limit is established	< 35 mg/L	No limit is established	
9	Industrial cooling, except for the food industry	No limit is established	<10.000 cfu/100 mL	< 35 mg/L	No limit is established	*Legionella pneumophila* 0 cfu/100 mL
10	Impoundments, water bodies and streams for recreational use in which the public's contact with the water is permitted (except bathing)	< 1 egg/L	< 200 cfu/100 mL	< 35 mg/L	No limit is established	
11	Impoundments, water bodies, and streams for recreational use in which the public's contact with the water is not permitted	No limit is established	No limit is established	< 35 mg/L	No limit is established	
12	Aquaculture (Plant or animal biomass)	< 1 egg/L	< 1.000 cfu/100 mL	< 35 mg/L	No limit is established	
13	Aquifer recharge by localised percolation through the soil	< 1 egg/L	<1.000 cfu/100 mL	< 35 mg/L	No limit is established	Total Nitrogen < 50 mg/L

Use of the reclaimed wastewater		Quality Criteria				
		Biological		Physical-chemical		Other Criteria
		Intestinal Nematode Eggs	*Escherichia coli*	Suspended solids	Turbidity	
14	Aquifer recharge by direct injection	< 1 egg/10 L	0 cfu/100 mL	< 10 mg/L	< 2 NTU	Total Nitrogen < 15 mg/L

Notes:

- cfu : Colony Forming Unit.
- The following genera are considered within the category of Intestinal Nematodes: *Ancylostoma, Trichuris, Ascaris, Strongyloides*, *Trichostrongylus*, *Toxocara*, *Enterobius* and *Capillaria*.
- The reuse of reclaimed wastewater is permitted for domestic uses with the exception of human consumption, which is strictly forbidden in the Hydraulics Public Domain Regulations (Royal Decree 849/1986, dated 11 April), except in catastrophe or emergency situations. Given the risk involved, the authorities should pay special attention to this type of concession, in addition to ensuring a strict control of the reuse conditions required.
- The reuse of reclaimed wastewater in industrial cooling for the food industry and similar is strictly forbidden.
- For uses no.'s 10 and 11, in addition to compliance with the parameters indicated in the table above, reclaimed wastewater to be reused must be odours free.
- The use of reclaimed wastewater for filtering shellfish aquaculture is strictly forbidden.
- The operation of recharging aquifers by localised percolation across the land will be carried out obligatorily via the use of a uniform soil depth with a minimum thickness of 1.5 meter.
- The quality criteria indicated for each of the uses established in Table 6, should be considered as minimum requirements for reuse, and these may be made more strict by the appropriate authorities if they consider this necessary.

The uses established in Table 6 above will not be the only possible nor permitted uses for reclaimed wastewater. However, until included in this list, any new use not contemplated in the basic regulations should be the object of a special regulation by the conferring authority of the same.

Table 7

Quality guidelines for water reuse in Andalusia

Type of application	**Faecal coliforms /100mL**	**Nematode egg/L**
Irrigation of sport fields and parks with public access	<200	<1
Vegetables to be consumed raw	<1000	<1
Production of biomass intended for human consumption and refrigeration in open circuits	<1000	None
Recreational lakes	<2000	<1
Refrigeration in semi-closed circuits	<10 000	None
Industrial crops, cereals, dry fodder seeds, forests and conserved or cooked vegetables	None	<1
Irrigation of green areas with no public access, production of biomass not intended for human consumption and recreational lakes with access prohibited	None	None

Table 8

Summary of water reuse regulations for groundwater recharge in Balearic Islands

(Source : Sintesis Del Plan Integrado Para La Reutilizacion de Aguas Tratadas En Las Islas Baleares, 1994-1997)

Requirements on the injectant	Requirements on the aquifer water
Groundwater recharge into non potable water aquifers by spreading, infiltration percolation or infiltration wells – protection against seawater intrusion	
pH = 6-9, BOD_5 < 40 mgL, COD < 120 mg/L, SS < 60 mg/L *E. coli* < 10 000/100 mL	No quality objective, at the exception of N and P limitations
Indirect potable water reuse - Groundwater recharge by spreading/percolation	
pH = 6-9, BOD_5 < 40 mg/l, COD < 120 mg/l, SS < 60 mg/l *E. coli* < 10 000/100 ml	Water should meet potable water standards after infiltration Daily monitoring of pH and coliforms Other potable water parameters monitored every 3 months Enterovirus or bacteriophages controlled monthly (0/10 L) Control on other organic and inorganic compounds, or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the potable water standards Minimum detention time : 1 year.
Indirect potable water reuse - Groundwater recharge by injection wells	
Potable water quality required at the point of injection Daily monitoring : pH = 6.5-8.5; *E. coli* absent/100 ml Continuous control: Cl_2 residual = 0.5 mg/l (30 min contact), NTU < 2 Monthly monitoring: no detectable enterovirus or bacteriophages in 10 L. All potable water standards monitored every 3 months Control on other organic and inorganic compounds, or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the potable water standards	Minimum detention time : 1 year

Table 9

Tunisian standards for reclaimed water reused in agriculture (1989)

Parameters [(a)]	**Maximum allowed concentration**
pH	6.5 - 8.5
Electrical conductivity (EC) ($\mu S\ cm^{-1}$)	7000
Chemical oxygen demand (COD)	90 [(b),(c)]
Biochemical oxygen demand (BOD_5)	30 [(b),(c)]
Suspended solids (SS)	30 [(c)]
Chloride (Cl)	2000
Fluoride (F)	3
Halogenated hydrocarbons	0.001
Arsenic (As)	0.1
Boron (B)	3
Cadmium (Cd)	0.01
Cobalt (Co)	0.1
Chromium (Cr)	0.1
Copper (Cu)	0.5
Iron (Fe)	5
Manganese (Mn)	0.5
Mercury (Hg)	0.001
Nickel (Ni)	0.2
Lead (Pb)	1
Selenium (Se)	0.05
Zinc (Zn)	5
Intestinal nematodes (arithmetic mean no. of eggs per litre)	< 1

(a): all units in mg/L unless otherwise specified;
(b): 24-hr composite sample;
(c): except special authorization for stabilization ponds.
Monitoring the physical-chemical parameters once a month, trace elements once every six months, and helminth eggs once every two weeks.
Secondary treated effluents allowed for all types of crops except vegetables, whether eaten raw or cooked.
Site restrictions related to harvesting, animal grazing, reclaimed water application methods, etc.

Table 10

Jordanian standards 893/1995 for treated domestic wastewater (mg/L)

Parameter	Irrigation of cooked vegetables	Irrigation of fruit and forestry	Irrigation of fodder crops	Irrigation of lawns, parks	Streams, wadis & reservoirs	Ground-water recharge	Fish ponds [(2)]
pH	6.9-9.0	6.9-9.0	6.9-9.0	6.9-9.0	6.9-9.0	6.9-9.0	6.9-9.0
BOD_5 [(1)]	150	150	250	50	50	50	-
COD	500	500	700	200	200	200	-
DO	More than 2	More than 2	More than 1	More than 2	More than 2	More than 2	More than 2
TSS	200	200	250	50	50	50	25
TDS	2000	2000	2000	2000	2000	1500	2000
Color (PCU)	-	-	-	75	75	75	-
Phenol	0.002	0.002	0.002	0.002	0.002	0.002	0.001
MBAS	50	50	50	15	25	15	0.2
Residual Cl_2	0.05	-	-	0.5	-	-	-
Total N	100	100	-	100	50	50	-
NO_3-N	50	50	50	25	25	25	-
NH_4-N	-	-	-	50	15	15	0.5
T-N	100	100	-	100	50	50	-
PO_4-P	-	-	-	15	15	15	-
Cl^-	350	350	350	350	350	350	350
SO_4^-	1000	1000	1000	1000	1000	1000	-
$CO_3^=$	6	6	6	6	6	6	-
HCO_3^-	520	520	520	520	520	520	-
Na^+	230	230	230	230	230	230	-
Mg^{++}	60	60	60	60	60	60	-
Ca^{++}	400	400	400	400	400	400	-
SAR	9	9	9	12	9	9	-
Al	5	5	5	5	5	1	-
As	0.1	0.1	0.1	0.1	0.05	0.05	0.05
Be	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cu	0.2	0.2	0.2	0.2	0.2	0.2	0.04
P	5.0	5.0	5.0	5.0	2.0	1.0	0.5
Fe	2.5	5.0	5.0	3.0	1.0	1.0	-
Li	0.2	0.2	0.2	0.2	0.2	0.2	1.0
Mn	0.2	0.2	0.2	0.2	0.2	0.2	0.4
Pb	5.0	5.0	5.0	0.1	0.1	0.1	0.15
Se	0.02	0.02	0.02	0.02	0.02	0.02	0.05
Cd	0.01	0.01	0.01	0.01	0.01	0.01	0.015
Zn	2.0	2.0	2.0	2.0	15	15	0.6
CN	0.1	0.1	0.1	0.1	0.1	0.1	0.005
Cr	0.1	0.1	0.1	0.1	0.05	0.05	0.1
Hg	0.001	0.001	0.001	0.001	0.001	0.001	0.00005
V	0.1	0.1	0.1	0.1	0.1	0.1	~
Co	0.05	0.05	0.05	0.05	0.05	0.05	-
B	1.0	1.0	3.0	3.0	2.0	1.0	-

Mo	0.01	0.01	0.01	0.01	0.01	0.01	-
FC (MPN/100 mL)	1000	-	-	200	1000	1000	10 000
Salmonella (MPN/100 mL)	-	-	-	None	-	-	100 000
Amoeba & Giardia (cysts/L)	<1	-	-	None	-	-	(3)
Nematodes (eggs/L)	<1	-	<1	<1	<1	-	-

(1): BOD in effluent from WSP (filtered), and from mechanical treatment plant (not filtered).
(2): These figures vary with the type of fish, pH, TDS, and temperature.

Table 11

USEPA guidelines for reclaimed water reuse[a] (1992)

Category of wastewater reuse	Treatment goals	Example applications
Urban use		
Unrestricted	Secondary, filtration, disinfection $BOD_5 \leq 10$ mg/L; Turbidity ≤ 2 NTU Faecal coliform: ND[b]/100 mL Cl_2 residual: 1 mg/L; pH: 6 to 9	All types of landscape irrigation: golf courses, cemeteries, residential, parks, playgrounds, school yards; Fire protection; construction; ornamental fountains, impoundments; In-building uses: toilet flushing, air conditioning
Restricted access area irrigation	Secondary and disinfection $BOD_5 \leq 30$ mg/L; $SS \leq 30$ mg/L Faecal coliform ≤ 200/100 mL Cl_2 residual: 1 mg/L; pH: 6 to 9	Sod farms, sylviculture sites, and other areas where public access is infrequent and controlled
Agricultural irrigation		
Food crops not commercially processed	Secondary, filtration, disinfection $BOD_5 \leq 10$ mg/L; Turbidity ≤ 2 NTU Faecal coliform: ND/100 mL Cl_2 residual: 1 mg/L; pH: 6 to 9	Surface or spray irrigation of any food crop, including crops eaten raw
Food crops commercially processed and non-food crops	Secondary, disinfection $BOD_5 \leq 30$ mg/L; $TSS \leq 30$ mg/L Faecal coliform ≤ 200/100 mL Cl_2 residual: 1 mg/L; pH: 6 to 9	Surface irrigation of orchards and vineyards, pasture for milking animals, fodder, fiber and seed crops
Recreational use		
Unrestricted	Secondary, filtration, disinfection $BOD_5 \leq 10$ mg/L; Turbidity ≤ 2 NTU Faecal coliform: ND/100 mL Cl_2 residual: 1 mg/L; pH: 6 to 9	No limitations on body-contact: lakes and ponds used for swimming
Restricted	Secondary, disinfection $BOD_5 \leq 30$ mg/L; $SS \leq 30$ mg/L Faecal coliform ≤ 200/100 mL Cl_2 residual: 1 mg/L; pH: 6 to 9	Fishing, boating, and other non-contact recreational activities
Environmental enhancement	Secondary, disinfection $BOD_5 \leq 30$ mg/L; $SS \leq 30$ mg/L Faecal coliform ≤ 200/100 mL	Wetlands, marshes, wildlife habitat, stream augmentation
Groundwater recharge	Site specific	Groundwater replenishment Salt water intrusion control Subsidence control

	Secondary	
Industrial reuse	$BOD_5 \leq$ 30 mg/L; SS $\leq$ 30 mg/L Faecal coliform $\leq$ 200/100 mL; pH: 6 to 9	Cooling-system make-up water, process waters, boiler feed water, construction activities
Potable reuse	Safe drinking water requirements	Blending with municipal water supply Pipe to pipe supply

[a] Adapted from U.S. Environmental Protection Agency, 1992.
[b]Not detected.

Table 12

Reclaimed water standards in Kuwait

Parameter	Irrigation of fodder & food crops not eaten raw, forestland	Irrigation of food crops eaten raw*
Level of treatment	Advanced	Advanced
SS (mg/L)	10	10
BOD (mg/L)	10	10
COD (mg/L)	40	40
Chlorine residual (mg/L) After 12 h at 20°C	1	1
Coliform bacteria (count/100 mL)	10 000	100

* not including salad crops or strawberries.

Table 13

Reclaimed water guidelines in South Africa

Reuse application	Level of treatment	Maximum faecal coliform (count/100 mL)
Irrigation of dry fodder, seed crops, trees, non-recreational parks, nurseries (restricted access)	Primary and secondary; humus tank effluent	< 1000
Food crops not eaten raw, cut flowers, orchards and vineyards, pasture, parks, sports fields, school grounds (restricted access)	Primary, secondary, and tertiary; oxidation pond system	< 1000
Pasture for milking animals, sports fields, school grounds (unrestricted access)	Standard - primary, secondary, and tertiary	0.0
Food crops eaten raw, lawns, nurseries, school grounds, play parks (unrestricted access)	(general drinking water standards)	-
Industrial reuse	Primary, secondary, and tertiary; oxidation pond system	< 1000
Toilet flushing and dust control	Standard - primary, secondary, and tertiary	0.0
Human washing	Advanced (general drinking water standards)	-

Table 14

Recommended revised WHO microbiological 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 A1 For vegetable and salad crops eaten uncooked, sports fields, public parks[e]	Workers, consumers, public	Any	≤ 0.l[f]	$\leq 10^3$	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)
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	$\leq 10^5$	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	$\leq 10^3$	As for Category A
		B3 Workers including children < 15 years, nearby communities	Any	≤ 0.1	$\leq 10^3$	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, socio-cultural 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 water 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.

Table 15

Japanese reclaimed water quality criteria for toilet flushing, landscape irrigation, and environmental water

Parameter	**Toilet flushing water**	**Landscape irrigation**	**Ornamental lakes & streams**	**Environmental water (aesthetic setting)**	**Environmental (limited public contact)**
Total coliform bacteria (cfu/100 mL)	≤1,000*	***Not detected***	***Not detected***	≤1,000	≤50
Residual chlorine (combined), (mg/L)	Trace amount	≥0.4	-		
Appearance	Not unpleasant	Not unpleasant	Not unpleasant	-	-
Turbidity, unit	-	-	-	≤10	≤5
BOD (mg/L)	-	-	≤10	≤10	≤3
Odor	Not unpleasant	Not unpleasant	Not unpleasant	Not unpleasant	Not unpleasant
pH, unit	5.8-8.6	5.8-8.6	5.8-8.6	5.8-8.6	5.8-8.6
Color, unit	-	-	-	≤40	≤10

* The Japanese measurement method for total coliforms uses plate count method with 1 mL sample size and should be equal to or less than 10/10 mL (i.e., ≤ 1,000/100 mL).

Table 16

Proposed State of California criteria for groundwater recharge and reuse projects. (After Asano and Cotruvo, 2002)

	TYPE OF RECHARGE	
Contaminant Type	**Surface Spreading**	**Subsurface Injection**
Pathogenic microorganisms		
Secondary treatment	SS ≤ 30 mg/L	
Filtration	≤ 2 NTU	
Disinfection	4-log virus inactivation ≤ 2.2 total coliform per 100 mL	
Retention time underground	6 mos.	12 mos.
Horizontal separation	500 ft	2000 ft
Regulated contaminants	Meet all drinking water maximum contaminant levels	
Unregulated contaminants		
Secondary treatment	BOD ≤ 30 mg/L, TOC ≤ 16 mg/L	
Reverse osmosis	Four options available	100% treatment to *TOC* ≤ 1 mg / L **RWC**
Spreading criteria for SAT 50% TOC Removal Credit	Depth to groundwater at initial percolation rates of: < 0.2 in/min = 10 ft. < 0.3 in/min = 20 ft.	NA
Mound monitoring option	Demonstrate feasibility of the mound compliance point	NA
Reclaimed water contribution	≤ 50%	

Note: RWC = the percent reclaimed water contribution in groundwater extracted by drinking water wells.

DEFINITIONS OF TERMS : Trickle irrigation and filtration systems (after ICID, 1977)

Trickle irrigation : The frequent application of small quantities of water directly on or below the soil surface, usually as discrete drops, continuous drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. Trickle irrigation encompasses a number of methods or concepts, such as drip, subsurface, bubbler, and spray irrigation.

Drip irrigation : The application of water to the soil surface as discrete or continuous drops, or tiny streams, through emitters. Often the terms drip and trickle irrigation are considered synonymous; however, in this Engineering Practice trickle irrigation also includes those systems which have higher discharge rates than most drip systems. For drip irrigation discharge rates for point-source emitters are generally less than 12 L/h (3 gal/h) for single-outlet emitters, and line-source emitters are generally less than 12 L/h/m (1 gal/h/ft) of lateral.
Subsurface irrigation : The application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation. This method of water application is different from and not to be confused with the method where the root zone is irrigated by water table control, herein referred to as subirrigation.

Bubbler irrigation : The application of water to the soil surface as a small stream or fountain, where the discharge rates for point-source bubbler emitters are greater than for drip or subsurface emitters but generally less than 225 L/h (60 gal/h). Because the emitter discharge rate normally exceeds the infiltration rate of the soil, a small basin is usually required to contain or control the water.

Spray irrigation (*): The application of water by a small spray or mist to the soil surface, where travel through the air becomes instrumental in the distribution of water compared to drip, bubbler, and subsurface irrigation (where the soil or distribution tubing is primarily responsible for the distribution of water). Discharge rates for point-source spray emitters are generally lower than 115 L/h (30 gal/h).

Trickle irrigation systems : The physical components required to apply water by trickle irrigation. System components that may be required include the pumping station, control station, main and submain lines, manifold lines, lateral lines, emitters, valves, fittings, and other necessary items.

Filtration system: The assembly of physical components used to remove suspended solids from irrigation water. This may include both pressure and gravity-type devices and such specific units as setting basins or reservoirs, screens, media beds, and centrifugal force units.

(*) In this document, spray irrigation is referred as micro-sprinkler irrigation.