WASTEWATER REUSE FOR AGRICULTURE

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Abstract

The present paper is based on a literature review and aims to tackle the most important aspects regarding the topic wastewater reuse with some recent examples, focusing on reuse in agriculture. Still in some countries the institutional and legal framework is weak or not existent or only referring to international standards (guidelines or laws) which are very general and most of the times demand very cost intensive solutions. An integrated planning approach is therefore necessary in case reuse of wastewater shall be one management alternative in a water stressed basin. Here the technological, economical and health aspect as well as the legal framework have to be considered. Therefore reuse of water is an interdisciplinary challenge for the present and for the future.

Keywords: Reuse of wastewater, irrigation, guidelines for water reuse, treatment, integrated approach, public acceptance

1 Introduction

An examination of the average residence times in the natural water cycle shows that, on the average, water that is used once then discharged and flows to the ocean will not return again as rain for about 2600 years. Groundwater residence times are often even longer (VEN-TE, 2001). This fact, as well as different studies about the world water problems, for example a release of the United Nations which predict a severe water shortage for about 2.7 billions people in the year 2025, urge us to develop and implement new water management strategies. One of the “Bonn keys” of the International Conference on Freshwater at the end of 2001 was decentralization, which means the development of small water cycles on a local level. One recommended target of the Johannesburg Summits (2002) is the increase of water productivity in agriculture to enable food security for all people without increasing water diverted for agriculture over that used in the year 2000 (HRH, 2002).

Seventy percent of world water use, including all the water diverted from rivers and pumped from underground, is used for irrigation, 20 percent is used by industry, and 10 percent goes to residences. The freshwater withdraw in agriculture and the industry worldwide is shown in the next figure.

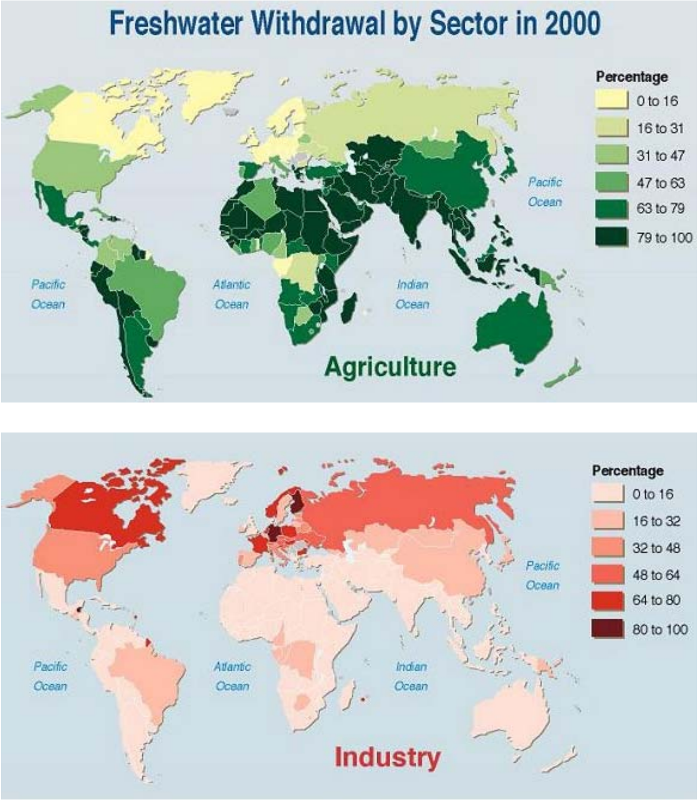


Figure 1: Freshwater withdraw worldwide by sector in 2000: Source World Resources 2000-2001. People and Ecosystems, Washington DC 2000

Thus if the world is facing a water shortage, it is also facing a food shortage. Water deficits, which are already spurring heavy grain imports in numerous smaller countries, may soon do the same in larger countries, such as China or India (Earth Policy Institute, 2002).

An example showing the severity of water scarcity in numbers has been done by a World Bank study of the water balance in the North China Plain. The study calculated an annual deficit of 37 billion tons of water. Using the rule of thumb of 1,000 tons of water to produce 1 ton of grain, this is equal to 37 million tons of grain - enough to feed 111 million Chinese at their current level of consumption. In effect, 111 million Chinese are being fed with grain produced with water that belongs to their children. Scores of other countries are running up regional water deficits, including nearly all of those in Central Asia, the Middle East, and North Africa, plus India, Pakistan, and the United States (Earth Policy Institute, 2002).

Therefore water supply and sanitation will be one of the main future challenges in a world of growing population and industrialisation. The growing awareness of water resource scarcity, the competition for water resources and the negative impact of contaminated water on human health and the environment demand the development of adequate strategies in water management. Next to the development of new management strategies to supply fresh water, the issue of treating and recycling wastewater will play an important role in tackling the existing and occurring problems. Here the shortage of water is usually the main driving force for conservation of water.

This conservation is realized through pricing reforms, wastewater treatment technologies and wastewater reuse.

Wastewater reuse is not a recent invention. There are indicators that wastewater was used back for irrigation in ancient Greece and in the Minan civilisation (ca. 3000 – 1000 BC) (ANGELAKIS ET AL., 1999; ASANO AND LEVIN, 1996).

During 1950-60, interests in applying wastewater on land in the western hemisphere as wastewater treatment technology advanced and quality of treated effluents steadfastly improved. Land application became a cost-effective alternative of discharging effluent into surface water bodies (ASANO T., 1998).

2 Possibilities of reuse

Two major types of reuse have been developed and practiced throughout the world:

(1) potable uses

- direct, use of reclaimed water to augment drinking water supply following high levels of treatment
- indirect after passing through the natural environment

(2) non-potable uses

- irrigated agriculture
- use for irrigating parks, public places of forestry (fastest reuse application in Europe: Irrigation of golf courses)
- use for aquaculture
- aquifer recharge (indirect reuse)
- or uses in industry and urban settlements

The following graph shows the percentage of total water reuse per sector for California, Florida and Japan. It can be observed that in agricultural irrigation the water reuse overall is highest, but strongly dependent on the regional context. In Japan the reuse for example is highest in the industrial and commercial sector.

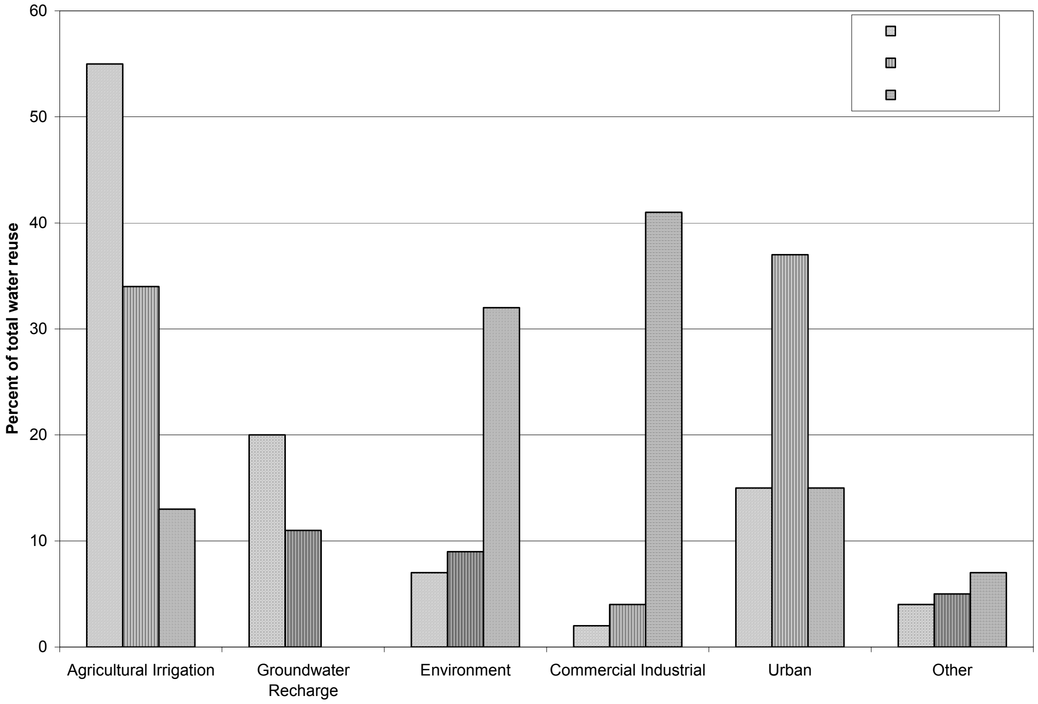


Figure 1: Comparison of distribution of reclaimed water applications in California, Florida, and Japan [Source: Asano T. 1998]

The integration of wastewater reuse in the existing water management master plans has been essentially geared towards agricultural irrigation (LAZAROVA V. ET AL, 2000).

The wastewater used in irrigation can be from different sources. It can be completely untreated municipal or industrial wastewater, mechanically purified wastewater or particularly or fully purified wastewater treated biologically (DONTA, A., 1997).

When considering wastewater reuse for irrigation an evaluation of the advantages, disadvantages and possible risks has to be made. The following table summarizes the advantages, disadvantages and possible risks regarding water conservation, different substances in the water and influences regarding the soil.

Advantages	Disadvantages	Risks
▪ Improvement of the economic efficiency of investments in wastewater disposal and irrigation ▪ Conservation of freshwater sources ▪ Recharge of aquifers through infiltration water (natural treatment)	Wastewater is normally produced continuously throughout the year, whereas wastewater irrigation is mostly limited to the growing season.	Potential harm to groundwater due to heavy metal, nitrate and organic matter

Use of the nutrients of the wastewater (e.g. nitrogen and phosphate) ⇒ reduction of the use of synthetic fertilizer ⇒ improvement of soil properties (soil fertility; higher yields)	Some substances that can be present in wastewater in such concentrations that they are toxic for plants or lead to environmental damage	Potential harm to human health by spreading pathogenic germs
Reduction of treatment costs: Soil treatment of the pre-treated wastewater via irrigation (no tertiary treatment necessary, highly dependent on the source of wastewater)		Potential harm to the soil due to heavy metal accumulation and acidification
Beneficial influence of a small natural water cycle		
Reduction of environmental impacts (e.g. eutrophication and minimum discharge requirements)		

Table 1: Advantages, disadvantages and possible risks of wastewater reuse

By summarizing the positive and negative aspects it can be stated that wastewater, even when treated, is often associated with health and environmental risks. In addition, there is often a time gap between supply of wastewater and demand by irrigated agriculture, making sometimes costly storage capacities necessary.

3 Different sources of wastewater

Most of the examples and recent research papers are dealing with reuse of municipal wastewaters. Nevertheless it is worth to study the potential of using industrial wastewater for irrigation considering that around 20 per cent of worldwide water production are used in the industrial sector compared to 7 per cent in the municipal sector.

Among industrial wastewater it is predominantly wastewater from food processing industries that has high potential to be reused in agriculture since the main constituents are organic substances. Förster et al. (1988) investigated already in the 80s the impact on the soil, the plants and the different yields of the crops when irrigated with wastewater from food processing industries. The main outcomes were positive by means of no neg. accumulation of harmful substances in the soil and higher yields of some crops. Table 2 specifies some food processing industries which could be employed for wastewater reuse.

Source of wastewater	Pre-treatment	Contaminants	N mg/l	P mg/l	K mg/l
Distilleries	mechanical purif. neutralization	Alkali, Acids, Soda, Chlorine-compounds	25	1	20
Brewery/Malting	mechanical purif. neutralization	Yeast, Carbohydrates, settleable solids	40	5	50
Fish processing	mechanical purif. fat separation, dilution, chlorination, desodoration	scale, fats, oils, org. acids, Salt, H_2O_2	500	-	-
Potato flour	mechanical purif.	none	550	140	95
Canning	mechanical purif. neutralization, desodoration	salts, organic acids, detergents, corrosive substances	60	10	35
Diary	mechanical purification	disinfectants	35	10	20
Starch	mechanical purification, neutralization, dilution	salts, acids	300	45	415
Cider	mechanical purif. neutralization, precipitation	detergents	870	160	-
Sugar	mechanical purif.	strontium, tar, prussic (cyanic) acid	50	10	-

- no data

Table 2: Selected food industries, treatment and composition of wastewater [SOURCE: KRETZSCHMAR, 1990 cited in DONTA]

4 Quality of the reused wastewater

The options for sustainable reuse projects are related to the quality of the effluent, and the environmental risk associated with land application for a variety of crops and activities. Patterson (2000) points at the different regulations existing for domestic and industrial effluent at an example of Australia which is valid worldwide. He describes the households as a high potential of pollution since they are able to discharge “a cocktail of chemicals at varying concentrations, together with biodegradable and non-biodegradable solids” without any concern as to the ramifications of those discharges either on the treatment system or the expected final quality of the discharged water. Whereas discharges from commercial and industrial premises into sewers are under greater scrutiny as government councils implement licensing and monitoring programs.

As already mentioned by specifying some advantages, agriculture can be understood as a land treatment system as part of the treatment cycle and is considered as the nutrient recycling part of the loop. The soil as a bioreactor and its capacity to attenuate contaminants are taken into account. Nevertheless quality requirements of the treated wastewater used for irrigation purposes have to be met (JUANICO, 1993 cited in BAHARI A. 1999).

The most important criteria for evaluation of the treated wastewater are as follows:

- Salinity (especially important in arid zones)
- Heavy metals and harmful organic substances
- Pathogenic germs

In Table 3 the most important water quality parameters and their significance are listed (in the case of municipal wastewater reuse further microbiological investigations have to be done) (refer to the next paragraph: Hygienic considerations).

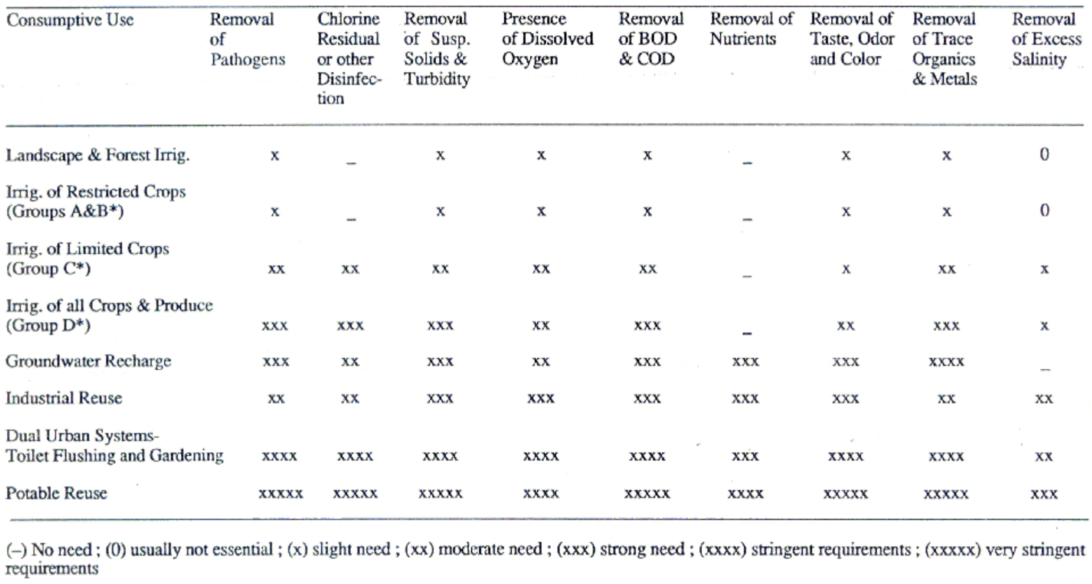
Parameter	Significance	Approximate Range in Treated Wastewater
Total Suspended solids (TSS)	TSS can lead to sludge deposits and anaerobic conditions. Excessive amounts cause clogging of irrigation systems Measures of particles in wastewater can be related to microbial contamination, turbidity. Can interfere with disinfection effectiveness	< 1 to 30 mg/l
Organic indicators		
TOC	Measure of organic carbon	1 – 20 mg/l
Degradable Organics (COD, BOD)	Their biological decomposition can lead to depletion of oxygen. For irrigation only excessive amounts cause problems. Low to moderate concentrations are beneficial.	10 – 30 mg/l
Nutrients N,P,K	When discharged into the aquatic environment they lead to eutrophication. In irrigation they are beneficial, nutrient source. Nitrate in excessive amounts, however, may lead to groundwater contamination.	N: 10 to 30 mg/l P: 0.1 to 30 mg/l

Parameter	Significance	Approximate Range in Treated Wastewater
Stable organics (e.g. phenols, pesticides, chlorinated hydrocarbons)	Some are toxic in the environment, accumulation processes in the soil.	
pH	Affects metal solubility and alkalinity and structure of soil, and plant growth.	
Heavy metals (Cd, Zn, Ni., etc.)	Accumulation processes in the soil, toxicity for plants	
Pathogenic organisms	Measure of microbial health risks due to enteric viruses, pathogenic bacteria and protozoa	Coliform organisms: < 1 to 10^4 /100 ml other pathogens: Controlled by treatment technology
Dissolved Inorganics (TDS, EC, SAR)	Excessive salinity may damage crops. Chloride, Sodium and Boron are toxic to some crops, extensive sodium may cause permeability problems	

Table 3: Physio-chemical parameters, their significance and approximate ranges for treated wastewater [SAR= Sodium adsorption ratio, for detailed information refer to ASANO, TAKASHI, 1998]

The goal of each water reuse project is to protect public health without necessarily discouraging wastewater reclamation and reuse. Regulatory approaches stipulate water quality standards in conjunction with requirements for treatment, sampling and monitoring. These standards or guidelines are highly dependent on the kind of water use.

Table 4 schematically depicts the various consumptive uses of reclaimed wastewater together with their respective water quality considerations in a more or less scending order of quality requirements (SHELEF, 1991).



Consumptive Use	Removal of Pathogens	Chlorine Residual or other Disinfection	Removal of Susp. Solids & Turbidity	Presence of Dissolved Oxygen	Removal of BOD & COD	Removal of Nutrients	Removal of Taste, Odor and Color	Removal of Trace Organics & Metals	Removal of Excess Salinity
Landscape & Forest Irrig.	x	–	x	x	x	–	x	x	0
Irrig. of Restricted Crops (Groups A&B*)	x	–	x	x	x	–	x	x	0
Irrig. of Limited Crops (Group C*)	xx	xx	xx	xx	xx	–	x	xx	x
Irrig. of all Crops & Produce (Group D*)	xxx	xxx	xxx	xx	xxx	–	xx	xxx	x
Groundwater Recharge	xxx	xx	xxx	xx	xxx	xxx	xxx	xxxx	–
Industrial Reuse	xx	xx	xxx	xxx	xxx	xxx	xxx	xx	xx
Dual Urban Systems-Toilet Flushing and Gardening	xxxx	xxxx	xxxx	xxxx	xxxx	xxx	xxxx	xxxx	xx
Potable Reuse	xxxxx	xxxxx	xxxxx	xxxx	xxxxx	xxxx	xxxxx	xxxxx	xxx

(–) No need ; (0) usually not essential ; (x) slight need ; (xx) moderate need ; (xxx) strong need ; (xxxx) stringent requirements ; (xxxxx) very stringent requirements

Table 4: Consumptive user of reclaimed wastewater and qualitative water quality requirements [source: SHELEF 1991]

Obviously the landscape and forest irrigation has the lowest requirements concerning the treatment of effluent, compared to the potable reuse. But also the requirements of irrigation of limited crops (crops that need further processing) are not high and therefore in economic terms applicable. The table shows that not only the source of the wastewater and therefore the substances in the effluent but also the planned reuse is important for evaluating the necessary kind of treatment.

IDELOVITCH E., RINGSKOG K. 1997 and SHELEF G. 1996 explain the distinction between restricted and unrestricted irrigation (depending on the kind of crop):

(1) Restricted

- use of low quality effluents in limited areas and for specific crops only
- Restrictions are imposed based on the type of soil, the proximity of the irrigated area to a potable aquifer, irrigation method, crop harvesting technique, and fertilizer application rate
- Simple and low cost, in general only applicable to small amounts of wastewater, used in specific locations, where areas and crops are well-defined and unlikely to change
- Imposed crop limitation must be enforced and controlled
- Farmers must be trained to handle the low-quality effluent

(2) Unrestricted

- Use of high quality effluents, instead of freshwater, to irrigate any crop on any type of soil, which means without limitations
- Contact and even accidental drinking do not pose health risks
- Crops without any restriction include also vegetables eaten raw.

The quality standard can even vary during irrigation and non irrigation period. It might be higher during interim periods when irrigation is not practiced to ensure a relatively safe discharge to receiving water bodies.

Table 5 provides values on water quality as a general guideline for interpretation of water quality for irrigation, depending on the degree of restriction.

Degree of Restriction of use				
Parameter	Units	Slight to None	Moderate	Severe
Salinity, Ecw	dS/m or µmhos/cm	< 0.7 dS/m	0.7 – 3.0 µmhos/cm	> 3.0 µmhos/cm
Total dissolved Solids, TDS	mg/l	< 450	450 - 2000	> 2000
Total suspended solids, TSS	mg/l	< 50	50 - 100	> 100
Bicarbonate, (HCO_3^-)	mg/l	< 90	90 - 500	> 500
Boron (B)	mg/l	< 0.7	0.7 - 3.0	> 3.0
Chloride (Cl^-), sensitive crops	mg/l	< 140	140 - 350	> 350
Chloride (Cl^-), sprinklers	mg/l	< 100	> 100	> 100
Chloride (Cl_2), total residual	mg/l	< 1.0	1.0 - 5.0	> 5.0
Hydrogen Sulfide (H_2S)	mg/l	< 0.5	0.5 - 2.0	> 2.0
Iron (Fe), drip irrigation	mg/l	< 0.1	0.1 - 1.5	> 1.5
Manganese (Mn), drip irrigation	mg/l	< 0.1	0.1 – 1.5	> 1.5
Nitrogen (N), total	mg/l	< 5	5 - 30	> 30
Sodium (Na^+), sensitive crops	mg/l	< 100	> 100	> 100
Sodium (Na^+), sprinklers	mg/l	< 70	> 70	> 70
SAR	mg/l	< 3	3 - 9	> 9

Table 5: Guidelines for interpretation of Water Quality for Irrigation [source: Ayers and Westcott (1985)]

5 Hygienic considerations

Predominantly with domestic sewage the issue of contamination with bacteria or viruses is extremely important. However, also with industrial wastewater pathogens might occur and should at least once in the beginning be analyzed.

Usually the coliform bacteria is taken as an indicator organism. In 1985 World Bank, UNEP, UNDP and WHO released a study giving recommendations for irrigation water used for raw consumable crops: Coliform bacteria ≤ 1000/100 ml; Helminths eggs: ≤ 1 (Note: European rivers, for example, have a count of coliform bacteria around 100/100 ml).

UNEP (1997) consider the protection of public health, especially that of workers and consumers for one of the most critical steps in any reuse program. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary. Table 6 presents a range of typical survival times for potential pathogens in water and other media.

Pathogen	**Freshwater and sewage**	**Crops**	**Soil**
Viruses	< 120 but usually < 50	< 60 but usually < 15	< 100 but usually <20
Bacteria	< 60 but usually < 30	< 30 but usually < 15	< 70 but usually <20
Protozoa	< 30 but usually < 15	< 10 but usually < 2	< 70 but usually <20
Helminth	Many Month	< 60 but usually < 30	Many Month

Table 6: Typical Pathogen Survival Times at 20 - 30°C (in days); [Source: U.S. Environmental Protection Agency, Process Design Manual: Guidelines for Water Reuse. Cincinnati, Ohio, 1992 (Report No. EPA-625/R-92-004)]

6 Existing international quality standards/regulations and guidelines

- EPA 1992: Guidelines for water reuse: Beside the reclaimed water quality guidelines, recommended monitoring and setback distances are given
- WHO 1989: “Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture“, they take into account the treatment process, irrigation system and the crops to be irrigated. This set of guidelines is controversial but has allowed a real development of wastewater reuse (BAHRI A. 1999)
- FAO 1985 (Quality criteria) determine the degree of suitability of a given effluent of irrigation (AYERS AND WESTCOT, 1985), for specific values refer to FAO Irrigation and Drainage Paper 47 (FAO, 1991)

The requirements are based primarily on defining the extent of needed treatment of wastewater together with numerical limits on bacteriological quality, turbidity and suspended solids. The Wastewater Reclamation Criteria adopted by California (see Table 7, first column) is one example: This regulation does not set any numerical limits, except for the bacteriological quality of water.

A comparison of international standards might help to develop guidelines for the reference area within each particular project. Table 7 summarizes some of the worldwide existing standards for reuse in agriculture. In many countries like USA and Spain only regional standards exist. A very limited number of European countries have guidelines or regulations on wastewater reclamation and reuse because first they usually do not need to reuse water and second their rivers have a sufficient dilution factor.

At the Third International Symposium on Wastewater Reclamation, Recycling and Reuse (Paris, 2000) the idea about the development of international guidelines for water recycling as a framework for national decision making was presented (ANDERSON, 2001). The international community is convinced that the health and environmental protection measures need to be tailored to suit the local balance between affordability and risk. As an recently drafted guideline, the Australian water recycling guidelines are presented. Here the attempt is done to link recycled water applications and grades of treatment (ANDERSON, 2001). The topic of national or even regional standards can be seen as an issue under discussion and still needs input from various professions and discussions between responsible institutions.

Table 7: Comparison of selected water quality guidelines/standards (Adopted from ANGELAKIS ET AL. 1999, compare: EPA 1992, WHO 1989, Norma Chilena Oficial Nch 409 (1984)/1333 (1978)) for water reuse in agriculture (see following page)

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[1] Spray Irrigation; advanced = Oxydation, coagulation, clarification, disinfection.

[2] As those of WHO with additional rules

[3] article 12 of the European Wastewater Directive (917271/ECC): 'Treated wastewater shall be reused whenever appropriate'. See also, ANGELAKIS, A.N. and ASANO, T. (2000)

[4] Zielvorgaben zum Schutz oberirdischer Gewässer Band I –III (1997,1998), Länderarbeitsgemeinschaft Wasser (LAWA)

Parameter	California[1] Ca/T-22 (1978)	US EPA (1992)	WHO (1989)	Israel (1978)	Tunisia (1975)	Cyprus (1997)	Chile 1984/1978	France[2] (1991)	Italy (1977)	Germany
								EU guidelines (for water use in agriculture not existent until now)[3]		
Type	Law	Guidelines	Guidelines	Law	Law	Provisional standards	Guidelines	Guide-lines	law	Guidelines LAWA[4]
minimum treatment required	Advanced	Adanced	Stabilization ponds	Secondary	Stabilization ponds	Tertiary		Stabilization ponds	Secondary	
BOD total (mg/l)		10		15	30	10				Only Heavy metals
SS (mg/l)		5		15	30	10				are
total colif. (MPN/100ml)	2.2	0		2.2					2	considered in the
feacal colif. (per 100 ml)		14 (which means not detectable)	1000			50	1000	1000		guidelines
Helmiths (eggs/100 cm3)	-	-	1		<1	0		1		
SAR									< 10	
main treatment process	Oxydation Clarification filtration disinfection	Filtration Disinfection	Stabilization ponds or equivalent	Long storage, disinfection	Stabilization ponds or equivalent	Filtration Disinfection		Stabilization ponds or equivalent		

7 Selection of Treatment Method

The degree of treatment required and the extent of monitoring necessary depend on the specific application, as mentioned before.

Regarding the place of agriculture in the wastewater treatment cycle there are two possible approaches to reach the target water quality. First would be the use of technically proven wastewater processes or a conservative approach in which the role of the soil in the attenuation of contaminants is neglected. The second possibility is a step by step approach where agriculture is integrated as a land treatment system to the treatment cycle.

An example of possible treatments (in the Mediterranean region) in connection with the type of crop is shown in Table 8.

Condition for use	Recommended Treatment
Irrigation of very restricted crops	Primary; anaerobic ponds; facultative ponds WHO (1989) Primary sedimentation and pretreatment
Irrigation of restricted crops	Stabilization ponds in series or aerated lagoons, followed by stabilization reservoirs WHO (1989): 8 -10 days retention in waste stabilization ponds (WSP)
Irrigation without restrictions	Stabilization ponds with polishing steps and reservoirs; or secondary: filtration (or equivalent) and disinfections WHO (1989): series of WSP

Table 8: Possible reuse and possible preceding treatment (comparison: WHO (1989) and SHELEF (1996))

In contrast ASANO and LEVINE (1996) refer to the so called “Monterey Wastewater Reclamation Study for Agriculture”, which was a 10 years field study in the 1980s in California designed to evaluate the safety and feasibility of using reclaimed municipal wastewater to irrigate food crops that may be eaten raw (Engineering Science, 1987). This study as well as the Pomona Virus study (Sanitation Districts of Los Angeles County, 1977) provided conclusive evidence that effective virus removal can be accomplished through alternative tertiary treatment systems. A major benefit of these studies was the demonstration of lower cost alternatives for the production of reclaimed wastewater for irrigation processes. By comparison of the WHO guidelines and the criteria from California it is evident that the latter require less treatment and different monitoring conditions. The California criteria for example stipulate conventional biological wastewater treatment followed by tertiary treatment including filtration and chlorine disinfection to produce effluent that is virtually pathogen-free. In contrast the WHO guidelines emphasize that a series of stabilization ponds is necessary to meet microbiological water quality requirements.

In accordance with MURCOTT (1995) the ideal characteristics of water to be used in crop irrigation are: (a) high organic content; (b) high nutrient content (N, P); (c) low pathogen content and (d) low metal and toxic organic compounds contents. To fulfil these specifications, biological and physiochemical processes can be applied, combined with three levels of treatment: primary, secondary and tertiary (compare Table 9).

Process	Organic Contents	Nutrients N and P	Pathogens
Primary	High	High	High
Primary Advanced	Medium	Medium	Medium to low
Activated Sludge	Low	Medium	Medium to low

Table 9: Effluent quality of different processes (MURCOTT, 1995)

The Environmental Protection Agency of the United States (EPA) set up some guidelines for utilization of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances, which are summarized in Table 10.

Type of Reuse	Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
Irrigation of: Food crops commercially processed	Secondary Disinfection	pH = 6 - 9	pH weekly	300 ft from potable water supply wells
		BOD ≤ 30 mg/l	BOD weekly	
Orchards and Vineyards		SS = 30 mg/l	SS daily	100 ft from areas accessible to public
		FC ≤ 200/100 ml	FC daily	
		Cl_2 residual = 1 mg/l min	Cl_2 residual continuous	
Pasturage	Secondary Disinfection	pH = 6 - 9	pH weekly	300 ft from potable water supply wells
Pasturage for milking animals		BOD ≤ 30 mg/l	BOD weekly	
Pasture for livestock		SS = 30 mg/l	SS daily	100 ft from areas accessible to public
		FC ≤ 200/100 ml	FC daily	
		Cl_2 residual = 1 mg/l min	Cl_2 residual continuous	

Type of Reuse	Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
Food crops not commercially processed	Secondary Filtration Disinfection	pH = 6 - 9	pH weekly	50 ft from potable water supply wells
		BOD ≤ 30 mg/l	BOD weekly	
		Turbidity ≤ 1 NTU	Turbidity daily	
		FC = 0/100 ml	FC daily	100 ft from areas accessible to public
		Cl_2 residual = 1 mg/l min	Cl_2 residual continuous	
Groundwater recharge	Site-specific and use-dependent	Site-specific and use-dependent	Depends on treatment and use	Site-specific

Table 10: Guidelines for water reuse [Source: EPA, Process Design Manual: Guidelines for Water Reuse, Cincinnati, Ohio, 1992: Report No. EPA-625/R-92-004]

Legend: SS= suspended solids; FC= fecal coliforms

When dealing with decisions about possible treatment systems more and more examples of non conventional solutions are being designed, tested and evaluated. Gearheart (1999) presents an example where constructed wetlands, a low cost alternative, serve as a part in a natural treatment system. The system under consideration had three components: oxidation ponds, wetland and UV disinfection). Even without the third component the system produces an effluent that can be used for a wide variety of reuse for irrigation and groundwater recharge. This shows that low cost possibilities can perform depending on the case quite well and should always be considered from decision makers.

When talking about reuse in agriculture not only different treatment technologies have to be taken into consideration but also different irrigation technologies. For example already on surface and subsurface drip irrigation shows differences in soil moisture content, soil salinity, nitrogen, phosphorus and Potassium content (Oron et al, 2001).

8 Planning of Agricultural Reuse Projects (Integrating Planning Approach)

Agricultural reuse development as one waste water reuse option has to be integrated in water management and a watershed approach. It is a wastewater reuse option which has to be included with wastewater reclamation, in an overall planning effort for public health protection, environmental pollution control, and water resources management (Asano and Levine, 1996).

Therefore the planning and management of agricultural reuse projects need to consider institutional and legal, socio-economic, financial, environmental, technical and psychological aspects (Lazarova V. et al, 2000). Most of the aspects have still to be studied in more detail since they require the development of appropriate strategies and qualified bodies for local management of treatment and reuse projects. One important key issue is often the lack of the institutional settings and guidelines or measures to be able to implement a planned reuse project. Regulatory settings of directives can be a tool for helping to get public acceptance and willingness to implement reuse projects.

A number of questions are being addressed, that have to be answered before extensive wastewater reuse operations are implemented (BAHRI A., 1999). Table 11 gives a summarization of the important issues that have been addressed in the planning phase.

Table 11: Summary of Major Elements of Wastewater Reuse Planning [Source: TAKASHI ASANO [1998]]

Planning Phase	Objective of Planning
Assess wastewater treatment and disposal needs	Evaluate quantity of wastewater available for reuse and disposal options
Assess water supply and demand	Evaluate dominant water use patterns
Analyse market for reclaimed water	Identify potential users of reclaimed water and associated water quantity and quality requirements
Conduct engineering and economic analysis	Determine treatment and distribution system requirements for potential users of reclaimed water
Develop implementation plan with financial analysis	Develop strategies, schedule, and financing options for implementation of project (including alternatives, which can be evaluated)

During the stage of planning a systematic and phased approach to evaluate project feasibility is therefore advisable.

The alternative formulation and analysis should consider the following major feasibility criteria:

- Engineering feasibility
- Economic feasibility
- Financial feasibility: Development of a construction financing plan and revenue program
- Institutional feasibility: Formal discussion with suppliers, wholesalers, retailers, and users of reclaimed water with the goal to reach an agreement on legal and operational responsibilities
- Environmental impact
- Social impact and public acceptance
- Market feasibility

The experience of other wastewater recycling projects emphasize on planning factors concerning the environmental impact and the public health:

- distance from irrigated land (economic criteria)
- distance from protection zones and surface water bodies

- wastewater quantities compared to crop water requirements/land capacities
- water balance at site, distance to aquifer
- temporal distribution of supply and demand
- type of agricultural use
- soil type and class
- Type of available water storage, distribution and irrigation technology
- composition of wastewater
- wastewater pre-treatment requirements
- selection of crops: forestry, orchards/fruit trees, crops which will be consumed cooked/processed or raw etc.

Integrated approach additionally contains the requirement of coordination and cooperation between wastewater treatment agencies and the reclaimed water users. So called participatory approaches based on water users associations are developing (in contrast to the generally adopted top-down approach). This might ensure safe and efficient use of effluent as well increase the reuse rate through more demand driven reuse (BAHRI A., 1999).

9 Economic considerations

To optimize the net benefits from implementation of waste water reuse, a well designed integrated planning process, as described before is essential. Conceptual level planning for wastewater reuse typically involves definition of the project, cost estimation, and identification of a potential reclaimed water market.

Furthermore social and economic benefits of agricultural wastewater reuse have to be assessed (BAHRI A. 1999; HARUVY NAVA 1997,1998; HARUVY ET AL.1999 among other studies).

A distinction between economic and financial analysis has to be made. The objective of the economic analyses of wastewater reuse projects is to quantify impacts on society, whereas financial analysis are targeted on the local ability to raise money from project revenues, governmental grants, and loans to pay for the project.

- Economic analysis: Focus on the value of resources invested in a project to construct and operate it, measured in monetary terms and computed in terms of present value estimations
- Financial analysis: determines if a favoured economic option is financially viable (PORTER, 1984).

The marginal financial analysis to be considered consists of the following costs:

Capital costs (include leads payments, dept serving), operation and maintenance costs, energy costs, revenue and timing of expenditure and receipts (examples refer to BURGESS, 1991).

A cost-benefit analysis of reuse operations is useful. A water reuse project generates monetary and non-monetary benefits. Positive aspects like

- Value of water and nutrients
- Improvement in the environment, e.g. quality of receiving bodies
- Improvement in public health
- Benefits for wastewater agencies and local authorities:
- Reduction of effluent discharge and preservation of discharge capacity
- Elimination of certain treatment processes to meet mass limits
- Sale of recycled water

Possible negative aspects like:

- Risks of aquifer pollution mainly by pathogens and organic trace elements
- Health risk of contaminated crops
- Storage and conveyance costs
- Treatment costs

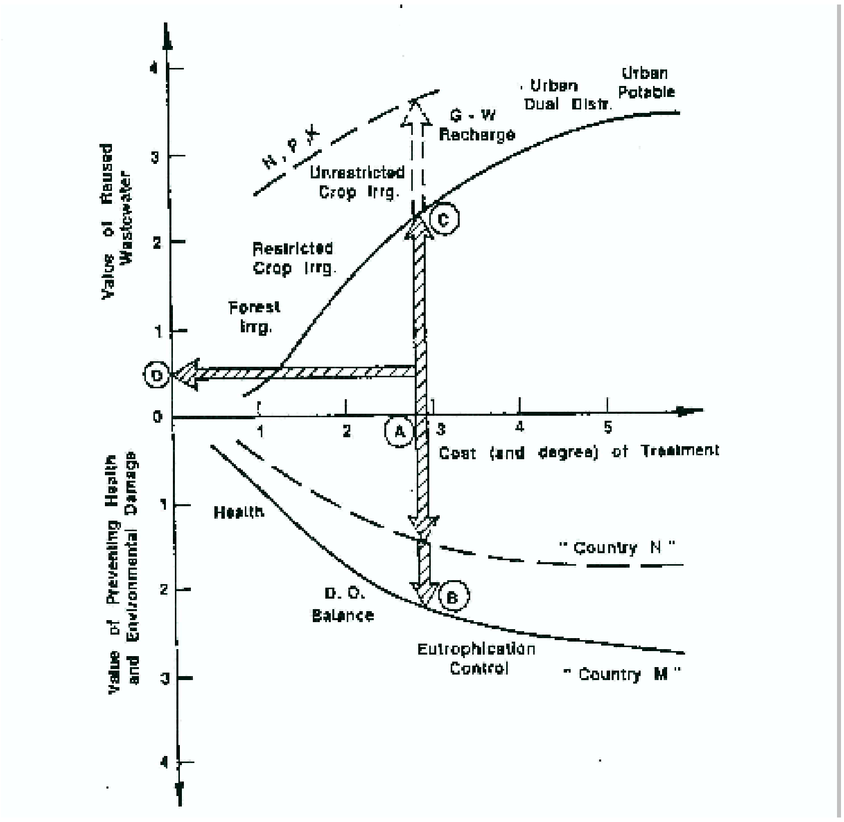

Figure 2: Benefits of wastewater reuse vs. costs of treatment (Source: SHELEF, G. 1991)

Figure 2 shows an conceptual economic justification made by delineation of the benefits gained by setting public health and environmental damage, achieved by a higher degree (and cost) of treatment and the growing benefit coincidentally gained by the higher quality of effluent to be reused.

It can be observed that the sum of the single benefits (A-B; A-C) is significantly greater than the costs of treatment (line A-D), resulting in an overall “profit”. Because the economic weight and expected benefit in health and environment might differ between countries, two different possibilities are shown. The positive value of agricultural nutrients (present in reused wastewater) should be considered as an extra bonus to this scheme.

BAHRI (1999) points out that there is often a lack of assessment of cost differentials between different alternatives of treatment concepts (treatment for reuse or treatment for sea or river outfall, the necessary transfer systems as well as the cost of fresh water).

The study of HARUVY et al. (1999) evaluates the beneficiary and hazardous effects of nutrients by irrigation with secondary water, by using an optimisation model. This model determines the monthly optimal treatment level while maximising the agricultural incomes, in the farmers point of view. As a result the added value increases with increasing nitrate concentration, but it is affected by possible hazards to crops. Adaptation of wastewater treatment levels to the regional mix of crops and to crop fertilization demands enhances agricultural incomes. One has to be carefully looking at the national point of view, this might lead to different results. There the analysis should also take account of environmental effects, such as nitrate leaching or salinity accumulation.

The paper of HARUVY (1997) demonstrates, in a simple way, how to tackle decision-making questions regarding the economic point of view of the reuse project. Various wastewater reclamation and reuse options (e.g. treatment levels, location of reuse) are compared by computing the net national benefit. A case study in Israel serves as an example. Here direct benefits as well as costs, indirect benefits and environmental damage have been considered. As a result the secondary treatment level and local irrigation (reuse option) was most beneficial, compared to southern conveyance and tertiary or secondary treatment. But still even this reuse options resulted in much more national benefit than the alternative of river disposal after tertiary treatment.

KHOURI NADIM et al. (1994) give guidelines for different scenarios which support an economic evaluation of a planned reuse project in agriculture. Differences between projects where irrigation already exists and wastewater can provide supplemental irrigation and projects without irrigation until now, where the benefits would be e.g. a higher production from existing farms are being described and mentioned to be considered while evaluating the economic benefit of a reuse project. The difficulty that positive as well as negative effects are not always quantifiable has to be realised and solved (e.g. environmental enhancements from the elimination of wastewater discharges).

The presented case study in XU P. et al (2000) about wastewater reuse on a French island makes one step forward. Here an integrated modelling of technical and economic issues has been realized. The economic sub-model estimates the economic efficiency of investments. Furthermore it makes clear that the evaluation of different scenarios is very important to come to comparable solutions. In addition it is stressed that water pricing is necessary and a way of water cost estimates is shown.

The financial analysis determines how the planned project can be financed, and if operating revenues can cover operating and dept services costs. Until now most of the water projects have been developed on the basis of subsidies and grants; only few projects have full cost recovery.

10 International experiences with waste water reuse projects (Selection)

Today in the EU water reuse is practiced predominantly in arid regions like Greece, Spain, and Italy. Israel, Jordan and Tunis are among the leading countries in wastewater reuse.

However, there are some experiences in Germany or Belgium as well. Wastewater of the city of Braunschweig, for example, has been reused since 1896. In 1996 there were 41 sites in Germany irrigated with domestic wastewater and 33 with industrial wastewater, the latter showing the following distribution: Sugar industry: 3, starch: 7, milk: 2, cleaning of vegetables: 2, sweets industry: 1, Distilleries: 13, agricultural cooperatives: 5 (DONTA, 1997).

Jeezrael Valley, Israel

Irrigation with reclaimed effluent is being performed in some areas in Israel for more than 30 years, in fact waste water reuse in irrigation was pioneered in the Jeezrael Valley, Israel (FRIEDLER, 1999). It is forecasted that in the near future, reclaimed effluents from various treatment schemes will form 80% of all irrigation water used in the previous mentioned valley, due to the increase in raw sewage production combined with a decrease in the amount of freshwater allocated for irrigation (due to freshwater shortages). In this project municipal wastewater is reclaimed as irrigation water. The project combines semi-intensive wastewater treatment plants (near to urban areas) with wastewater reservoirs (extensive treatment units, situated in rural areas) acting as an integral part of the treatment system. This idea enhances the systems performance and reduces costs because reservoirs are utilized as storage and furthermore as treatment units. The first results were effluents of high quality. When operating with all components the system is expected to release effluent of unrestricted irrigation quality.

Mexico City

The study describes and illustrates the problems related to wastewater treatment in mega-cities of the developing world. Here reuse in agriculture is used as a possibility to get rid of the wastewater without treatment. Untreated wastewater of about 75 m^3/s and the raw sewage of Mexico City is used to irrigate 85,000 ha of agricultural land in the neighboring state of Hidalgo. Besides the positive effects of freshwater conservation and higher agricultural production, which feeds and provides income to the local population, this method evokes a lot of diseases. The reason for the positive as well as for the negative side effects is the high content of organics, nitrogen and phosphorus nutrient as well as the fecal coliforms and debilitating parasites (here helminth eggs, 250 eggs/l). The high content of organic matter and plant nutrients in the water has improved the physical and chemical conditions of the soils. Soil organic matter increased and so did the crop harvest: the crop yield increased by 94 – 150 %. The irrigated area receives over 80kg/ha of nitrogen per year. Nevertheless a high prevalence of enteric and parasitic diseases among more than 100,000 workers had to be noticed. Here it can be seen that agricultural reuse is being advocated, but coupled with the need for secondary treatment prior to distribution. In the cited paper the authors urge to consider chemically enhanced primary treatment, which should produce an effluent that could be effectively disinfected (HAREMAN and MURCOTT, 1999)

Belgium

Not only in particular semiarid or arid regions reuse projects are realized. In the case of Belgium reuse has been implemented because of water quality issues (water scarcity isn't a problem there). A food processing industry, which freezes locally grown garden market products, has recycled all its wastewater by irrigating 550 ha of crops located around the factory. By adopting this solution, the processing plant was able to avoid paying a tax. Here the soil is only used as purification facility for the industrial effluent which consists of wastewater from washing and processing the vegetable and cleaning the building. Additionally it is worth to mention that since the early states of the project adaptations and technical adjustments in the industrial process have been made, such as minimizing the volume of process water or changing the method of vegetable processing (e.g. peeling with steam instead of soda). In short the project respects the environment, maintains the production potential of soils, preserves the quality of products, guarantees a regular supply to the firm, recycles nutritive elements and water in a natural cycle (GUILLAUME and XANTHOULIS, 1996).

Sharjah, United Arab Emirates

An interesting example for wastewater reuse, although not only related to agriculture, is the project in Sharjah, United Arab Emirates. It is one of the most water-poor states in the world, but its waste water recycling programme has enabled it to expand its green spaces and to conserve valuable groundwater supplies. The recycled wastewater is used for landscape and horticulture irrigation. To protect public health Sharjah established conditions and regulations for the safe use of recycled wastewater for irrigation (COOPER, 2001). Implemented projects like the previously mentioned in semi-arid or arid regions show again, that public acceptance and the willingness to implement such projects is highly connected with the grade of water scarcity in the country.

Trying to specify all interesting reuse projects would go beyond the scope of this work. There are certainly a number of examples in the Mediterranean region (arid and semi arid climate) such as Israel, Palestine and Jordan, but also in Europe where temperate climate prevails. Some examples for integrated resource management with water reuse are numerous islands in France (Noirmoutier, Porquerolles), Spain (Balearic and Canary), Italy (Sardinia, Sicily) and UK (LATAROVA V. 2000).

11 Public Acceptance

As mentioned in the introduction the psychological factor is essential for initiating, implementing and sustaining a long-term waste water reuse program. Therefore the development of sustainable water recycling schemes needs to include an understanding of the social and cultural aspects of water reuse. In absence of social support a reuse project may fail. Even for non-potable reuse purposes, the public attitude plays an important role, including the perception of water quality, willingness to pay or to accept any wastewater reuse project (LAZAROVA V. 2000).

By working on the public as well as on the institutional acceptance, one has also to keep in mind that wastewater reuse has different driving forces. First it is a supplemental water supply in water scarce regions and second it can be a viable alternative to the disposal of treated effluents in rivers and coastal waters and therewith a driving force also for regions with humid climate.

The use of alternative solutions to the discharge of wastewater in sensitive areas, where advanced tertiary treatment is not affordable, was encouraged. FABY ET AL. (1999) criticize the very strict restrictions which are even in some parts much higher than the WHO (1994) guidelines concerning reuse in agriculture. Nevertheless they found out that the decree of 1994 in France, which provided the basis for water reuse rules, were followed by 16 wastewater irrigation projects worked out during the 1990's. In the future new projects are expected to be developed as alternative solutions to wastewater discharge in sensitive water bodies.

A study about the industrial sector in Thailand and its willingness to adopt wastewater reuse practices indicates that only 10.5 per cent of the surveyed industries reuse their treated effluent. Furthermore the tendency of the surveyed industries is directed into non-adoption of industrial waste water reuse. (VISVANATHAN AND CIPPE, 2000). Again this shows the need for analysing the costs and benefits in all sectors.

Related to public acceptance and health issues a risk assessment should be part of the planning process. For example a careful assessment of the extent of potential health risks involved in wastewater reuse for irrigation is necessary. The extent of risks then might be weighted against urgency and derived benefits of the water reuse in order to make a sound decision on the project (SHAHALAM et al., 1989).

Last an example of widespread public relation work associated with water reuse or recycling is shown. The "Queensland water recycling strategy" serves as an example (Queensland Government, 2001). This strategy was initiated from the department of Natural Resources (DNR) in Australia and is managed from the EPA to increase the beneficial use of a largely untapped resource. The reports, which range from educational needs, agricultural water recycling, urban water recycling, health effects and legislative considerations were all published (the last in 2001) with the goal to reach all people involved in water management issues, to promote the possibilities of water recycling in all sectors and give governmental support by planning and implementation.

12 Conclusions

This review about wastewater reuse in agriculture shows that an integrated planning approach, considering economic as well as environmental and health issues, related to water reuse is essential to guaranty a success. Furthermore it has been shown that the issue of wastewater reclamation is discussed and implemented all over the world.

Although wastewater has been used already for decades and even back in the ancient Greece in the Minoan civilization (ca. 3000 – 1000 BC), (ANGELAKIS et al., 1999) the need for adaptations of the guidelines to the specific area of concern is high and still a challenge to all involved disciplines. The adaptation to the local conditions should increase the benefits and decrease the health risk. Furthermore this will result in a higher public acceptance which is crucial for implementation of reuse projects.

Wastewater reuse in agriculture has been shown as one important management issue for sustainable use of the limited freshwater resource, next to demand oriented water allocation and water desalination. Important, because of the potential economic and environmental benefits. It is necessary and worth to initiate and support wastewater reuse projects all over the world, since our population and with that the food demand is growing steadily, whereas water availability will stay the same.

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