www.aquarec.org

Handbook on feasibility studies for water reuse systems

AQUAREC

Integrated Concepts for Reuse of Upgraded Wastewater

February 2006

HANDBOOK ON FEASIBILITY STUDIES FOR WATER REUSE SYSTEMS

Project full title:
Integrated Concepts for Reuse of Upgraded Wastewater
WP4. Development of analysis tools for social, economic and ecological effects of water reuse

Project acronym:
AQUAREC

Duration:
36 Months

Funding by
EESD PROGRAMME, EUROPEAN COMMISION

Contract No. EVK1-CT-2002-00130

Edited by
AQUAREC

Project Co-ordinator: RWTH Aachen (DE)

Handbook responsible: GAIKER CENTRO TECNOLÓGICO (E)

Handbook contributors: Ana Urkiaga and Libe de las Fuentes - GAIKER (E)
Barbara Bis – UNIVERSITY OF LODZ (P)
Francesc Hernández – UNIVERSITY OF VALENCIA (E)
Tamas Koksis and Bodo Balasz – GEONARDO (CZ)
Epsica Chiru – APANOVA BUCURESTI (HU)

Handbook revisers: Thomas Wintgens and Thomas Melin – RWTH Aachen (DE)

Legal Deposit: BI-499-06

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ASPT	Average Score Per Taxa
BMWP	Biological Monitoring Working Party
BOD	Biochemical Oxygen Demand
BQE	Biological Quality Elements
CFU	Colony Forming Unit
CNV	Current Net Value
COD	Chemical Oxygen Demand
CV	Contingent valuation
DDS	Decision Support System
DEA	Data Envelopment Analysis
DEFRA	Department for Environment, Food and Rural Affairs
DPSIR	Driving force – Pressure – State – Impact - Response
EC	Electrical Conductivity
EDDS	Environmental Decission Support System
EEA	European Environment Agency
EI	Economic Indicator
EIA	Environmental Impact Assessment
EIB	European Investment Bank
ENGREF	Ecole Nationale du Génie Rural des Eaux et des Fôrets
EPA	Environmental Protection Agency
EPI	Environmental Performance Index
EPS	Extended Period Simulation
EPT	Ephemenoptera Plecoptera Trichoptera
ESI	Environmental Sustainability Index
EUREAU	European Union of National Associations of Water Suppliers and Waste Water Services
EVI	Environmental Indicator
FC	Faecal Coliforms
FEDER	Fonds Européen de Développement Regional
GIS	Geographical Information System
HACCP	Hazard Analysis and Critical Control Point
HP	Hedonic Prices
IBI	Index of Biotic Integrity
ICID	International Commission on Irrigation and Drainage
IFC	International Finance Corporation
IPTS	Institute of Prospective Technological Studies
ISPA	Instrument of Structural policies for Pre-Accession
IWA	International Water Association
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management

LIFE	L'Instrument Finnacier pour l'Environnement
MBI	Marine Biotic Index
MCDA	Multi Criterion Decision Analysis
MED-REUNET	Mediterranean Network on Wastewater Reclamation and Reuse
MP	Market Price
NFSMI	National Food Service Management Institute
NGDC	National Geophysical Data Center
NJDEP	New Jersey Department of Environmental Protection
NTU	Nephelometric Turbidity Units
O&M	Operation and Mainteinance
ORNL	Oak Ridge National Laboratory
PFU	Plaque Forming Unit
PI	Performance Indicator
QBR	Riparian habitat quality index
RC	Restoration Cost
RM	Risk Management
SAFFIRE	Strategic Alliance for Freswater Information Resources and Education
SANDRE	Service d'Administration Nationale des Données et Référentiels sur l'Eau
SAR	Sodium Adsorption Ratio
SEA	Strategic Environmental Appraisal
SI	Social Indicator
SMAP	Short and Medium term priority environmental Action Programme
TC	Total Coliforms
TC	Travel Cost (in environmental valuation)
TGD	Technical Guidance Document
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TT	Treatment Train
WFD	Water Framework Directive
WHO	World Health Organisation
WQI	Water Quality Index
WSI	Water Sustainability Index

1. EXECUTIVE SUMMARY

Water is an essential need, a limited and scarce resource that must be protected. Water reuse and desalination are nowadays the most outstanding solutions to increase water resources availability. However, as long as desalination is not a sustainable option, wastewater treatment and reuse is the most sustainable solution for the used water.

In this sense, the full implementation of the Urban Waste Water Treatment Directive (91/271/EEC) in Europe will contribute to obtain treated wastewaters of quite high quality that could be reused for certain uses or improved by polishing steps for applications with higher quality requirements. Moreover, Article 12 of this Directive mentions that treated water shall be re-used whenever appropriate.

Nevertheless, regardless the extensive application of reclaimed water for irrigation, the potential for water re-use and recycling has not yet been exploited in many European areas. A decisive factor to achieve a higher percentage of water re-use is the establishment of effective incentives, which in many instances will be of either an economic or a regulatory nature. One fundamental advantage of water re-use is the fact that in many cases the resource employed is available in the vicinity of its prospective new use, i.e. urban agglomerations and industrial sites. The limiting factor for water re-use can in many circumstances be the quality of the water available linked to the treatment processes (technology) and potential hazards for secondary users. To examine the economic viability of water re-use a careful cost-benefit analysis for the various parties involved needs to be carried out.

Even though water reuse is currently implemented in many countries, different water reuse projects did not succeed due to the absence of a Integrated Water Resources Management Plan. Likewise, feasibility studies can contribute to succeed in the implementation of a water reuse project. A feasibility study is defined as an evaluation or analysis of the potential impact of a proposed project or program, covering extensive data related to its financial and operational impact, including its advantages and disadvantages and its comparison with the existing situation and scheduling the proposed plan.

Taking into account all these considerations, in the framework of the AQUAREC (*Integrated Concepts for Reuse of Upgraded Wastewater*) European Project these *Guidelines on feasibility studies for water reuse systems* have been prepared with the purpose of developing a useful methodology to assist the different stakeholders (administration, engineering companies, water management bodies, etc.) involved in the planning of a water reuse programme in a specific area. A thorough feasibility study should be tackled from a multidisciplinary approach considering many different aspects such as geological, technical, economical, environmental, sociological, and quality and risks issues. All of them can condition the final decision and success of a water reuse project. Consequently, the consideration of them all is recommended to reach a reliable decision when facing water reuse practices. Accordingly, within AQUAREC methodology the different aspects and their assessment tools are addressed.

Considering the great number of issues to be addressed and the aim of this handbook of being a practical, easy to read and understand as well as brief document, only the key points and basic information considered in each section and some relevant links supporting the information supplied are described.

This handbook strictly follows a pre-defined structure to perform a feasibility study on water reuse, as described in *Chapter 2*, and its subsequent chapters further develop its major features.

As most publications, a feasibility study starts with an executive summary where the existing situation, scope of the project and major findings are described.

Next, a full and extensive compilation and review of the background information and data related to the studied zone is needed. Accordingly, *Chapter 3* summarises the methodology to achieve this, comprising data analysis on the main characteristics of the tackled zone such as geography and topography or climate, water balance of the region, characteristics of water supply and sanitation, planning and identification of reclaimed water potential users, etc.

In parallel, according to the wastewater composition and reclaimed water quality for specific uses different technological alternatives are feasible. Therefore, in *Chapter 4* the methodology for the proposed technology options evaluation is presented including a brief description of the system, its advantages and disadvantages, equipment and land requirements as well as costs, basic system layout and site possibilities. Regarding this topic, the risk analysis, foreseen treated water quality and technological considerations (main treatment trains, technological advances, etc.) should be analysed too.

Moreover, the accomplishment of an environmental impact assessment of those proposed solutions compared to the situation at present is a compulsory requirement to fulfil when implementing any water reuse project. In view of that, in *Chapter 5* an Environmental Impact Assessment Multiple-Level (EIAML) approach and its multidisciplinary application for water reuse feasibility studies is addressed. This systematic analysis, covering social, cultural, economic and ecological constraints, supports ecologically sustainable water management using the best practicable techniques of decision-making processes addressed to the environmental effects of a water reuse project. Basic strengths of the EIA procedures are proposed by reflecting both the application of the procedures laid down by the current legislation and the potential application of best practices by individual Member States that could be adopted in their own guidance on screening, scoping, reviewing and performing cumulative impact assessment. The main supportive procedures and tools for developing Decission Support Systems (DSS) and determination of all EIA components in the feasibility and operational phases of the water reuse project are analysed and include:

1. Hazard Analysis and Critical Control Points - HACCP system, with an analysis and definition of major requirements of a water reuse programme and environmental values to be protected;

2. Driving Force – Pressure – State – Impact –Response - DPSIR system, focusing on the formal optimisation of the relationships between various sectors of human activity and the environment as causal chains;

3. Strategic Environmental Appraisal - SEA supportive framework, aiming at making explicit the cause-effect relationships between interacting components of complex social, economic and environmental systems and at organising the effective information flow between its parts.

Likewise, the impact of the implementation of the proposed solutions on population, industry, agriculture, etc. needs be analysed too. In this sense, *Chapter 6* defines main social, environmental and economical key indicators to be considered in the formulation of water reuse feasibility studies and describes their assessment methodologies. Additionally, public acceptance to water reuse and a public participatory plan are two other important issues also covered in this chapter. The latter is needed to confirm the public acceptance of the considered water reuse project and, consequently, the approval of the final users and consumers of reclaimed water. In this sense, several water reuse projects have not succeeded due to the over-estimation of the potential users of the obtained water.

According to this general feasibility study methodology structure, once the proposed systems evaluation is performed, covered by Chapters 4-6 in these guidelines, the proposals should be faced with the existing system for comparison. Hence, *Chapter 7* briefs different assessment methodologies and computer network modelling analysis approaches. In fact, probable costs (cost of reclaimed water reuse, price of reclaimed water…) and cost-effectiveness analysis of the different proposed options must be conducted. Most of the existing methodologies for economical assessment only consider internal costs, but external impacts (environmental and social) and the opportunity cost derived from the proposed project have to be taken into consideration too. A financial analysis might also be conducted. Last but not least, the different funding sources in Europe for this type of projects are also summarised, as funding and management of a water reuse system are key elements for its feasible implementation. Without a workable funding and management component, any capital development program obviously remains only a plan.

This thorough analysis will help to choose the most suitable alternative, so the last sections in a feasibility analysis performance refer to the main conclusions of the whole feasibility study, the proposed recommendations, the foreseen schedule for the implementation plan - including the possible demonstration projects - and other issues such as needed agreements, contracts and responsibilities of the different involved parts or even references. All these aspects are framed within *Chapter 8* of this handbook.

To finish, attached to the main report different annexes with useful data and supporting information are included. *Annex I* deals with general information on data collection, *Annex II* widens information on wastewater treatment technologies and *Annex III* presents and describes the key indicators (social, environmental and economical) developed for supporting water reuse feasibility studies.

Beyond these guidelines, further interesting and complementary information on water reuse is available at the AQUAREC web site (www.aquarec.org) including different case studies on feasibility studies on water reuse, guidelines on stakeholder engagement, education and surveys, a manual on management of water reuse systems in the implementation /operation phase, a design support software for water reuse (WTRNet) and so on.

2. INTRODUCTION

2.1 Main considerations on water reuse

The Second World Water Forum in The Hague in March 2000 noted that water will be one of the central issues of the 21st century in the globe, and thus the life of billions of people will depend on its wise management. Water is an essential and basic human need for urban, industrial and agricultural use and has to be considered as a limited resource. In this sense, only 1% of the total water resources in the world can be considered as fresh water and in 2025 nearly one-third of the population of developing countries, some 2.7 billion people, will live in regions of severe water scarcity. They will have to reduce the amount of water used in irrigation and transfer it to the domestic, industrial and environmental sector. Moreover, water pollution by human interference, e.g. by industrial effluents, agricultural pollution or domestic sewage will increase and the world's primary water supply will need to increase by 41% to meet the needs of all sectors which will be largely due to the increase in the world population.

In this scenario, a unique and viable opportunity to augment traditional water supplies provides water reclamation and reuse, the only solutions to close the loop between water supply and wastewater disposal. Promising is the fact that since many years it is feasible to treat wastewater to a high quality. Hence, wastewater could be regarded as a resource that could be put to beneficial use rather than wasted. Accordingly, in many parts of the world reclaimed water is used as a water resource.

Water reuse accomplishes two fundamental functions: the treated effluent is used as a water resource for beneficial purpose and the effluent is kept out of streams, lakes, and beaches thus reducing pollution of surface water and groundwater. In addition to the economic savings due to water reuse, valuable substances and heat recovery can be achieved by water recycling favouring a zero emission process.

The practise of waste water re-use is increasing greatly within the EU, mostly to alleviate the lack of water resources in certain regions, such as in Southern European countries, but also to protect the environment especially in coastal waters by removing all discharges into fragile receiving waters (IPTS, 1997). In this sense, the full implementation of the Urban Waste Water Treatment Directive (91/271/EEC) in Europe will contribute to obtain treated wastewaters of quite high quality, that could be reused for certain uses or that could be improved by polishing steps for applications with higher quality requirements. Moreover, Article 12 of this Directive mentions that treated water shall be re-used whenever appropriate. The largest application of water re-use is the irrigation of crops, golf courses and sports fields where pathogens from the wastewater may be in contact with the public. However at present there are no supra-national regulations on wastewater re-use in Europe.

Nevertheless, the potential for water re-use and recycling has not yet been fully exploited in many European areas. A decisive factor to achieve a higher percentage of water re-use is the establishment of effective incentives, which in many instances will be of either an economic or a regulatory nature. One fundamental advantage of water re-use is the fact that in many cases the resource employed is available in the vicinity of its prospective new use, i.e. urban agglomerations and industrial sites. The limiting factor for water re-use can in many circumstances be the quality of the water available linked to the treatment processes (technology) and potential hazards for secondary users. To examine the economic viability of water re-use a careful cost-benefit analysis for the various parties involved needs to be carried out.

Even though water reuse is currently implemented in many countries, different water reuse projects did not succeed due to the absence of an Integrated Water Resources Management and Implementation Plan. Within this framework, feasibility studies can contribute to obtain successfully completed water reuse projects.

During the planning and implementation of water reclamation and reuse, the reclaimed water application will usually govern the type of wastewater treatment needed to protect public health and the environment, and the degree of reliability required for each sequence of treatment process and operations. Water reuse applications, from a global perspective, have been developed to replace or increase water resources for specific applications depending of course on local water use standards. Depending on water origin and treatment process, water reuse applications can be divided in seven categories. These categories, in order of significance (number of implemented projects), and their main constraints are shown in Table 2.1 (Asano, 1998). The largest application is the irrigation of crops, golf courses and sports fields.

Water from recycling systems used in each one of the seven categories should fulfil four criteria: hygienic safety, aesthetics, environmental tolerance as well as technical and economical feasibility.

In order to guarantee the protection of the public health and eliminate the medical risks, it is essential to set up standards and strict regulations. In this sense there are two great groups of standards: guidelines of WHO (WHO, 2002) and Title 22 of the California Code of Regulations (1978). For instance, for irrigation without restriction, the major application of reclaimed wastewater, the microbiological pollution of wastewater must - according to WHO - remain below 10,000 faecal coliforms (FC).L^{-1} and 1 egg of helminthes.L^{-1}, whereas the Californian "Title 22" fixes more severe restrictions, even the total absence of germs (less than 22 total coliforms (TC).L^{-1}).

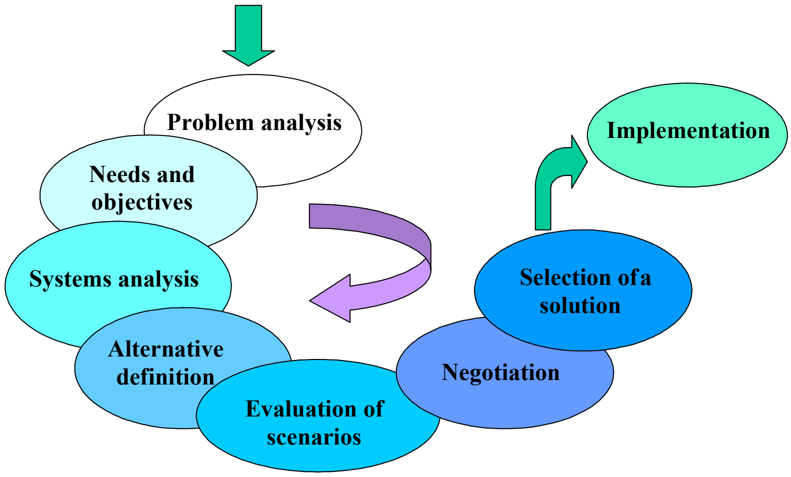
Table 2.1 Categories of water reuse and main constraints (Asano, 1998)

Wastewater reuse categories	Potential constraints
1. Agricultural irrigation • Crop irrigation • Commercial nurseries 2. Landscape irrigation • Parks • School yards • Freeway medians • Golf courses • Cemeteries • Greenbelts • _Residential uses	Surface and groundwater pollution if not properly managed Marketability of crops and public acceptance Effect of water quality, particularly salts, on soil and crops Public health concerns related to pathogens (bacteria, viruses, and parasites) Use area control including buffer zone. High costs for user may result
3. Industrial recycling and reuse • Cooling • Boiler feed • Process water • Heavy construction	Constituents in reclaimed wastewater related to scaling, corrosion, biological growth and fouling Public health concerns, particularly aerosol transmission of pathogens in cooling water
4. Ground water recharge • Ground water replenishment • Salt water intrusion control	Organic chemicals in reclaimed wastewater and their toxicological effects Total dissolved solids, nitrates, and pathogens in reclaimed wastewater
5. Recreational/environmental uses • Lakes and ponds • Marsh enhancement • Stream flow augmentation • Fisheries • Snowmaking	Health concerns of bacteria and viruses Eutrophisation due N and P in receiving water Toxicity to aquatic life
6. Non potable urban uses • Fire protection • Air conditioning • Toilet flushing	Public health concerns on pathogens transmitted by aerosols Effect of the quality on scaling, corrosion, biological growth, and fouling Cross connection
7. Potable reuse • Blending in water supply reservoir • Pipe to pipe water supply	Constituents in reclaimed wastewater, especially trace organic chemicals and their toxicological effects Aesthetics and public acceptance Health concerns about pathogen transmission, particularly viruses

2.2 What is a feasibility study?

A feasibility study is defined as an evaluation or analysis of the potential impact of a proposed project or program (NFSMI, 2002) and is conducted to assist decision-makers in determining whether or not to implement a particular project or program. It is based on extensive research on the current practices and the proposed project / program and its impact. Accordingly, it will contain extensive data related to the financial and operational impact of the project, including advantages and disadvantages, describing the existing situation and the proposed plan. In Figure 2.1 the different steps followed in a decision-making process are represented (Thomas, 2003).

Figure 2.1 Cyclic decision-making process (Thomas, 2003)



2.3 Purpose of the handbook

As previously mentioned, water reuse has to be considered in the preliminary stages of a more general framework of an Integrated Water Resources Management and Implementation Plan.

Feasibility studies can contribute to reach the success of a water reuse project. Hence, the aim of the AQUAREC *Handbook on feasibility studies for water reuse systems* is the development of a useful methodology to assist the different stakeholders (administration, engineering companies, water management bodies, etc.) involved in the implementation of a water reuse programme in a specific area and to provide the needed tools to prepare feasibility studies on water reuse.

A thorough feasibility study should address many different aspects such as geological, technical, economical, environmental, sociological, and quality and risks issues. All of them can condition the final success and decision on a water reuse project. Consequently, the consideration of all of them is recommended to reach a reliable decision when facing these reuse practices. Within AQUAREC methodology, the different aspects and tools helping the analysis of each of them are also provided.

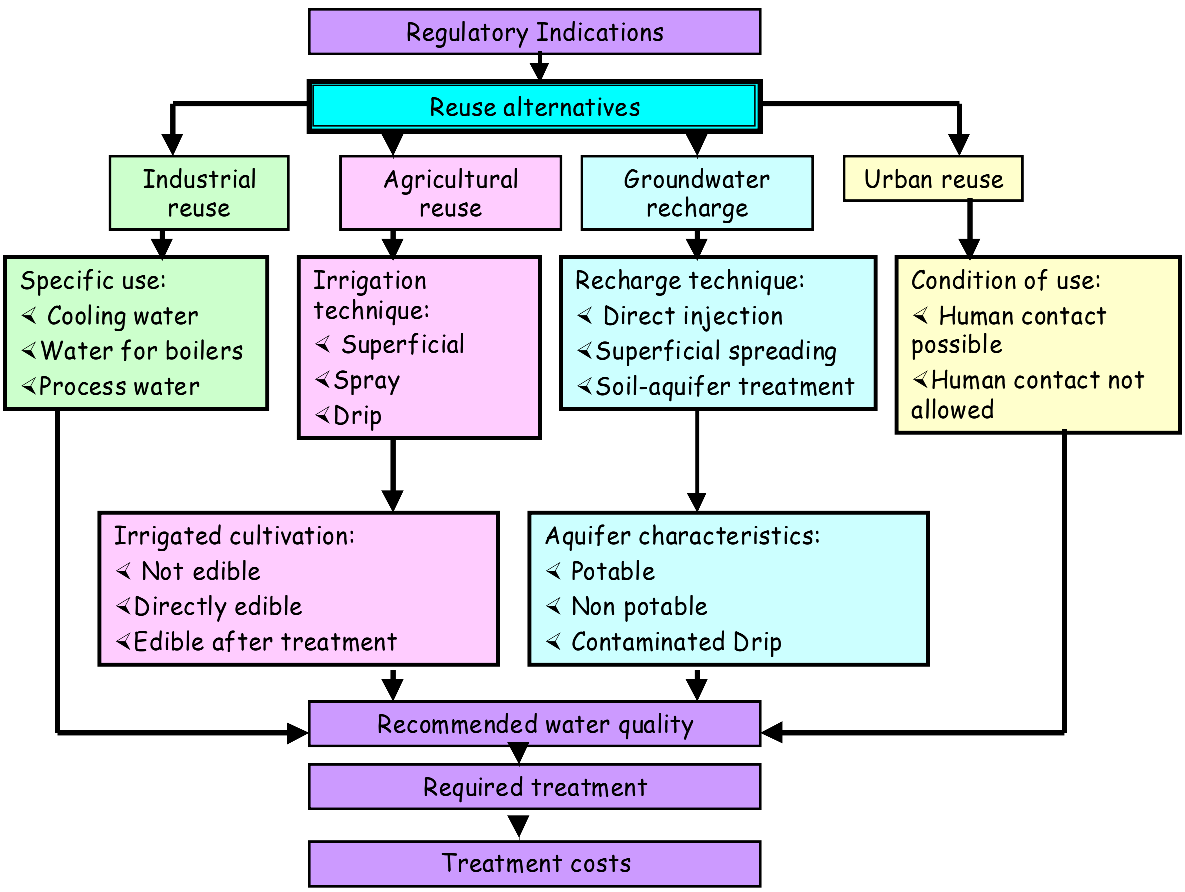
In this sense, although the economic viability of a given water re-use project has to be proved, and this is the key point in most of the projects, other aspects such as over-estimation of the potential users of the reclaimed water, which is closely linked with public acceptance of this type of water, or environmental issues can condition the final success of the project.

To finish, other different factors such as the establishment of effective incentives, which in many instances will be of either an economic or a regulatory nature, or those closely linked to political decisions can contribute greatly to the final implementation and spread out of water reuse projects.

2.4 Methodology

There are very few reference methodologies for addressing water reuse feasibility studies. For instance, Figure 2.2 shows an illustrative process chart proposed by Sipala (2003). As it can be observed, regulatory indications govern the reuse alternative to be evaluated and depending on the specific application of the reclaimed water a needed quality of the obtained water is needed thus requiring at least a minimum treatment (or treatment train) resulting in a given economic cost.

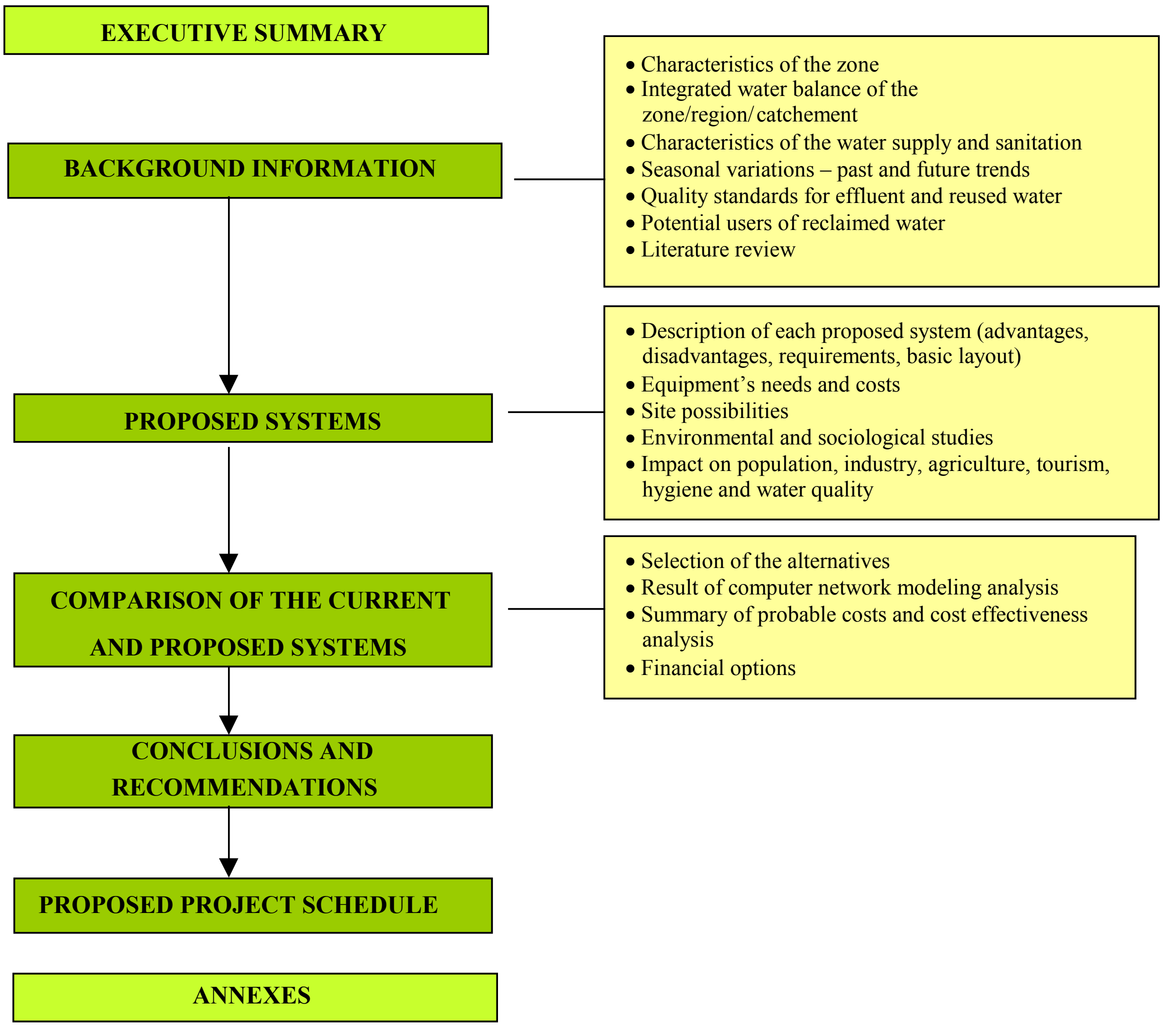
Figure 2.2 General structure proposed for feasibility studies on water reuse (Sipala, 2003)



Within AQUAREC, after an extensive survey and review of already accomplished feasibility studies, the adopted flow chart to develop feasibility studies on water reuse is shown in Figure 2.3.

In principle, a great number of different aspects have to be considered when addressing a complete water reuse feasibility study. However, the objective of this handbook is not to profusely study each one of them that might result in a very long and dense publication. Conversely, its main objective is to identify those different key aspect and briefly describe them, providing the most relevant references if a more extensive knowledge is sought.

Figure 2.3 General structure proposed for feasibility studies on water reuse (AQUAREC)



Accordingly, in the following chapters of the handbook the different basic aspects considered in the proposed methodology are addressed and their key features more explicitly developed.

Furthermore, the proposed methodology has been successfully applied to three different real case studies within the project partners. The resulting information is available at the AQUAREC web site (www.aquarec.org).

3. BACKGROUND INFORMATION

This section is one of the most important ones in a feasibility study, as data acquisition and collection stands as a fundamental step. When facing a feasibility study it is essential to count with varied and reliable data values, indicators and information regarding different issues.

For instance, diverse information on how collect and validate data is available at the Balanced Scorecard Institute web page (www.balancedscorecard.org).

Generally speaking, the data needed when studying a specific area and evaluating its potential of hosting a water reuse project are of very different nature. Some basic records to be collected include:

- Water supply and demand (local and seasonal).
- Water and wastewater management agencies in the area.
- Regional water and wastewater facilities (in operation and planned).
- Water cost and quality requirements.
- Environmental setting: climate, geography and topography, water resources (surface and ground water).
- Land use and population (current state and projections).
- Structure and location of potential users.
- Ecological and hydro-geological boundary conditions.
- Water related socio-economic facts (water supply restrictions on domestic, industrial and/or irrigation uses)
- Status of public acceptance of water reuse.

To obtain this information it is necessary to contact the main stakeholders (different institutions, organisations and associations related to water) in the analysed zone such as Water and Wastewater Agencies, Regional Environmental Agencies, Councils and Regional Governments (land and population projections, funding options…), Farmers Associations, End-Users Associations, etc.

Moreover, assorted maps (with the boundaries, location of the water and wastewater facilities, location of the different water sources, the different zones of land uses, location of the possible users of the reclaimed water and population zones, different geological zones and so on) should also be compiled.

In the last years, Geographical Information System (GIS) provided by ESRI (www.esri.com) appears as a very valuable tool for this purpose, for its ability to integrate different recorded data and maps. More information about GIS application for water management and risk assessment can be downloaded from the AQUAREC web site.

Within AQUAREC, an extensive table compiling the most relevant aspects of data collection for the different issues considered in water reuse feasibility projects has been developed and is included in this handbook (Annex I). This table covers the methodology, scope, sources and means of verification of the data and main assumptions regarding each aspect to be considered.

3.1 Characteristics of the zone. Basic data

3.1.1 Geography and topography

Geography and topography determine the intrinsic characteristics of the target zone with conditions like location of river basins and wells, urban settlements, agricultural lands, dispersion of the discharged wastewater, etc. They will also influence the evaluation of site possibilities and location of pumping stations, treatment facilities or distribution lines of the proposed water reuse options.

For those reasons, within this heading the following aspects should be evaluated when facing a feasibility study on water reuse:

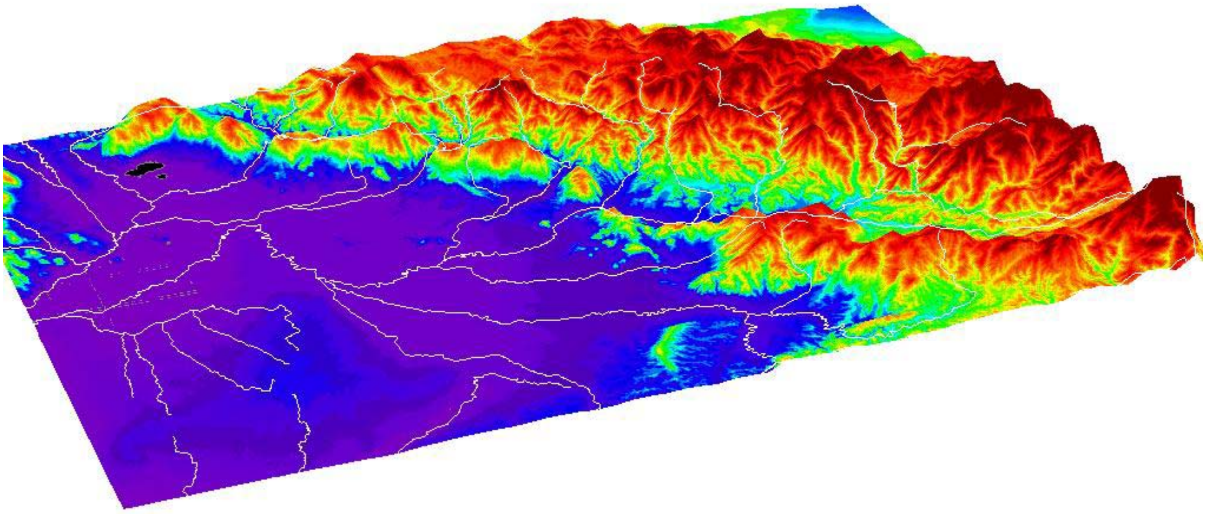
- Analysis of the topography and geography of the zone and their main characteristics (e.g. borders, inter-relations with other zones).
- Studies of land use projections.
- Main settlements with their relative population.
- Crops and volume of the land used for each crop.
- Irrigation volumes in the agricultural sector.

Besides, aspects like if the zone is flat or mountainous, the unevenness of the soil or the type and classification of the different soils should be pointed out (inventory) supported by the corresponding maps.

Other outstanding aspects such as main types of plants, vegetation, trees and animal species could be included in this section as well.

As previously mentioned, GIS can be an extremely useful tool to illustrate and compare the different proposed options. Next, an illustrative GIS topography figure from a specific area is shown (Figure 3.1).

Figure 3.1 Dimension image (GIS) of a specific area (AQUAREC)



3.1.2 Climate

Climate will definitely determine water resources and future water needs. It is for this reason that this aspect should be addressed in a feasibility study on water reuse. The information to be surveyed might include:

- Precipitation data in the study zone.
- Annual evaporation, average temperature and average annual high and low temperatures.
- Main type of winds
- Risks associated to the climate.

The normal precipitation data in the studied zone in the last twenty years (or at least last ten years) including total and average precipitation figures should be recorded. Moreover, the mean net and gross annual evaporation, average temperature and average annual high and low temperatures should also be specified. Precipitation and temperature seasonality, main drought periods, etc. might be included in this section with charts enclosed. Furthermore, future changes and trends (droughts, floods…) might be pointed out.

3.2 Water balance of the region

The existing situation and forecast of surface and groundwater resources in the study area should be analysed with the forecast schedule of the main changes to be carried out when an Integrated Water Resources Management (IWRM) is planned. Most outstanding issues to be developed under this heading include:

- Consideration and calculation of water flows, hydrological plans (at regional and national level), water abstraction and water use intensity index together with other key indicators of water supply and demand to perform the water balance assessment.
- Realisation of an inventory of the different surface and groundwater resources in the target area considering trans-boundary streams. Completing the water balance inventory with other alternative water sources such as desalination or reclaimed water reuse.
- Listing of current and possible risks
- Performance of a water market analysis and location of water deficits.

Two important terms to be considered when accomplishing a water balance assessment are water stress and water scarcity. Water stress is the condition in which the annual availability of renewable fresh water falls within the range of 1,000-1,667 $m^3.y^{-1}.inhab^{-1}$ and water scarcity is attained when the annual availability of renewable fresh water is equal or below 1,000 $m^3.y^{-1}.inhab^{-1}$ (Engelman, 1993).

Integrated Water Resources Management (IWRM) is a participatory planning and implementation process that has to be carried out in each case. Managing water resources and demand, decision-making systems and planning of interventions to be performed are different phases to be addressed.

To evaluate Water Balance and Water Resources Management (WRM) different tools are available. For instance, Decision Support Systems (DSS) using GIS and ArcView3.2 tools for water modelling can be used. There are plenty of other available programmes/models such as the Water Balance Model for Canada (www.waterbalance.ca) or a global water balance model (Miller, 2003).

In the following figures (Figure 3.2 and 3.3) a scheme for the development of an Environmental Decision Support System (Turon, 2004) and the interactions among the expert systems tasks and the different models (Economopoulou, 2003) are represented.

Figure 3.2. Flow diagram for the development of an EDSS (Turon, 2004)

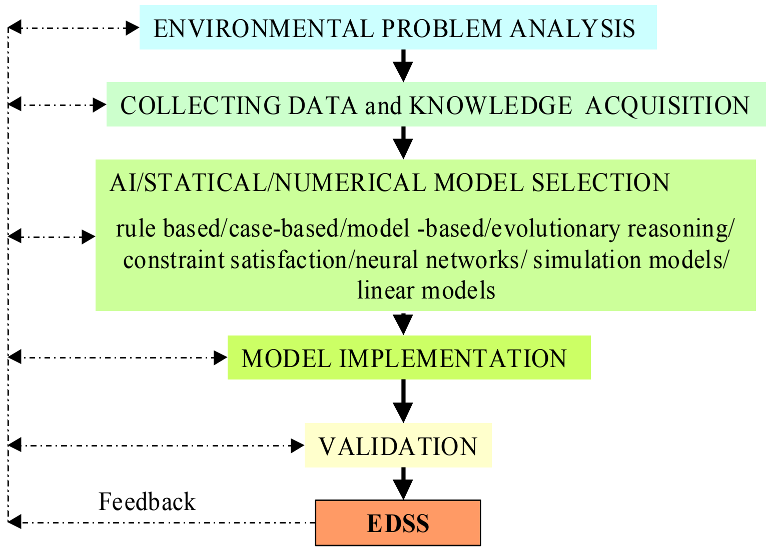
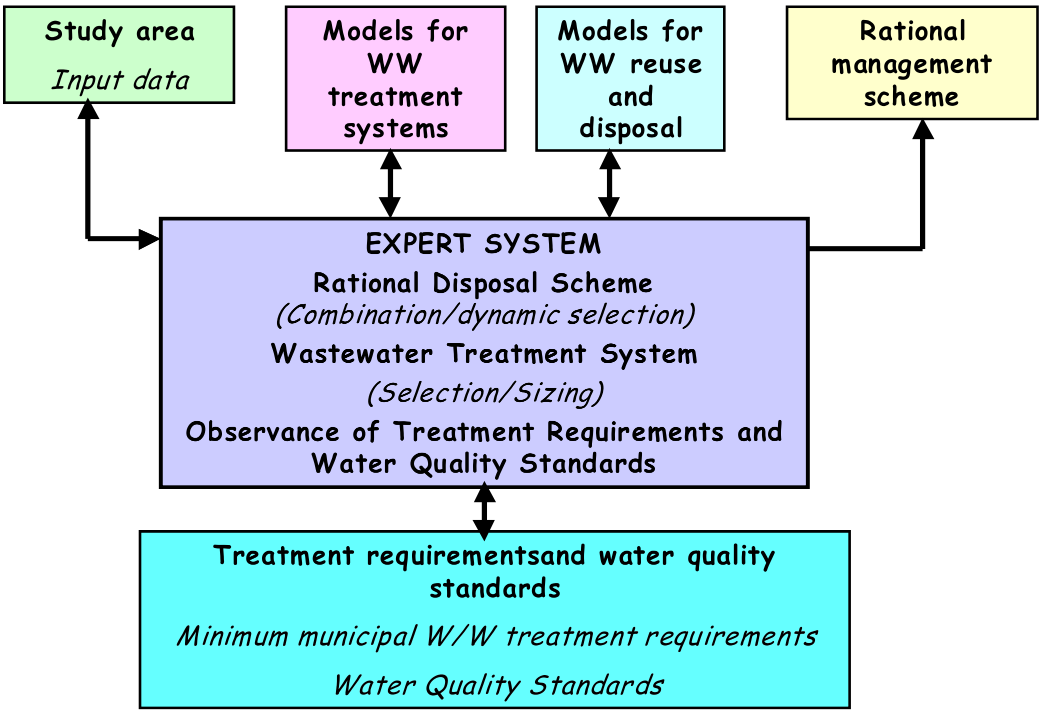


Figure 3.3 Expert system tasks, models and interactions in a water reuse project (Economopoulou, 2003)



Next, some interesting web links containing information related to water issues are enclosed. Moreover, in the AQUAREC web site additional information regarding water supply and demand as well as water prices in Europe can be found.

General information

- European Commission, DG Environment (europa.eu.int/comm/environment/water) dealing with water-related regulations, interesting links, etc.
- The World Bank (www.worldbank.org) offering data, indicators, events, reports, programs, etc. on different issues included water.
- Water Quality Association (www.wqa.org) providing information on events, news and reports related to water quality.
- UNESCO World Water Assessment Programme (www.unesco.org/water/wwap) including water-related links and events.
- European Union of National Associations of Water Suppliers and Waste Water Services – EUREAU (www.eureau.org).
- WaterStrategyMan Project (environ.chemeng.ntua.gr/wsm) aiming at the establishment of a broad framework on the existing knowledge on IWRM practices for special application in water deficient regions.
- Earth Trends Environmental Information Portal (www.earthtrends.wri.org).
- Strategic Alliance for Freshwater Information Resources and Education – SAFFIRE (www.water-saffire.net/IWRM.asp) offering various links and information on IWRM.
- Centro Canario del Agua, with a review document on water-related interesting web links (www.fcca.es/Docs/Links%20a%20paginas%20Web3.pdf).
- Office International de l'Eau, with a review document on water-related interesting web links (www.oieau.fr/ciedd/esp/frames/siteau.htm).
- FAO Corporate document "Review of World Water Resources by Country" Water Reports 23 (ftp.fao.org/docrep/fao/005/y4473E/y4473E00.pdf).
- EEA report "Resources problems in Southern Europe" (reports.eea.eu.int/92-9167-056-1/en/TopicReportNo15-1996.pdf) where the current and future state of water resources in Southern Europe is profusely analysed.
- International Water Management Institute report "World Water Demand and Supply, 1990 to 2025: Scenarios and Issues" (www.iwmi.cgiar.org/pubs/PUB019/REPORT19.PDF)

National information

Italy

- Istituto Nazionale di Statistica (www.istat.it) offering statistical data on water resources and precipitation, climate, etc. in Italy.

- International Commission on Irrigation and Drainage - ICID report on water balance, water resources, development policies, etc. for different Italian regions (www.icid.org/v_italy.pdf).

France

- Agences de l'Eau (www.lesagencesdeleau.fr).
- Service d'Administration Nationale des Données et Référentienls sur l'Eau – Sandre (sandre.eaufrance.fr) in charge of the water information system in France.
- Water information portal EAUDOC (eaudoc.oieau.fr/sie/gedoieau.asp).
- Office International de l'Eau (www.oieau.org/index.htm)
- Institut Français de l'Environnement (www.ifen.fr) offering water data and indicators, amongst others.

Portugal

- Instituto da Água (www.inag.pt) offering water-related data, maps, inventory of water supply and wastewater treatment systems, etc.

Spain

- Ministerio de Medio Ambiente, providing plenty of data on water supply and sanitation (www.mma.es/rec_hid/depuracion/index.htm)
- Ministerio de Medio Ambiente, Programa Agua regarding water management and use (194.224.130.163/agua/entrada.htm).
- Ministerio de Medio Ambiente, Hispagua, Spanish Water Information System (www.mma.es/ciclo_hidr/hispagua/index.htm)
- Centro Canario del Agua (www.fcca.es) providing information from a Spanish water stressed region (Canary Islands) and general reports and water-related data.
- Consorci de la Costa Brava (www.ddgi.es/ccb), organism in the Catalonia Region with a long experience on water reuse and offering different reports and information on this issue.

United Kingdom

- Environment Agency, Water Resources Area (www.environment-agency.gov.uk/subjects/waterres/?lang=_e).

Ireland

- Ireland's Environmental Protection Agency (www.epa.ie/ourenvironment/water)

U.S.A.

- US Environmental Protection Agency water-related topics (www.epa.gov/ebtpages/water.html)
- State of California Department of Water Resources (www.owue.water.ca.gov) with its Recycled Water Task Force final report downloadable from www.owue.water.ca.gov/recycle/docs/TaskForceReport.htm.
- California Department of Health Services, Division of Drinking Water and Environmental Management (www.dhs.ca.gov/ps/ddwem) with its regulations and guidance for recycled water.

Australia

- Queensland Government Environmental Protection Agency with its Water Recycling Strategy to encourage water recycling (www.epa.qld.gov.au/environmental_management/water/water_recycling_strategy).

3.3 Water state

When addressing this topic, the different categories of water quality in the study zone should be described and the different water sources inventoried and rated.

Present and potential risks such as sea water intrusion or pollution (origin, type, and intensity) of surface and groundwater wells should be included and water quality trends as well.

Organisms, administrations, institutions and companies with provinces and responsibilities in the water sector with the distribution of main functions and responsibilities should be indicated.

Lastly, water quality guidelines and parameter ranges within the studied zone should also be enclosed.

3.4 Characteristics of water supply and sanitation

3.4.1 Water supply system for public use

The water supply system will determine the location of the potential reclaimed water users as well as the location of the wastewaters. Currently in most European countries more than 88% of the population is connected to water supply systems. The different issues to be inventoried and consulted within this section might include:

- Sources and quality characteristics of each type of water supply.
- Description and characteristics of the main water supplying facilities. Location and treated water flows.

- Population supplied by each facility, percentage of population connected to water mains.
- Water consumes trends. Average flows, distribution by sectors (industry, agriculture and domestic uses).
- Forecast of needed plants in the future.
- Management of groundwater and associated problems.
- Current and future costs of the tap water, funding and water prices. Institutions responsible for fixing water prices.
- Other relevant aspects like percentage of installed measurement devices, water losses, etc.

For instance, in Spain the province of water management responsible for fixing water prices, sewerage and wastewater treatment, etc. corresponds to the local governments. In Europe great differences can be found not only at country but also at regional level. AQUAREC provides specific information regarding water prices in different European countries in its web site (www.aquarec.org).

Water consumption is directly linked to water price. A recent study carried out in California (Asano, 1998) proved that there is a strong elasticity in this sector and an increase of 50% in the water price produced a decrease in the range of 23-75% in water consumption.

3.4.2 Sanitation system for public use

The sanitation system will determine the location of the wastewaters to be treated and potentially reused, and should be included in an IWM Planning. As previously mentioned, the implementation of the Urban Waste Water Treatment Directive (91/271/EEC) will provide treated wastewaters with a quite high quality amenable for direct reuse for certain applications or needing further polishing for other reclaimed water uses.

Towards the end of the 1990s around 80% of European Union population was connected to public sewerage systems and 77% to waste water treatment plants. These figures vary widely for the different countries, as some European countries have a treatment rate close to 100% of the wastewater collected by urban wastewater collection systems (e.g. Netherlands, Luxembourg or Sweden).

The different information to be compiled and analysed under this topic section should include:

- Location and number of water sewage and wastewater treatment plants.
- Percentage of population connected to sewerage. Percentage of the collected wastewater that is treated.

- Enterprises responsible of sewerage and WWTPs construction, operation and maintenance. Construction date.
- Main characteristics, types of treatment, treatment costs and cost of the different wastewater treatment plants.
- Price paid for sanitation and future trends.
- Treated flows and quality of the effluents and of the treated waters. Fluctuations (flow, quality) along the day, week and season.
- Wastewater legislation to be fulfilled.
- Forecast of needed plants in the future.
- Failures and risks
- Receiving source of the treated water. Monitoring program.

Within AQUAREC a revision of the state of urban wastewater treatment in several countries has been accomplished and available at its web (www.aquarec.org). Moreover, information about this topic can also be found in some of the web links included in section 3.2.

3.5 Planning in the area

Population projections for the study area and surrounding area should be compiled from different sources, and an analysis of the results of these forecasts should be carried out.

The expected changes in single-family and multifamily connections, commercial, and institutional (schools, churches, sports fields, swimming pools, and parks) uses should be considered.

Studies of land use projections should also be analysed in this section. Projections and possible changes in the location, type of crops and volume of the land used for each crop, irrigation volumes, etc. should be noted down. Schedule of the expected development should be included. The land use plan will be used for prediction of water needs for the study area.

3.5.1 Potential users for the reclaimed water

One of the first aspects to be evaluated in a reclaimed water project is the existence of the need of having at one's disposal the resource (water). For it, potential users of the reclaimed water must be inventoried. Volumes, frequencies, applications and required quality in each case have to be compiled. Location and distance between users and distance and most outstanding geological characteristics to the existing wastewater treatment plants has to be described.

In order to identify possible users, location of greatest water consumers is essential. Examples of great water demanders are for example golf courses, extent agricultural zones, some industries (e.g. power industry, paper industry), parks, gardens, and great recreational zones, etc.

Next a list of the different issues to be tackled within this section is enclosed:

- Inventory of potential users and volumes of reclaimed water that they could demand.
- Location and distance between users and wastewater treatment plants.
- Distribution of water flows, present and future quantity needs, timing and reliability of needs, water quality needs.
- Required on site facilities modifications to convert to reclaimed wastewater and meet regulatory requirements for protection of public health and prevention of pollution problems for reclaimed wastewater. Capital investment for on-site facilities modifications, changes in operational costs, desired pay-back period or rate of return, and desired costs savings. Plans for changing use of site in future.
- Potential demand of reclaimed water for irrigation (agricultural, landscaping, golf courses…), grey water and cooling water reuse and other potential reuses (industrial recycling or reuse, environmental uses…).
- Description of the used methods for market analysis performance.
- Results and conclusions of the enquiry to potential users. Main obtained concerns. Maximum prices that are available to pay for.
- Existing distribution network (i.e. tap water, sanitary systems, and reclaimed water systems) and needed infrastructures (storing, pumping, pipelines, etc.).

As part of the AQUAREC project a model to estimate the potential of wastewater reclamation and reuse in Europe has been developed (Hochstrat, 2005). Different key indicators to evaluate water reuse demand and supply have been proposed and a review of the background and current state on water reuse for different European countries has been performed.

Whenever a water reuse project is considered a fully structured questionnaire has to be prepared and a field survey conducted in the studied zone in order to know and determine the potential users of the reclaimed water, their main concerns, etc. The number of people interviewed will depend on the size of the proposed water reuse project (flow, proposed applications, characteristics of the studied zone, population and its distribution, type of land uses, incomes and so on). As a guiding number, between 300 and 500 interviews could be carried out.

Within AQUAREC a template questionnaire on public acceptance for reclaimed water has been prepared. The questionnaire is divided into 5 sessions:

1. Personal Data
2. Previous knowledge about wastewater
3. Informative session on wastewater recycling
4. Post-informative session and
5. Session open to comments on the issue for the interviewees.

Although public acceptance and users identification are different issues they are very cross-linked, as for example in the case of water reuse for agriculture irrigation public acceptance could condition the demand of products irrigated with reclaimed water.

This point is a key-issue in the planning of water reuse projects. Water reuse must be considered as part of an Integrated Water Management Plan. Public consultation must be taken into account from the very first steps of a Water Management or Water Reuse project, as the higher is the public involvement the higher is the social acceptance of the proposal. Social opinion can determine the final viability of water reuse projects. Many projects have failed because potential users have been over-estimated. Moreover, in many cases the greatest risk of delays in achieving recycled water use is not in the design and construction of facilities, but in obtaining customer agreements and getting site delivery systems planned and ready to accept recycled water (Kennedy & Jenks Consultants, 2002).

In this context, the Water Framework Directive WFD (2000/60/EC), that aims to achieve "good status" of all European waters by 2015, directly takes into consideration public participation and involvement in water projects through the WFD information centre (www.euwfd.com). Furthermore, the EC through its WFD Common Implementation Strategy has edited its guidance document nº8 titled "Public participation in relation to the WFD" covering general principles and tools in public participation and giving numerous examples of public participation in water management projects.

3.6 State of water reuse in the zone and proposed water reuse options

3.6.1 State of water reuse in the zone

The state of water (water scarcity, water quality), wastewater (volumes, qualities) and implemented water reuse options in the studied zone are essential issues to be considered in an Integrated Water Management Planning. When analysing the water reuse state in the target area different issues have to be tackled, such as:

- Description of the current applications of water reuse in the study zone. Inventory of location of implemented water reuse projects, users, flows, qualities, existing agreements and price rates of regenerated water… Detected problems and improvements to be carried out should also be listed.

- Study of the quality regulations for water reuse for each specific use (permitted uses), required levels of treatment, other restrictions and control rules for the different studied zones where water reuse is accomplished.
- Description of water quality and health protection regulations.

The full implementation of the Urban Waste Water Treatment Directive (91/271/EEC) in Europe will contribute to obtain treated wastewaters of quite high quality, that could be reused for certain uses or improved by polishing steps for applications with higher quality requirements. Water quality for each reclaimed water use should be regulated by legislation, but in Europe at present there is no general regulation on wastewater reuse and each country establishes its limits and quality standards when needed (Kamizoulis, 2003; US EPA, 2004). In some countries like Spain, there is not a common legislation yet, though some regions such as Catalonia, Andalusia or Balearic Islands have established their own guidelines as referred to in EC INCO-MED EWATRO project (www.dica.unict.it/users/fvaglias/EWATRO/Struttura/leggi/Mediterranean/upv.htm).

More information about the state of water reuse all over the world can be found in the AQUAREC project web site (www.aquarec.org) and in the final report of the CATCHWATER project (Lazarova, 2001). Furthermore, some web links where varied information related to this topic can be found are listed below:

- Water Magazine (www.watermagazine.com/secure/reuse.htm) with links to different water reuse articles.
- Global Water Intelligence (www.globalwaterintel.com), monthly electronic newsletter providing analysis and strategic data on the international water market. It has recently edited an special report titled *Water Reuse Markets: 2005-2015: A global assessment and forecast*.
- US EPA (www.epa.gov), author of the updated version (2004) of the *Guidelines for water reuse*, available at www.epa.gov/ORD/NRMRL/pubs/625r04108/625r04108.htm.
- Mediterranean Network on Wastewater Reclamation and Reuse (Med-Reunet) with interesting links, bibliography and case studies (www.med-reunet.com/05ginfo/01_links.asp).
- Aquatlan European Interreg project (www.itccanarias.org/aquatlan) addressing the situation regarding agricultural use of wastewaters in the Atlantic areas and favouring the exchange of technological experience.
- Earth Trends Environmental Information Portal (www.earthtrends.wri.org).

- Ministerio de Medio Ambiente, Hispagua, Spanish Water Information System (www.mma.es/ciclo_hidr/hispagua/index.htm)
- International Water Association – IWA specialist group on Water Reuse (www.iwahq.org.uk/template.cfm?name=sg14), with the publication of a Newsletter available for members and specific publications on the topic.
- Sanitation Connection environmental sanitation network, a multipartner Internet-based resource administered by the WHO (core group is formed by IWA, United Nations Environment Programme – UNEP, WHO and the Water and Sanitation Program – WSP) and addressing varied topics such as water reuse (www.sanicon.net/titles/topicintro.php3?topicId=3) with associated publications, web sites, etc.
- State of California Department of Water Resources (www.owue.water.ca.gov) with its Recycled Water Task Force final report downloadable from www.owue.water.ca.gov/recycle/docs/TaskForceReport.htm.
- California Department of Health Services, Division of Drinking Water and Environmental Management (www.dhs.ca.gov/ps/ddwem) with its regulations and guidance for recycled water.
- Queensland Government Environmental Protection Agency with its Water Recycling Strategy to encourage water recycling (www.epa.qld.gov.au/environmental_management/water/water_recycling_strategy).
- Queensland Government Natural Resources and Mines water-recycling discussion list (www.nrm.qld.gov.au/cgi-bin/lwgate/water-recycling).

3.6.2 Proposed options of water reuse

After evaluating the existing water reuse situation in the zone and the different potential users of the reclaimed water, the most suitable alternatives have to be selected for further consideration and evaluation. The area of influence of the project should be very well defined. The different needed treatment processes to obtain the required quality and quantity characteristics have to be pointed out. The final quality of the reclaimed water after storing should be considered and its monitoring programme specified. The followed selection criterion has to be also described.

At this stage, it has to be considered that two different visions are feasible in water reuse. On one hand, there are some supporters of obtaining reclaimed water of not very high quality but quite enough for the proposed use (e.g. agricultural irrigation). In this way, not very intensive treatment methods are needed and, consequently, cost and water price will decrease. This option is more favourable for some developing countries where water scarcity exists and where not many high-qualified personnel to operate advanced treatments and technologies (for example UV light, ozone or membrane bioreactors) is available.

On the other hand, there is another knowledge trend that supports producing reclaimed water of the highest quality as possible as independently of the quality of the reclaimed water you produce end users always are prone to ask for a higher and higher quality of the supplied water. Thus, if a not very high quality water is produced, e.g. for irrigation of crops to be cooked and this is successfully implemented and farmers are satisfied, they will very probably want to use it for other uses, such as irrigation of raw vegetables. Furthermore, maybe a new user demanding a higher quality is installed in the coverage zone that might make decision-makers change the wastewater treatment. Another option is linked to changes in water regulation requiring more restrictive limits for the same use.

All these aspects should be considered in the planning phases of the water reuse project.

Potential options, information to be compiled in each case and other key issues are more deeply dealt with in Chapter 4.

4. PROPOSED WATER REUSE OPTIONS

4.1 Description of each proposed system

Depending on the composition of the wastewater to be treated and on the required reclaimed water quality, the treatments and systems will be different. In Table 4.1 different treatment trains are proposed depending on the reclaimed water application (Lazarova, 2001). Usually, intensive treatments are more expensive, more technological and require less space compared to extensive ones.

Table 4.1 Recommended treatment schemes as a function of wastewater reuse applications (Lazarova, 2001)

Reuse application type	Extensive treatment	Intensive treatment
1. Irrigation of restricted crops	E.1. Stabilisation ponds in series or aerated lagoons; wetlands; infiltration - percolation	I.1. Secondary treatment by activated sludge or trickling filters with or without disinfection
2. Irrigation of unrestricted crops, vegetables eaten raw	E.2. Idem as E.1. with polishing steps and storage reservoirs	I.2. Idem as I.1. with tertiary filtration and disinfection
3. Urban uses for irrigation of parks, sport fields, golf courses	E.3. Idem as E.2.	I.3. Idem as I.2. with filtration in the case of unrestricted public access
4. Groundwater recharge for agricultural irrigation	E.4. Idem as E.2. completed by soil-aquifer treatment	I.4. Idem as I.2. with nutrient removal (when necessary)
5. Dual distribution for toilet flushing	E.5. Not applicable	I.5. Idem as I.3. with activated carbon (when necessary) or membrane bioreactors and disinfection
6. Indirect and direct potable use	E.6. Not applicable	I.6. Secondary, tertiary and quaternary treatment, including activated carbon, membrane filtration (including reverse osmosis) and advanced disinfection

In general, the main information that must be compiled in this section should include the following issues:

- Water quality obtained with each system. Analysis of flows (fluctuations, seasonality) and flow chart. Study of water demands and needs by different uses (current and future ones).
- Description of the types of possible treatments and treatment trains. Summary with the fundamentals of the technologies or processes involved in the different treatment options.

In Annex II some information on wastewater treatment technologies is enclosed. In this sense, 27 key indicators have been defined and the different technologies have been evaluated for each one. Moreover, a table with the average efficiency yields for the most common studied parameters is enclosed. To finish a quite extensive table with interesting information supporting the design and operation of the treatment process is presented.

4.1.1 Water quality and risk analysis

Water quality will depend both on the specific use of the reclaimed water and on the followed treatment. Moreover, depending on the country, region, or specific situation (industrial uses, environmental applications…) the required quality of the reclaimed water will change. Likewise, depending on the quality of the inlet water (raw wastewater), its flow, etc. the quality of the obtained water (reclaimed water) will be different for the same treatment or treatment train carried out.

The different water quality parameters to control in a wastewater reclamation process can be classified into chemical and biological ones. Although the list of parameters to control in water reuse can be very long, the most common or main or reference parameters to take into account are the following:

- BOD (Biochemical Oxygen Demand)
- Turbidity or Suspended Solids
- Coliforms (Total or Faecal)
- Nitrogen
- Residual Chlorine and contact time.

In literature a great amount of information on water reuse guidelines and reclaimed water quality is available. Next, some interesting reference sites are quoted:

- AQUAREC site (www.aquarec.org) providing profuse information on pollutants analysis and monitoring, their associated risks or criteria and guidelines for water reuse can be obtained.
- Mediterranean Network on Wastewater Reclamation and Reuse (Med-Reunet) (www.med-reunet.com/05ginfo/04_references.asp) providing plenty of information including a proposal for quality standards dividing them by countries with already implemented reuse systems (advanced standards for developed countries), Mediterranean countries standards and standards for other countries with less developed reuse systems or with needs of reused water.
- EWATRO Inco-Med European project website (www.dica.unict.it/users/fvaglias/EWATRO), offering varied information about criteria for different water reuse applications.

The current lack of a general reference regulation in Europe for water reuse should be sorted out to promote water reuse implementation and to overcome the lack of confidence of the final users on the reclaimed water quality and suitability for each specific use.

Up to the moment, among the most important legislation pieces that different countries have taken as reference guidelines three main ones stand out:

- The World Health Organisation (WHO, 1989) recommended microbiological guidelines for wastewater use in agriculture, restricted to this specific application.
- The suggested guidelines of the U.S. Environmental Protection Agency (EPA) for different water reuse applications (US EPA; 2004), and
- The legislation of the Title 22 of the California Code of Regulations (1978), more restrictive in analytical and treatment needs.

For instance, for irrigation without restriction wastewater microbiological pollution must, according to WHO, remain below 1,000 Faecal Coliforms (FC)/100 mL and 1 egg of helminthes/L while the Californian "Title 22" fixes more severe restrictions, even the total absence of germ-tests - less than 2.2 Total Coliforms (TC)/100 mL.

In this context, the difference between criterion and standard has to be distiguished. A standard is a level of performance achieved when it is judged against a criterion. For example, Title 22 of California is a criterion and the European Directive of Water Quality Standards presents, as the same title points out, standards.

Risk analysis, evaluation and assessment is closely linked to the reclaimed water quality and the application given to this water. Usually, risk related tools start with risk assessment, proceed with risk calculation and end with risk management and communication.

Risk assessment should follow the European Technical Guidance Document (TGD) of the EC (1996) on Risk Assessment, based on the Commission Directive 93/67/EEC and Commission Regulation (EC) 1488/94 and Directive 98/8/EC. Chapter 2 in Part I of this TGD addresses human risk assessment while Chapter 3 in Part II centres on environmental risk assessment.

Both human health and environmental risk assessment proceed always in the following sequence:

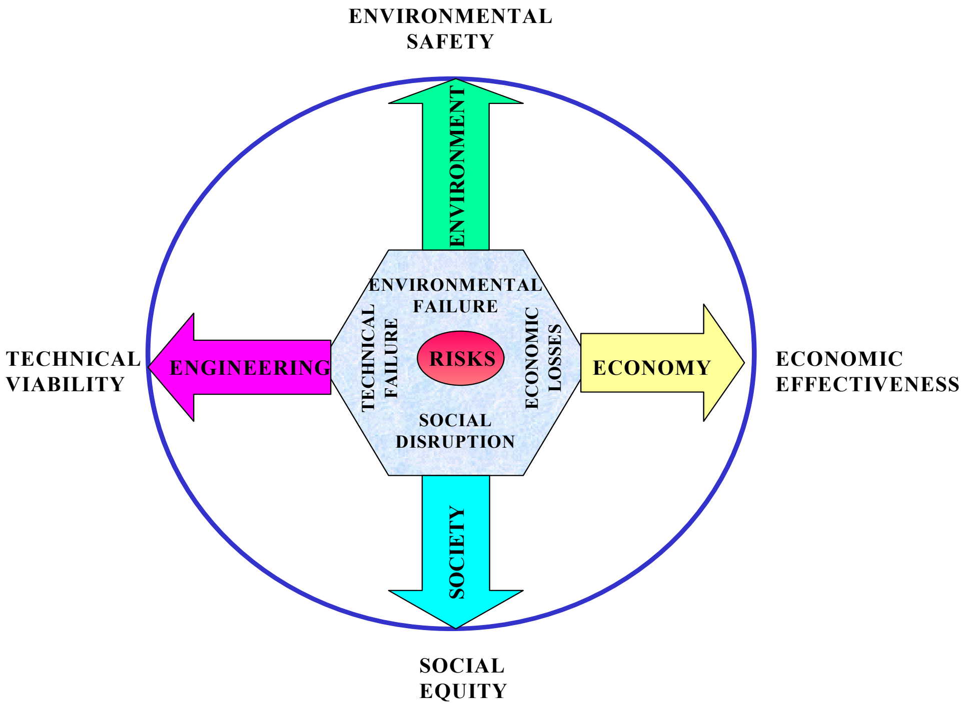
1. hazard identification
2. dose (concentration) – response (effect) assessment
3. exposure assessment, and
4. risk characterisation

Although there is a range of formalised risk management (RM) approaches, the Hazard Analysis Critical Control Point (HACCP) is considered the most suitable one in the case of water reuse projects. More information on this specific issue can be found at the AQUAREC project web site (www.aquarec.org).

In order to minimise as much as possible the potential risks associated to water reuse, it is encouraged to carry out a very strict and complete monitoring programme together with a guideline of best practices.

The different types of risks associated to water reuse projects are catalogued in four main categories (Figure 4.1): environmental, technical, social and economical risks.

Figure 4.1 Risks and objectives for sustainable wastewater reuse (Ganoulis, 2003)



Amongst them, the possible transmission of infectious diseases by pathogen agents is the most important concern. Environmental engineering and preventive sanitary practices have contributed to maintain the appearance of epidemic episodes under control. Accordingly, even though for many uses it is not necessary to obtain recycled water free of pathogens, the most common practice is to obtain reclaimed water with the needed quality corresponding to the most restrictive use.

Furthermore, anthropogenic and industrial activities have led to the release of many different chemicals (pesticides, drugs, hormones, phthalates…) to natural waters. Some of them have been proved to present an endocrine disrupting character or to produce cancer and other illnesses although being in very small concentrations. However, the possible effects and risks of a very large amount of compounds have not been analysed yet. Future legislation and regulations will take into consideration these types of substances and it is for this reason that for preventing any type of concern, the most suitable treatment should be carried out in each case.

4.2 Advantages and disadvantages of the proposed options

The advantages and disadvantages of the different technology proposals have to be analysed and summarised to compare them with the existing situation. It is also essential to point out and range potential difficulties and propose possible solutions to them.

The issues to be considered as advantages or disadvantages of a proposed solution might match the proposed key indicators in Table 1 of Annex II. Among them, usually the most outstanding ones when evaluating a given option are the following:

- resources requirement (land requirement, civil works, installation of pipelines, energy and water requirements, human resources…)
- reliability (quality and changes on the quality of the outlet water, healthy and sanitary issues, safety and risk issues)
- ease of construction (time to be operative)
- adaptability (i.e. capacity to treat different flows or inlet loads)
- capacity to be upgraded (e.g. improvement of the quality changing the membrane cut-off in a membrane bioreactor treatment) or to be enlarged)
- environmental sustainability of the considered alternative, and
- economical cost (investment and operation and maintenance costs). Under the O&M costs, labour and energy costs are usually the main items to be analysed. The need of qualified personnel or a treatment with a very time-intensive demand of operators will highly increase the labour costs associated to a given treatment.

As an example, some main advantages of a submerged membrane bioreactor versus a conventional activated sludge treatment include less space requirements, higher reliability and adaptability or less construction time requirements. However, the activated sludge treatment currently needs lower O&M costs.

Tables 2 and 3 in Annex II comprise the most outstanding aspects for different water treatments and some useful data (design parameters, some energy and cost data as well as references) to consider when evaluating a treatment or treatment train for water reuse.

4.3 Implementation requirements

Each proposed treatment option in a water reuse project will need some requirements for its implementation such as land needs, power availability, roads and infrastructures, etc. Furthermore, the treatment system may require a minimum quality in the inlet water, a specific monitoring plan or restrict the water feed flow.

In summary, some of the relevant information to be gathered under this heading includes:

- Description of the additional wastewater treatment needs.
- Summary of storage and land requirements, distribution lines, pressure maintenance, security needs, auxiliary power and special considerations.
- Evaluation of personnel needs, cleaning and chemicals requests, needs of sprinklers or other suitable systems to minimise pipeline and irrigation systems obstruction, study of related regulations as well as legal and administrative constraints.

Reclaimed water distribution is a key aspect to consider in a water reuse project. It is estimated to be 8% of the total construction costs of the project, while maintaining the pipelines and storage tanks is calculated to be 2% of the capital cost. Accordingly, the different alternatives for reclaimed water distribution and storage have to be firmly evaluated.

When designing the distribution and storage systems different aspects such as orography, geology and soil availability need consideration. The precise coordinates and elevation of the proposed systems have to be indicated, specifying if they imply water supply, water storage, pumping or treatment. In case of dual distribution of tap water and recycled water, their differences and the adopted security measures (risk assessment) need to be pointed out (e.g. distances between their distribution lines, specific materials and elements to be used, etc).

Moreover, the type of demand (constant or seasonal), demand head and demand flow (or monthly demand flows) will be other aspects to consider.

Regarding pumping requirements, the different aspects to consider might include capacity (flow to pump) in $m^3.s^{-1}$, types (size, amount) of needed pumps, pumping head (m), distance to pump (m), capital cost ($EUR.m^{-3}$), operating hours per year (h), pump efficiency (%) and considered maintenance cost (% of annualised capital cost).

In the analysis of storage needs, the main four types of storage elements to consider include reservoir, covered tank, concrete tank and earthen basin. The main aspects determining the economical cost due to water storage are its type and the size of the needed storage. If other systems or facilities are needed, they should be included too.

For the distribution network, different simulation softwares (Linear Programming - LP formulation) can be used to estimate the optimal size and length of the pipes in each case, such as:

- WTRNet software developed within AQUAREC
- The S-Pipe (Service Supply Pipe Sizing) Programme distributed by Elite Software Development Inc.

- The Fluid Flow Calculator provided for free at the Free Engineering Software Website (www.connel/freeware)

Moreover, different referable pieces of literature and reports are available at:

- AQUATLAN Interreg Project reports (www.itccanarias.org/aquatlan)
- US Environmental Protection Agency water-related topics (www.epa.gov/ebtpages/water.html)
- *Practical hydraulics handbook* (Hauser, 1996).
- *Perry's chemical engineers' handbook* (Perry, 1997).
- *Waste-water treatment technologies: a general review* (United Nations Economic and Social Commission for Western Asia, 2003).
- Section 2.1.3.2. of the U.S. EPA *Guidelines for Water Reuse* (2004).

In general, the following items should be considered when planning a water pipeline system:

- discharge (flow) requirements
- size of the pipe and material comprising it
- distance from the source to the point of consumption
- elevation difference between the source and the point of consumption and variation in elevation along the pipeline route
- permanence of the installation (i.e. year-round vs. seasonal use, need for portability)

Other considerations such as pressure requirements for delivering the desired amount of water and the amount of pressure the pipe must be able to withstand are considered implicitly in the preceding list, because they are functions of discharge requirements, elevation differences and the size and material composition of the pipe.

In the referred programmes, different methods can be selected to calculate head-losses using Hazen-Williams, Darcy-Weisbach or Manning formulae. Moreover, installed pipe unit costs for different land-use areas of installation (rural, suburban and urban), and up to 20 different commercially available pipe diameters from which to choose in sizing of the distribution system are included. Capital and O&M costs will depend on the size, types and length of the utilised pipes.

Furthermore, GIS can be used to determine the most suitable option for a given piping line, place for reservoirs, etc. Next, some reference web links and documents supporting GIS application to wastewater management and water reuse are listed:

- GeoCommunity GIS online portal (www.geocomm.com)

- GISportal (www.gisportal.com) with the fundamentals, showcases and demo of this tool
- GIS Lounge portal (www.gislounge.com)
- Water Framework Directive Common Implementation Strategy guidance document No. 9 on GIS, downloadable from forum.europa.eu.int/Public/irc/env/wfd/library?l=/framework_directive/guidance_documents&vm=detailed&sb=Title
- U.S. National Geophysical Data Center – NGDC (ftp://ftp.ngdc.noaa.gov) and National Ocean Service, Management and Budget Office – NOS, Special Projects (spo.nos.noaa.gov/busline/gis.html)
- U.S. EPA wastewater planning funded project report (Dulay, 2002) downloadable from ESRI webpage (gis.esri.com/library/userconf/proc02/pap0263/p0263.htm)
- Paper on Integrated Water Management in Broward County, Florida, using GIS (Henderson, 2002) downloadable from ESRI webpage (gis.esri.com.library/userconf/proc02/ pap0744/p0744.htm)
- Jouravkova (KTH, Sweden) master thesis on problems and perspectives of GIS applications for transboundary water management in Europe, downloadable from www.lwr.kth.se/Publikationer/PDF_Files/ LWR_EX_2003_03.PDF
- International Water Management Institute – IWMI research report no. 28 on performance evaluation of the Bhakra Irrigation System, India, using remote sensing and GIS techniques (Sakthivadivel, 1999), downloadable from www.iwmi.cgiar.org/pubs/pub028/RR028.htm

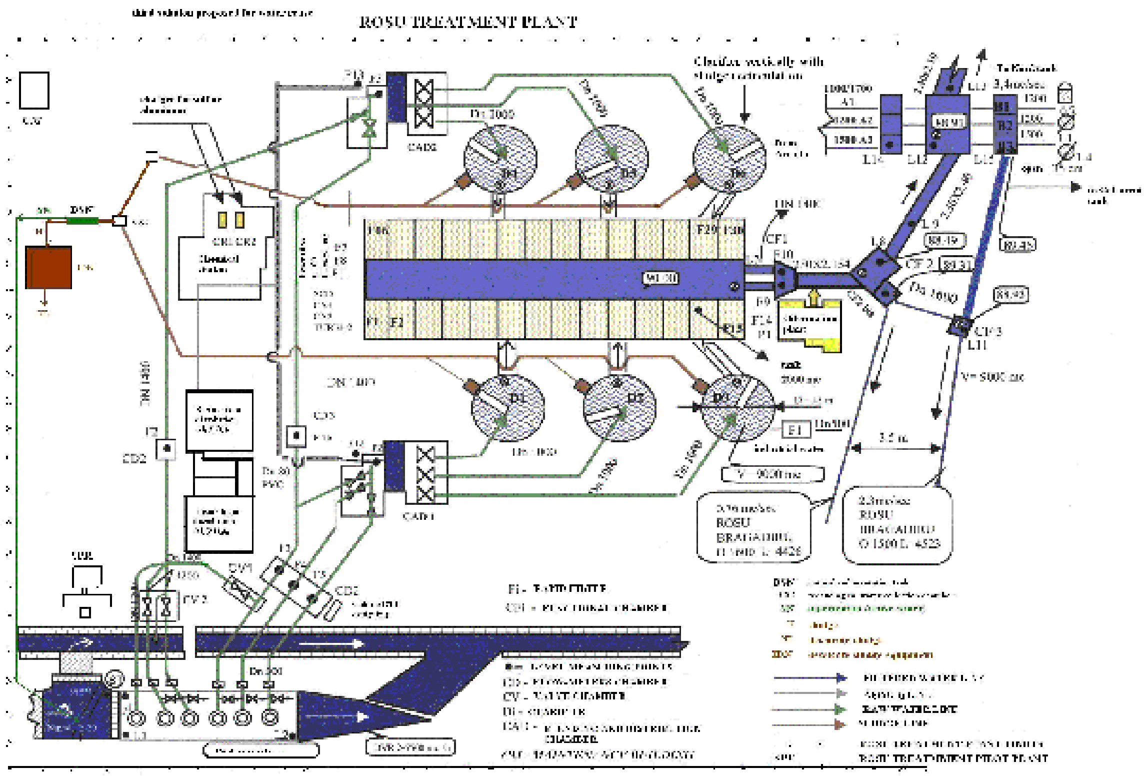
Regarding wastewater treatment needs, usually in addition to the most common wastewater treatment, i.e. secondary treatment, filtration and disinfection are generally required for reuse in an urban setting. In the case when a single large consumer needs reclaimed water of higher quality, this user may have to provide additional treatment on site.

4.4 Basic layout

It is essential to provide the basic layout of the existing and proposed options. In the case of wastewater treatment plants, the flow charts with the location of the different systems, the measures and distances among them, the position of the alarm and security systems, the control and administrative facilities, etc. have to be compiled. For already existing facilities, the comparison between the current and the proposed situation needs to be carried out. Moreover, when different location options for the same wastewater treatment trains are feasible, their main differences and their advantages and disadvantages have to be pointed out. Besides, flow ranges, expected treatment yields, etc. have to be provided.

In the following figure (Figure 4.2) an example of a block scheme for a wastewater treatment system in Romania is shown.

Figure 4.2 Example of a wastewater treatment system layout in Romania (AQUAREC project)



As previously mentioned, in Annex II some information and references to further develop this section can be found. Furthermore, some interesting web sites providing related information are:

- The Northern Shoalhaven REclaimed water Management Scheme (REMS), one of the largest and more complex water-recycling schemes undertaken by the Australian water authority (www.shoalwater.nsw.gov.au/3currentprojects/rems/SCHLAOUT.HTM)
- The OWASA (North Carolina Orange Water and Sewer Authority) Mason Farm WWTP water reuse project (www.owasa.org/pages/WaterReuse/questionsandanswers.html)
- The McGraths Hill effluents reuse & wetlands project in Australia (www.hawkesbury.nsw.gov.au/environment/1237/1259.html)
- Sydney Water projects (www.sydneywater.com.au/ProjectsandTendering/MajorProjects).

4.5 Equipment needs and costs

Under this heading the major issues to be tackled include:

- Capital costs of the treatment system: design cost, material cost (technology and equipment needs and costs), construction and assembly cost (distribution systems, storage tanks, infrastructure needs…)
- Running costs: O&M needs and costs (personnel costs, equipment replacement, systems' failures, monitoring and control needs and costs), chemicals needs and costs, power needs and costs
- Waste disposal needs and costs
- Others

The evaluation of investment and operation and maintenance costs is a fundamental phase in the planning of wastewater reuse systems, as it is necessary for an economic comparison with the other conventional and unconventional water resources. Unfortunately, wastewater treatment costs are not usually well documented (Sipala, 2003).

Capital costs include land acquisition, civil works, and equipment. Operation and maintenance costs include manpower wages and salaries, power consumption, sludge treatment and disposal, ordinary and extraordinary maintenance and costs for chemicals.

Reported water reclamation costs range widely. It is, therefore, important in comparing costs that differences in assumptions and factors associated with allocation of costs among wastewater treatment and water reclamation and reuse are correctly understood. Although costs associated with secondary treatment of wastewater are often considered to be pollution control costs in industrialised countries, they serve as a baseline cost for comparison with tertiary and/or advanced treatment facilities for water reuse. As an example the construction cost breakdown for various treatment processes is estimated on the basis of 3,785 m^3d^{-1} with the total capital cost 0.44 EUR m^{-3} distributed as: primary treatment 24%, secondary treatment 40%, sludge treatment 22%, and control, laboratory, and maintenance buildings 14% (based on the total capital cost of secondary treatment system in California).

A common misconception in planning for water reclamation and reuse is that reclaimed water represents a low-cost new water supply. This assumption is generally true only when water reclamation facilities are conveniently located near large agricultural or industrial users and when no additional treatment is required beyond the existing water pollution control facilities from which reclaimed water is delivered. The conveyance and distribution systems for reclaimed water represent the principal costs of most water reuse projects (Asano, 2001).

A recent experience in California indicates that approximately 3.52 million EUR in capital cost are required for each 1 million m3 per year of reclaimed water that are made available for reuse. Assuming a facility life of 20 years and 9% interest rate, the amortised cost of this reclaimed water is about 0.44 EUR m^{-3}, excluding operation and maintenance costs (Asano, 1998).

Furthermore, in the Table 3 of Annex II and in section 7.4.1 additional information and references referred to this topic can be found.

4.6 Site possibilities

It is also essential to describe the site possibilities for the construction of the wastewater treatment plant (in case of non-existing facilities), for its enlargement, for the location of water distribution pipelines, storage tanks, pumping stations and other needed facilities. Plans of the different proposed options should be enclosed. GIS is a very valuable tool supporting this task. Main advantages and disadvantages of each alternative, including proximity to potential users or possible social and/or environmental problems, should also be summarised.

Not only site possibilities but also the price of land and the cost of each alternative need to be considered. Value or availability of land can be very important leading to select compact systems, such as membrane bioreactors, versus other more space-requiring, like aerated lagoons or activated sludge. This is a key factor in places like Japan, in very populated areas, coastal locations, and islands as well as for small-scale water reuse projects.

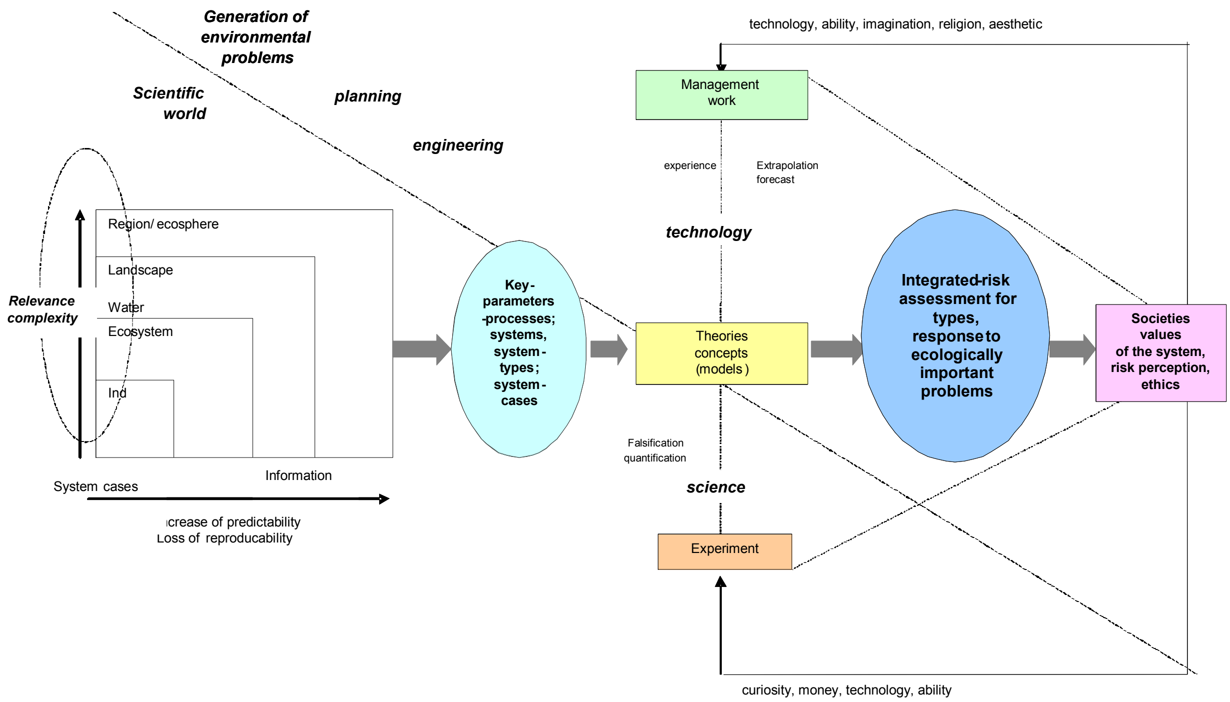
5. ENVIRONMENTAL IMPACT ASSESSMENT

5.1 Introduction

Within the AQUAREC water reuse feasibility study methodology, the issues covered under the Environmental Impact Assessment (EIA) heading focus on EIA methodology, environmental risk analysis procedures (HACCP) in different reuse applications, ecological driving force indicators, their potential environmental effects on quality, thresholds and absorbing capacity of receiving environments in terms of integrated water cycle (hydrological regime alterations, streams disturbance factors, groundwater recharge) and ecologically sustainable water management (removal/remediation actions, monitoring).

The EIA ensures that environmental consequences of projects are identified and assessed before authorisation is given (Council Directive 85/337/EEC, amended by Directive 97/11/EC). Its prime purpose is to identify any significant environmental effects of a major development project, and where possible to design mitigation measures to reduce or remedy those effects, in advance of any decision to authorise the construction of the project. As a <u>tool to aid decision making</u>, EIA is widely seen as a proactive environmental safeguard <u>together with public participation and consultation</u>. Consequently, the <u>multidisciplinary framework</u> supporting environmental impact assessment is based on the hierarchy of different organisational and analytical levels in the important involvement of social and political economy (Figure 5.1).

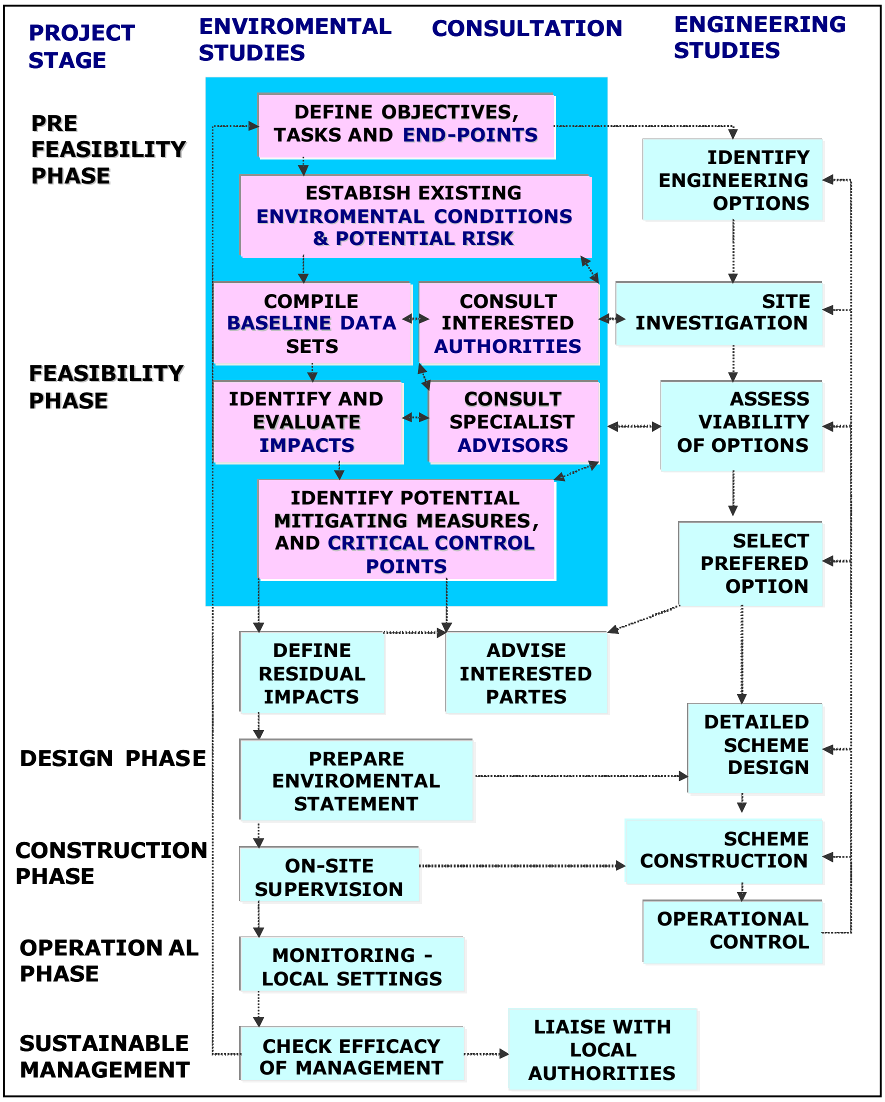
Figure 5.1 An Environmental Impact Assessment Multi-level Approach (adapted from Lunz, 2002)



5.2 Establishing substantial requirements for EIA

An Environmental Impact Assessment (EIA) is a systematic analysis using the best practicable techniques and best available sources of information on the environmental effects of a project covering social, cultural, economic constraints and ecological attributes (Figures 5.1 and 5.2).

Figure 5.2 The Environmental Impact Assessment procedures (modified, CIRIA, 1994)



Accordingly, EIA is a <u>compulsory</u> requirement for the project realisation and is addressed by the project developer <u>in the pre- and feasibility stages</u> in consultation with other institutions involved. The results of this assessment are considered by the planning or other statutory authority in forming its judgement as to whether - on environmental grounds - the project development could be accepted.

The main substantial steps/levels involved in the standard EIA include following recommended procedures (CIRIA, 1994; Calow, 1998; Jain, 2001):

- A **detailed project description** of the proposed development comprising information about the site and the design and size or scale of the development. Its physical characteristics of should particularly include the land use requirements during the construction and operational phases (Figure 5.1) and the main characteristics of the technological processes involved. In the preliminary planning of a water reuse system incorporating existing facilities, the following information is needed for the initial evaluation: (1) residential areas and their principal sewers, (2) industrial areas and their principal sewers, (3) wastewater treatment facilities, (4) areas with combined sewers, (5) existing effluent disposal facilities, (6) areas and types of projected development and (7) locations of potential reclaimed water users (see also previous chapters).
- A **scoping study**, i.e. a conservative qualitative determination of whether there are any ecological receptors and/or exposure pathways present at or in the locality of the facility. Scoping is intended to identify and assess base related to potential impact and environmentally sensitive areas in the catchment. The analysis might be supported by: (i) the empirical data collection (e.g. regional environmental settings; hydrological regime, topography; maps showing structures, land use, wetlands, surface water bodies, sensitive environments; hydrogeology, local authorities) and/or (ii) commissioning of "baseline" surveys. The site-specific history of hazardous substances uses and releases is more typically the source of potential contaminant information. Besides, the water resources should be characterized to roughly establish the wastewater effluent's suitability for reclamation and reuse. To compare the quality and quantity of available reclaimed water with the requirements of potential users, information about the operation and performance of the existing projects and related facilities should be examined. Important factors to consider in this preliminary stage of reuse planning are: (1) level of treatment (e.g., primary, secondary, advanced) and specific treatment processes (e.g. ponds, activated sludge, filtration, nutrient removal, disinfection); (2) effluent water quality; (3) effluent quantity (e.g. daily uptake m^3day^{-1}; use of historical data to determine daily and season at average, maximum, and minimum flows); (4) industrial wastewater contributions to flow; (5) system reliability and (6) supplemental facilities (e.g., storage, pumping, transmission).
- A **screening study/conceptual site model development**, based on the evaluation of the potential main components of environmental risk assessments, particularly: exposure-pathway[1] analysis (site-specific ecological receptors for each habitat type; food webs; assessment end-points); demonstration of the critical control points of the proposed scheme (with recommendation of Indicative Thresholds and Criteria, and Mandatory Thresholds and Criteria – e.g.

[1] An exposure route is the way a chemical or physical agent comes in contact with a receptor (i.e., by ingestion, inhalation, dermal contact, etc.).

UNEP, 2002); methods of evaluation of the potential types and intensity of the risk[2]; demonstration of the alternative management options (Tables 5.1, 5.2 and 5.3); potentially significant direct and indirect effects on the environment of the project proposed that should particularly include the use and/or the degradation risk of natural resources, the emission of pollutants, the creation of nuisances and the disposal of wastes (e.g. concentrates and sludges from the water reclamation process).

- A **design of alternative management strategy** related to the different types of impact and its intensity; predicted scenarios, early-warning network, protected areas and lack of know-how.
- The **DPSIR system** (Driving force – Pressure – State – Impact –Response), developed by the Environmental Agency and Eurostat (EEA, 1999) as a supportive framework for Decission Suppport Systems (DSS) of any environmental projects. It provides an overall mechanism for analysing environmental problems based on a cause-effect model. Driving forces, such as industry and transport, produce Pressures on the environment, such as polluting emissions, which then degrade the State of the environment, that then Impacts on human health and eco-systems causing society to Respond with various policy measures, such as regulations, information and taxes, which can be directed at any other part of the system (lead.virtualcentre.org/en/dec/toolbox/Refer/EnvIndi.htm).
- A **design of consultations and monitoring network setting** (statutory consultees, local and country authorities, etc.).
- An **establishment and design of mitigation measures and auditing scheme**, and finally the arrangement of the **Environmental Statement** (ES) related to the subject of ecologically sound water management.

5.3 Ecological risk analysis

The main component of the Environmental Impact Assessment in the feasibility and operational phases of any project is an involvement of the Hazard Analysis process with Critical Control Points (**HACCP**) establishment. The EIA process requires identifying environmental values to be protected (Tables 5.1 and 5.5), deciding the appropriate scale and level of biological organisation, assembling multidisciplinary data collection and assessment teams, rigorously interpreting results using both quantitative and qualitative methods and communicating the results in a way that

[2] The evaluation of environmental risk includes range of categories: secondary, cumulative, short-, medium-, and long-term, permanent, temporary, positive and negative, because a quantitative risk assessment programme is long-term and site-specific, and very often is a subject to uncertainty. Therefore, the management of risk should be a general judgement-based assessment of risk, forming the first action in a risk management programme, with detailed risk analyses being performed as a separate studies.

facilitates risk management. Further information on this methodology is provided in the AQUAREC web site (www.aquarec.org).

Table 5.1 Selected environmental indicators in the DPS chains (USEPA 2004, Giupponi 2004 and AQUAREC's criteria)

Driving Force Indicators	Pressure Indicators	State Indicators
▪ Urban settlements (inhabitants km^{-2}) ▪ Impermeable (developed) areas (ha) ▪ Irrigated land (ha) ▪ Buffer strips (ha) ▪ Use of nitrogen fertilisers in agriculture (kg ha^{-1} yr^{-2}) ▪ Land reclamation by pumping machines (m^3 yr^{-1}) ▪ Land reclamation by drainage network (m^3 yr^{-1}) ▪ Social acceptance (index) ▪ Bureaucratic pressure (index) ▪ Variation of social welfare (index) ▪ Local legislation (index) ▪ Public investments (MEur) ▪ Maintenance costs (Eur yr^{-1})	▪ Urban net emission of BOD_5 (t yr^{-1}) ▪ Loads of hazardous substances to water bodies by sector (tHS yr^{-1}) ▪ Use of water for irrigation (m^3 yr^{-1}) ▪ Drainage water interception by vegetation (m^3 yr^{-1}) ▪ Nitrogen balance: total surplus from fertilisers and manure applications (kg ha^{-1} yr^{-2}) ▪ Hydraulic risk: return time (yr) ▪ Total discharge of nitrogen (t yr^{-1}) ▪ Surface water drainage (mm yr^{-1})	▪ BOD/COD in rivers (mg L^{-1}) ▪ Hazardous substances (e.g. pesticides) in rivers (μg L^{-1} HS^{-1}) ▪ N organisation with irrigation (t yr^{-1}) ▪ N organisation with buffer strips (t yr^{-1}) ▪ Nitrate concentrations in water bodies (mg L^{-1}) ▪ Flooding damages (MEur) ▪ Self-remediation of water bodies: N retention (t yr^{-1}) ▪ Water retention time (hrs)

Table 5.2 Selected potential methods used in a Strategic Environmental Appraisal (SEA) (UNEP, 2002 and AQUAREC's criteria)

Step	Examples of methods
Baseline Study	Inventory of environmental settings 'Points of reference' from comparable studies Direct assessment of impact
Screening/Scoping	Formal/informal checklists of CCPs Survey, case comparisons – DPSIR system Effects networks Public or expert consultation
Formulating options	Environmental policy, standards, strategies Prior commitments/ precedents Regional/local plans Public values and preferences
Impact analysis	Scenario development Risk assessment Environmental indicators & criteria: indicative/mandatory thresholds & criteria Policy impact matrix Predictive and simulation models GIS, capacity/habitat analysis at local and catchment-scale Benefit/cost analysis and other economic valuation techniques Multi-criteria analysis
Documentation for Decision Making	Cross-impact matrices Consistency analysis Sensitivity analysis Decision 'trees'

In the **DPSIR** system the description of the environmental problems is optimised by formalising the relationships between various sectors of human activity and the environment as causal chains. This framework, called **Strategic Environmental Appraisal** (SEA) scheme, aims at making explicit the cause-effect relationships between interacting components of complex social, economic and environmental systems and at organising the information flow between its parts (Tables 5.1, 5.2).

Hazard identification

Hazard analysis is a key component of qualitative and quantitative risk assessment and risk management. This step determines whether a risk exists, if the effects associated with the hazard are significant to warrant further study or immediate management action and the data type and range required to determine the level of risk. A major factor to be considered at this step is the selection of ecologically based endpoints relevant to the ultimate decisions to be made.

Exposure assessment

It refers to the determination of exposure to the hazardous agent in question. This process includes measurement or prediction of movement, fate and partitioning of chemicals in the environment. This step is typically accomplished through chemical analysis of site media or ecological receptors and/or mathematical modeling.

Exposure-response assessment

This process refers to the determination of the relation between the magnitude of exposure and the probability of occurrence of the expected effects. Useful information in this step includes toxicity data (chronic toxicity, mode of action, sensitivities of particular species), mesocosm or field test data, field surveys comparing exposed and unexposed sites and population or ecosystem modelling. The dose/response assessment determines the impact that a hazard has on the population, given the concentration that the population is exposed to. The results of these studies provide information on the severity of the health and environment from exposure to different intensity of a stressor.

Risk characterisation

This step involves describing the nature and magnitude of risks including the inherent uncertainties, expressed in understandable terms to decision-makers and to general public. It integrates information from the previous steps, determines indicative and critical points and limits and communicates it to decision makers in a relevant manner to the decisions being made.

Risk management

In this process decisions are made about whether an assessed risk needs to be managed and the means for accomplishing it, for the protection of public health and environmental resources. Managing risks involves making decisions based on the information collected in the previous steps of the risk assessment along with a consideration of social and cultural values, economic realities and political factors (SCOPE 53, 1995; WS-DH, 1997; US EPA, 2004). Monitoring and audit are used to provide the data necessary to conduct an environmental risk assessment. Important aspects to consider when planning monitoring for a risk assessment are levels of biological organisation and the temporal and spatial scales relevant to the study.

Table 5.3 Baseline data requirements for the potential application in the EIA procedures at catchment scale (CIRIA, 1994; Calow 1998)

Environmental media	Potential Major Constraints at Catchment Scale
Geology	Lithology, protected areas
Climate	Water cycle, rainfall, precipitation, hydrological balance, evaporation
Hydrology	Discharge, flood and low flows, channel morphology, abstractions
Oceanography	Bathymetry, seabed materials, sediment quality
Air quality	Existing levels and sources of pollution
Water quality	Physical, chemical, microbial and ecological components
Odour	Degree of offensiveness, sources
Sediment quality	Particle size, cohesion, lithology, characteristics of sludges
Dust	Deposition rates, incidents of spoiling, areas affected
Soil/ground conditions	Soil type, geotechnical characteristics, contaminated land
Groundwater	Water quality, recharge flow, abstractions, designated nitrate sensitive areas
Tidal regime	Tides, currents, storm surges, waves, wind
Noise	Existing levels, diurnal variations, sources
Flora and fauna	Habitat type, species composition/abundance, rare species, designated sites, breeding grounds
Population	Density, numbers, structure, trends
Local community	Attitude to development
Housing	Settlement patterns, quality, location
Employment	Major industry types/employers, unemployment rate, trends
Health and safety	Health of population (e.g. incidence of respiratory diseases)
Emergency services	Location and resources
Land use	Type, economic value, planning policies
Agriculture	Grade of agricultural land, farm structure and viability, severance, trends
Landscape	Designated areas, quality, characteristics
Commercial fisheries	Type, location, economic value
Leisure and amenity	Activities, facilities
Tourism	Numbers, seasonality, facilities, attractions
Heritage	Designated sites
Infrastructure	Transport network and capacity, utilities
Traffic	Mode of transport, amount of traffic, percentage HGV on roads, noise, vibration
Navigation	Discharge regime and minimum flow required in rivers

5.4 Outlines of key environmental requirements for water-reuse projects

The Environmental Impact Assessment of a water reuse project should address the following groups of risk:

1. Substantial alteration of land use
2. Conflict with the land use plans or policies regulations

3. Adverse impact on wetlands
4. Affection to endangered species or their habitats
5. Populations displacement or alteration of existing residential areas
6. Antagonistic effects on a flood-plain or important farmlands
7. Adverse effect on parklands, preserves or other public lands designated to be of scenic, recreational, archaeological, or historical value;
8. Significant contradictory impact upon ambient air quality, noise levels, surface or groundwater quality or quantity
9. Substantial adverse impacts on water supply, fish, shellfish, wildlife and their actual habitats (Tables 5.1, 5.5).

Planning for the use of recycled water should take into account all relevant aspects of the integrated water cycle in an area. Thus, consideration of the use of recycled water should take place on an equal basis with all alternative sources of water services and with the involvement of all relevant stakeholders as part of an integrated planning process.

A general classification of receiving environment and selected constituents of hazard analyses is presented in Table 5.4.

Table 5.4 Receiving environments and constituents of concern. Potential risk

Receiving environment	**Hydrological Regime**	**Temperature**	**Oxygen/BOD_5**	**Salinity/Sodicity**	**pH/Solubility of chemicals**	**Sedimentation (Ss)**	**Odour/tainting**	**Floatables/scums/oil**	**Colour/turbidity (Ss)**	**Nutrients/enrichments**	**Toxic compounds**	**Pathogens**
Lake /reservoir	4	3	4	3	3	4	3	4	3	4	3	3
River/stream (<50% base flow)	3	2	4	3	3	4	3	4	2	4	3	2
River/stream (>50% base flow)	3	2	4	3	3	4	3	2	2	4	3	2
Estuary	1	1	2	2	2	3	3	4	2	3	2	2
Nearshore Marine (shoreline)	1	1	2	2	3	3	3	2	2	3	2	2
Groundwater	4	2	3	4	3	2	3	3	3	4	4	2
Air		4	3	3	3	2	3	4	4	2	4	4
Soil			3	4	4	2	2	3	1	4	3	2
Flora				4	4	2	2	4	1	4	4	1
Fauna				3	3	2	4	4	1	4	4	4
Human Health				1	1	1	4	4	1	2	4	4

Potential risk/hazard	**4 Critical**	**3 High**	**2 Medium**	**1 Low**	**0 None**

Table 5.5 Selected examples of ecological risk endpoints and associated measures (referenced and ULODZ's criteria)

Risk Assesment Endpoints	Site-Specific Ecological Receptors	Risk Measures	
		Exposure	Effect
Acute and chronic toxic effects in benthic community	- Freshwater benthic community	▪ Ecological community structural and functional indices (abundance, diversity, FFG[3]) ▪ Contaminant levels in sediments, surface water and upwelling groundwater ▪ Bioassays	▪ Estimated exceedance of ecological benchmark values (EBVs) ▪ Estimated exceedance of population-level effect thresholds ▪ Reference vs. on-site differences in community indices ▪ Bioassay results
Acute and chronic toxic effects in non-migratory (resident) fish	- Freshwater fish community	▪ Food chain exposure modeling ▪ Contaminant levels in surficial soils ▪ Contaminant levels in food items (plankton, macroinvertebrates)	▪ Estimated exceedance ofEBVs ▪ Estimated exceedance of population-level effect thresholds ▪ Reference *vs.*onsite differences in community indices ▪ Contantaminant tissue residue levels
Protect predators from acute and chronic toxic effects due to consumption of contaminated food items and incidental ingestion of surficial soils	- Raptors community (e.g. owls, falcons) - Predatory mammals (e.g. otters, wolves)	▪ Food chain exposure modeling ▪ Contaminant levels in surficial soils ▪ Contaminant levels in food items (small invertebrates and mammals, insects, birds)	▪ Estimated exceedance of EBVs ▪ Estimated exceedance of population-level effect thresholds
Acute and chromic toxic effects in mammals community	- Mammals community (e.g. field mice, voles, hares, minks, wild boar, hedgehog, red deer, roe dears)	▪ Food chain exposure modeling ▪ Contaminant levels in surficial soils ▪ Contaminant levels in food items (vegetation, insects, earthworms) ▪ Contaminant tissue residue levels	▪ Estimated exceedance of EBVs ▪ Estimated exceedance of population-level effect thresholds ▪ Long-term effects: Measurement of bone density & strength; ▪ Contaminant tissue residue level

Land use alteration

A water reuse project can directly induce significant changes in land use including shifts in ecosystem characteristics - induced by alterations in water balance in an area. Other examples of land use alteration resulting from available water for reuse include the potential for urban or industrial development in areas where natural water availability limits the potential for growth. If the supply of potable water can

[3] Feeding Functional Groups

be increased through recharge using reuse supply, then restrictions to development might be reduced or eliminated. Even non-potable supplies, made available for uses such as residential irrigation, can affect the character and desirability of developed land in an area. Commercial users such as golf courses, garden parks, or plant nurseries have similar potential for development given the presence of reuse supplies. However, the potential interactions associated with land use changes are very complex. For this reason, the decision-making process involved in implementing a reclamation program should result from a careful consideration of stakeholder goals (FAO, 1995; USEPA, 2004).

Stream discharge impact

Surface waters are the primary receiving environment for almost all wastewater discharges. In each situation where reuse is considered, there is the potential to shift water balances and effectively alter the prevailing hydrologic regime in an area. For instance, in streams where dry weather base flows are groundwater dependant, land application of reclaimed water for irrigation or other purposes can cause an increase in base flows if the prevailing groundwater elevation is raised. Furthermore, increases in stream flows during wet periods can result from reduced soil moisture capacity in a tributary watershed if there is pervasive use of recharge on the land surface during dry periods. In such a case, antecedent conditions are wetter and runoff greater for a given rainstorm (USEPA, 2004).

In addition to water quantity issues, reuse projects can potentially impact aesthetics or recreational use and damage ecosystems associated with streams where hydrologic setting is significantly affected. Where wastewater discharges have occurred over an extended period of time, the flora and fauna can adapt and even become dependent on that water. A new or altered ecosystem can arise and a reuse program implemented without consideration of this fact could have an adverse impact on such a community. In some cases, water reuse projects have been directly affected by concerns for instream flow reduction that could result from a reuse program.

Hydrogeological impact

One of the better-known sources of potential groundwater pollution is nitrate, which may be found in, or result from, the application of reclaimed water. However, additional physical, chemical, and biological constituents found in reclaimed water may pose an environmental risk. In general, these concerns increase when there are significant industrial wastewater discharges to the water reclamation facility. Impacts of these constituents are influenced by the hydrogeology of the reuse application site. Where karst conditions exist, for example, constituents may potentially exist within the reclaimed water that will ultimately reach the aquifer. In many reclaimed water irrigation programs, a groundwater-monitoring program is required to detect the impacts of reclaimed water constituents (see e.g. REMS Shoalhaven project, Tomkinson 2002).

5.5 Types of reuse applications and strategic environmental parameters

A multi-functional approach of reclaimed water management tries to strike a balance between all desired uses in an area. It allows the introduction of a hierarchy in uses and provides flexibility for the different levels of development of water resources management policies and for prioritisation in time. Since the receiving environment represents the final step in any wastewater treatment and discharge process, the way in which an effluent is incorporated into the receiving environment is of critical importance in determining the extent and degree of adverse effects to that environment (NZWERF, 2002; EPA Queensland, 2004; USEPA, 2004). Receiving environment classification and reuse requirements should be addressed to main checkpoints and realistically selected interactions/processes to be monitored (Table 5.6).

Additionally, reuse application types and receiving environment characterisation should be divided into two primary categories: (i) type of environment (e.g., lake, estuary etc.) and (ii) characteristics within each environment that affect the extent to which wastewater components will be assimilated (assimilative/buffering capacity).

In these guidelines the main recommended **physical, chemical and biological factors** are analysed without full incorporation of social and cultural aspects (Tables 5.1, 5.5, 5.6). The characteristics of each of these receiving environment types (e.g, substrate, ecology, etc.) are used to derive which constituents of the wastewater (e.g., pH, nutrients, etc.) are most important for consideration in the risk assessment and the design of the monitoring programmes and remediation actions.

Table 5.6 Water-reuse applications and ecologically relevant constraints of HACCP and EIA procedures (referenced and ULODZ's major environmental constraints)

Water Reuse Categories	Potential Constraints of Environmental Risk	Recommended Critical Control Points (Water quality parameters)	Recommended Monitoring Frequency	Risk Management
Urban *Non-potable* Fire protection Air conditioning Toilet flushing	▪ Acute & chronic exposure health risk ▪ Public health concerns on pathogens transmitted by aerosols ▪ Effects of water quality on scaling, corrosion, bio-fouling; ▪ Nutrient &chlorine contamination of receiving water and land; ▪ Air pollution problems from	pH = 6-9,5 <10 mg L^{-1} BOD TSS ≤10 mg L^{-1}; 1 mg of residual Cl_2 (minimum) Turbidity < 2 NTU EC > 1.5 dS m^{-1}; SAR > 6mmol L^{-1}; no detectable fecal: < 10 coli/100ml *Gardia*<5.5 x10^{-6}cysts L^{-1}; Intestinal nematode <0.1 eggs L^{-1}, Enteroviruses <1.8x10^{-7} PFU L^{-1}, *Salmonella* < 0.2 CFU L^{-1}	pH, TSS - weekly BOD - weekly Coliforms - daily Cl_2 residual - continuous Turbidity - continuous (24 hr median); Coliforms *or E. coli* daily; *Giardia* , nematodes - at least 6 times per year;	Corrective action if NTU>2, Ec>4 dSm^{-1}, SAR>13 mmol L^{-1}; Supply shutdown if NTU>5 or chlorine residual falls below 1 mgL^{-1} A higher level of disinfection, e.g., to achieve < 14 Faecal Coli/100 ml, should be provided when frequent work contact with reclaimed water is possible.

Water Reuse Categories	Potential Constraints of Environmental Risk	Recommended Critical Control Points (Water quality parameters)	Recommended Monitoring Frequency	Risk Management
Urban (cont.) *Non-potable* Fire protection Air conditioning Toilet flushing	aerosols generated by the spray application ▪ Over-spray and run-off to receiving environments ▪ Detrimal effects/ damage of some phosphate-sensitive plants (e.g. Proteacea family).			
Industrial Cooling water Boiled feed Process water Heavy construction	▪ Relatively high risk of human exposure to potential aerosol transmission and pathogens in cooling water ▪ Constituents in reclaimed wastewater cause scaling, corrosion, biological growth, and fouling	pH=6-9 <30 mg L^{-1} BOD TSS <150 mg L^{-1} 1 mg/Cl_2 residual Turbidity <2 NTU <1000 fecal coli/100 ml Nutrients, mist, heavy metals, odour, toxic compounds, floatable /scums : a site-specific monitoring	pH - weekly BOD - weekly Turbidity continuous Coliform *or E. coli* weekly Cl_2 – residual continuous treatment	Windblown spray should not reach areas accessible to workers or the public. Disinfection Corrective action if NTU>2; Supply shutdown if NTU>5 or chlorine residual falls below 1 mg L^{-1}
Agricultural Irrigation Crop irrigation Park/school yards Golf courses Greenbelts Residential areas Freeways Cemeteries Commercial nurseries	▪ Acute and chronic exposure health risk; ▪ Public health concerns related to: pathogens – bacteria, viruses, and parasites; heavy metals and pollutants such as chlorinated - hydrocarbons – accumulated in sufficiency concentration in crops to pose a serious hazard to the health of both livestock and humans; ▪ Detrimal effects and risk of damage some sensitive crops (heavy metals, persistent organics and ions such as boron, chloride and sodium can harm crops and soils); ▪ Decrease the agricultural productivity; ▪ Nutrient enrichment of receiving water and land; ▪ Chlorine contamination of sensitive environments from use in non-permitted locations or	pH=6-9 <30 mg L^{-1} BOD TSS <30 mg L^{-1} <1 mg/Cl_2 residual Turbidity < 2NTU ; COD: 20-200 mg L^{-1}; Dissolved oxygen >0,5mgL^{-1}; EC > 1.5 dS m^{-1}; SAR > 6mmol L^{-1}; Nitrogen <15 mg L^{-1}; Phosphorus< 0.1-2mgL^{-1}; Sodium: < 200 mg L^{-1}; Chlorides:250-300mgL^{-1}; Potassium: 14 mg L^{-1}; Boron < 0,4 mg L^{-1}; Cadium < 0.1 mg L^{-1}; Lead < 1mg L^{-1}; UV 254 absorbance: 30-70 cm-1*$(10)^3$; Sulphate 500 mg L^{-1} Soil porosity 30-60%; Soil conductivity >5 mm/hour; FC or E. coli/100mL < 10^3-10^5 FFU/100ml); *Gardia* < 5.5 x10^{-6} cysts L^{-1}; Intestinal nematode <0.1 eggs L^{-1}, Enteroviruses <1.8x10^{-7} PFU L^{-1}, *Salmonella* <0.2 CFU L^{-1} Structural and species-diversity components of habitat for plants, aquatic organisms, and wildlife: e.g. taxa	pH - weekly BOD - weekly Turbidity - continuous Coliform *or E. coli* - daily Cl_2 residual - continuous Nutrients -3 month. monitoring; Odour /tainting - weekly; Patogens: *Giardia*, nematodes - at least 6 times per year; Helminth control for cattle is required Toxic compounds and TOC control are site specific Soil porosity and conductivity at last 4 times per year; Soil Quality: Saline : pH<8.5, EC>4; Saline-sodic: pH<8.5, EC>4; Sodic pH>8.5, EC<4; Nutrients, mist, odour, floatable /scums, toxic compounds, heavy metals: a site-specifc monitoring Discharge (runoff, storm/flood peak reduction) – daily/monthly	If spray irrigation, TSS less than 30 mg L^{-1} may be necessary to avoid clogging of sprinklers heads Corrective action if NTU>2; SAR>13 mmolL^{-1};Ec >4dSm^{-1}. The supply shutdown if NTU>5 or chlorine residual falls below 1mgL^{-1} High nutrient levels may adversely affect some crops during early growth stages; For chlorine sensitive crops, an alternative disinfection method should be used. Spray buffer zone (from edge of recharge operation to the nearest potable water supply well) for Class III of reclaimed water - 30 meters

Water Reuse Categories	Potential Constraints of Environmental Risk	Recommended Critical Control Points (Water quality parameters)	Recommended Monitoring Frequency	Risk Management
Agricultural Irrigation (cont.) Crop irrigation Park / school yards Golf courses Greenbelts Residential areas Freeways Cemeteries Commercial nurseries	discharge to waterways; ▪ Excess sodicity from overuse ▪ Deterioration of soil structure; loss of soil permeability ▪ Loss (erosion) of saline or nutrient-rich (particularly phosphorous) soils ▪ Water logging effects of over-irrigation (high water tables); ▪ Bio-fouling and bacterial regrowth of sprinklers and nozzles in irrigation systems ▪ Reduction of biodiversity – loss of rare or sensitive species; quantitative changes of long-lived species (e.g. in age structure: birds, small mammals); dominance of opportunistic and/or invasive species.	richness of native (terrestrial, and aquatic) and invasive species – a site specific monitoring		
Environmental and recreational Lakes and ponds Marsh, wetlands enhancement Streamflow augmentation Fisheries	▪ Acute and/or chronic exposure health risk; ▪ Health concerns from bacteria and viruses ▪ Nutrient contamination of receiving water and land; Eutrophication due to nitrogen and phosphorus in receiving waters ▪ Chlorine contamination of sensitive environments from use in non-permitted locations or discharge to waterways; ▪ Toxicity of aquatic	pH = 6.0-9.5 < 10 mg/l BOD < 2 NTU 8 1 mg/l Cl_2 residual (minimum) TSS ≥ 30 mg L^{-1}; Turbidity < 2NTU [b]; BOD ≥ 30 mg L^{-1}; COD: 100 mg L^{-1}; Dissolved oxygen >0,5mgL^{-1}; EC > 1.5 dS m^{-1}; SAR > 6mmol L^{-1}; Active chlorine 0.2-1 mg L^{-1}; Phosphorus <0.1-2mgL^{-1}; Nitrogen <10 mg L^{-1}; UV 254 absorbance: 30-70 cm-1*(10)[3]; Sodium: < 200 mg L^{-1}; Chlorides:250-300mgL^{-1}; Potassium: 14 mg L^{-1};	pH - weekly BOD - weekly Turbidity -continuous Coliforms - daily Cl_2 residual - continuous FC or *E. coli* weekly; *Giardia* , *nematodes* - at least 6 times per year; Discharge (runoff issues) - daily/monthly Hydrochemical survey (national criteria) [5] - 3 months; hazard substances -monthly; Ecomorphological survey – 6 years Sediment quality (national criteria) – 3 years Biological Quality Elements (BQE) monitoring:	Dechlorination may be necessary to protect aquatic species of flora and fauna. Reclaimed water should be non-irritating to skin and eyes. Reclaimed water should be clear and odorless. Nutrient removal may be necessary to avoid algae growth in impoundments. . Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality. The reclaimed water should not contain

[4] A polluted site with many low scoring species may have a BMWP score higher than that of a clean site with only a few species – but all of which are oxygen sensitive. To overcome this problem, the ASPT (average score per taxon) is calculated.

[5] The surface water monitoring criteria and frequency are recommended according to the EU-WFD criteria, however all analytical methods, as well as frequency would be adapted to the national legislation and water quality standards.

Water Reuse Categories	Potential Constraints of Environmental Risk	Recommended Critical Control Points (Water quality parameters)	Recommended Monitoring Frequency	Risk Management
Environmental and recreational (cont.) Lakes and ponds Marsh, wetlands enhancement Streamflow augmentation Fisheries	life - reduction of biodiversity; loss of rare or sensitive species; dominance of opportunistic and/or invasive species; quantitative changes of long-lived species (e.g. in age structure: birds); contamination of organisms (deformities, tissue contamination); ▪ Reduction of water purification from natural processing; ▪ Scouring of soil and stream banks; accelerated sedimentation and erosion	Cadium < 0.1 mg L^{-1}; Lead < 1mg L^{-1}; Chlorophil a <8 mg L^{-1} FC or E. coli/100mL (≤ 200 CFU/10ml); *Gardia* < 5.5 $x10^{-6}$ cysts L^{-1}; Intestinal nematode <0.1 eggs L^{-1}; Enteroviruses <$1.8x10^{-7}$ PFU L^{-1}; *Salmonella* < 0.2CFU L^{-1} Freshwater Macrophytes/Algae: Heavy metals control - are phytotoxic: Hg ≤ 0.001 mg L^{-1};Cd≤ 0.001 mgL^{-1}; Ni≤ 0.001mgL^{-1}; Boron ≤ 1 mg L^{-1} Salinity - lethal doses for aquatic biota: Aquatic plants 1000-2000 mgL^{-1}, Invertebrates1,000mg L^{-1} Fish > 10,000 mgL^{-1} Freshwater Macroinvertebrates - the standard national biological assessment, e.g. The BMWP-ASPT score (UK): Reference conditions > 150; I > 101 Excellent; II 61-100 Good; III 36-60 Fair; IV 16-35 Poor; V <15 Bad. The BMWP score[4] is divided by the number of taxa used to calculate it - the ASPT score value is then obtain. For ASPT < 25 Bad; 26-50 Poor; 51-100 Moderate; 101-150 Good; >150 Excellent. Fish - standard national biological assessment, e.g.The Index of Biotic Quality (IBI USA): I 58-60 Excellent; II 48-60 Good; III 40-44 Fair; IV 28-34 Poor; V 12 - 11 Bad.	• Phytobenthos (composition, abundance, biomass) - 6 months; • Macrobenthos (composition, abundance, biomass) - 3 years • Fish (composition, abundance, biomass) - 3 year Discharge (runoff issues) -daily/monthly Structural and species-diversity components of habitat for plants, aquatic organisms, and wildlife: biological survey: taxa richness, density, and biomass of biota (BQE) - macrophytes, macroinvertebrates, fish;	measurable levels of viable pathogens. A higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. Fish caught in impoundments can be consumed.

Water Reuse Categories	Potential Constraints of Environmental Risk	Recommended Critical Control Points (Water quality parameters)	Recommended Monitoring Frequency	Risk Management
Groundwater recharge Groundwater replenishment Salt water intrusion control Subsidence control	▪ Groundwater table modification due to overapplication ▪ Toxicological effects of organic chemicals in reclaimed wastewater ▪ Total dissolved solids, nitrates, and pathogens in reclaimed wastewater ▪ Risk of soil salinity ▪ Deterioration of soil structure ▪ Loss of soil permeability ▪ Loss (erosion) of saline or nutrient-rich (particularly phosphorous) soils ▪ Water logging effects of over-irrigation, poor drainage, high water tables, etc. ▪ Impact on soil biota and risk of disease transmission to native flora and fauna ▪ Risk of hyphorheic and groundwater contamination	pH :7-9; TSS ≤ 30 mg L^{-1}; Turbidity: >5 NTU[b]; COD: 70-100 mg L^{-1}; EC: 1400 [μS/cm]; Nitrate: 25 mg L^{-1}; Chloride: 100 mg L^{-1}; Sulphate 100 mg L^{-1} ; UV 254 absorbance: 30-70 cm-1*(10)[3]; FC or *E.coli* ≤ 1,000 CFU/100mL - <u>Percolation to aquifer through the soil</u>: horizontal separation[6] < 150 m; Minimum retention time underground: 6 months; Minimum depth to groundwater aquifer at initial percolation rate of:< 0.5cm min^{-1} = 3m; <0.8cm min^{-1} = 6m; - <u>Surface water/direct injection to aquifer</u> : Horizontal separation[d] – 600 m; Minimum retention time underground: 12 months; Maximum allowable reclaimed water in extracted well water < 50%	Site specific depending on the receiving water quality Alternative control of the nitrogen and phosphorous surplus in the aquifer Groundwater quality: I <2 dSm^{-1} pure fresh; II 2-4 dSm^{-1} submarginally saline; III 4-6 dSm^{-1} marginally saline; IV >6 dSm^{-1} saline; TOC – for a measure of total organic content: extracted groundwater should contain no more than 1 mgL^{-1} of wastewater origin; Discharge, water table depth, salinity, retention time, spreading area operation – a site specific monitoring	Project specific contaminant monitoring, health and safety testing, and system reliability evaluation After percolation through vadose zone meet drinking water standards Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers For spreading projects, secondary treatment (minimum) may be injection into needed to prevent clogging.

5.6 Ecosystem quality: ecological status assessment of freshwaters

As stated, surface waters are the primary receiving environment for almost all wastewater discharges therefore the overall components for its monitoring programme should be established. In general, surface water management is currently focused on the beneficial achievement of a <u>good ecological and hydrochemical status of all surface water bodies</u> in Europe (WFD, 2000). Methodologically, the term ecological status corresponds to the general philosophy of the WFD's integrated

[6] From edge of recharge operation to the nearest potable water supply well (Crook & Surampalii, 1996)

assessment of water bodies, covering both the analysis of hydrochemical, hydromorphological surveys and an evaluation of the Biological Quality Elements (BQE) (periphyton, phytoplankton, macrophytes, macroinvertebrates, fishes).

Algae as ecological indicators

Ambient biological monitoring of freshwaters based on phytoplankton and periphyton and other freshwater biota (structural and functional metrics) is rigidly included in the WFD for determining ecologically-based integrated water quality assessment. As primary producer, algae and aquatic macrophytes are considered as early-warning groups that distinctly react on hydrochemical disturbances (e.g. eutrophication symptoms).

Aquatic and terrestrial plants as ecological indicators

Dependent on the scope of the environmental analysis, many options for indicative as well as for casual identification of environmental disturbance and plants changes were defined[7]. The most common metrics, e.g. Ellenberg's indicator values (for each species the range is 1-10), give information on the qualitative relationships between the occurrence of plants and its natural environment by highlighting major environmental determinants of plant habitat preferences and/or tolerance.

Macroinvertebrates as ecological indicators

The utility of macroinvertebrates assemblage structure for describing the integrity of aquatic ecosystems and diagnosis of the anthropogenic stress has been widely recognized (Resh, 1993; Verdonschot, 2000; Bis, 2002). The role of macroinvertebrate assemblages in the aquatic food web as primary consumers of producers (periphyton) and decomposers (heterotrophic bacteria and fungi) and as prey for secondary and tertiary consumers (fish) make this group of organisms important for the holistic assessment of streams: the community's total integrity of the system, and multiple-stress indication (all stressor types and its intensity: chemical contaminations/organic pollution/acidifidication, morphological and biotic degradation).

Single metrics methods. Nowadays, there are three principal approaches for biological assessments based on macroinvertebrates that utilise taxonomic and pollution tolerance data:

1. Saprobic indices, which focus on species presence in relation to organic pollution. The tolerance of an organism is described by the parameters of the indicator (on a scale of 1 to 5), weighting (within tolerance ranges) and species abundance.

[7] EU analytical methodology for macrophytes sampling:
EN 14184:2003 Water quality - Guidance standard for the surveying of aquatic macrophytes in running waters.

2. Diversity indices, which focus on the decrease in species diversity observed under increasing disturbance or stress. The number of observed species (richness) is related to the number of individuals (abundance). Some diversity indices provide additional insight into the biotic community by calculating the uniformity of the distribution (evenness) of the number of individuals of the counted species, and
3. Biotic indices and scores, which focus on both the saprobic and diversity index approaches to evaluate taxa richness and pollution tolerance (mostly organic) using a scoring system. Examples of these systems include the Average Score Per Taxon BMWP-ASPT and BMWP Scores (Armitage, 1983; Table 5.5).

Multivariate statisitcs effectively supporting bioassessment, as more advanced procedures are able to detect subtle differences across taxa in space and time. These statistical techniques allow detection of patterns of variability within groups of taxa and/or between groups of taxa and environmental variables.

Multimetric and rapid assessment techniques. The use of rapid assessment techniques and multimetric techniques to evaluate instream biological impairment has become an essential assessment approach to river management. These techniques use a number of single metrics to assess environmental degradation. Multimetric methods remain based upon the ecological attributes of biological communities. The RBPs have been designed to be efficient, effective, easy to use, and low in cost and to be applied in wide regions (Resh, 1995; Barbour, 1996; Bis, 2000 and 2004). The following metrics groups are commonly used in multimetric and rapid assessment techniques:

1. Richness/composition measures (e.g. total number of taxa, number of EPT[8] taxa, number of *Chironomidae* taxa, number of individuals, percent of dominant taxa, percent of sediment tolerant taxa, etc.) used to detect organic pollution
2. Tolerance/intolerance measures (e.g. the presence of pollution is indicated by the ratio of intolerant to tolerant taxa), which rely on an assignment of (in)tolerance values to taxa
3. Diversity measures (e.g. Shannon-Wiener Index or sequential comparison index)
4. Biotic indices (e.g. Hilsenhoff family biotic index, BMWP score and ASPT score) which use both the assignment of (in)tolerance values to taxa and richness and/or diversity measures
5. Similarity/loss measures (e.g. community loss index, Bray-Curtis Index, etc.), which are based upon comparisons between sites (reference vs. disturbed conditions); these are often calculated but rarely used in multimetric analyses, and

[8] EPT: Ephemeroptera, Plecoptera, Trichoptera

6. Functional measures (e.g. percentages of functional feeding groups and life cycle measures) which reflect the alteration of feeding styles and life spans in response to different types of disturbances.

Fishes as ecological indicators

Fish are good bioindicators of ecological integrity assessment in the catchment-scale, because during their life cycle, the various ecological guilds integrate a wide range of riverine conditions, including the properties of bed sediment relevant for egg development and the longitudinal integrity for spawing migrations. As a result, they are good indicators of structural properties of river systems (habitat structure and connectivity). Therefore its application in the assessment of wastewater reuse impact could be profitable mainly for ecotoxicological studies and standard operative monitoring.

The use of invertebrates and fishes has been highly recommended also for actively monitoring the water quality of industrial effluents and drinking water systems in continuously running and automatically working as an early warning system, with the focus on short-term changes of toxicity.

Ecosystems quality methods

In practice there are two main groups of biological methods useful in measuring the quality of different types of ecosystems:

1. Ambient Biological Monitoring based on the autecological knowledge about the "presence-absence" of different indicator species, their tolerance to pollutants and the evidence of impairments, that can be easily identified, and
2. Bioassay Methods mainly focused on bioaccumulation process evaluations in tissues/organs of selected animals/plants. These techniques have become increasingly important due to advances in ecotoxicology (Munawar, 1995). They assess chemical, cellular, or genetic changes within an organism. Biomarkers[9] are a primary tool in this kind of assessment, providing a promising way to identify hazards to the health of human and the environment, particularly in wastewater management and monitoring.

Biomonitors and biomarkers are in the early stage of development in most European countries and USA. From the operational point of view, bioindicators must be relatively inexpensive (cost-effective biomonitoring) and easy to use in extensive surveys. Sophisticated indicators (bioassay - biomarkers, biosensors) requiring highly qualified expertise could be supportive in routine survey.

[9] A biomarker is defined as measurements of body fluids, cells, or tissues that indicate in biochemical or cellular terms the presence of contaminations or the magnitude of the host response.

5.7 Supporting references

The aim of this subsidiary section is to serve as a preliminary guide to information that may prove helpful in dealing with integrated Environmental Impact Assessment (EIA) applied in water re-use projects.

The evidence of EIA and HACCP systems related to the reclaimed and reuse water is well-documented. For instance, the Thukela Water Project Feasibility Study performed in KwaZulu-Natal, South Africa, intended to augment water supplies to the industrial heartland of the country (www.dwaf.gov.za/thukela). In this project, all the issues integrated in the environmental impact assessment (EIA) study are described: the environment of the old receiving medium, the potential changes with the reuse project, the environment of the new receiving medium of the reclaimed water, plant diversity, faunal diversity, natural resource utilisation, tourism, visual impact, cultural history, archaeological, human health, hydrology, geomorphology, downstream impacts, migration, freshwater requirements, reserve considerations, etc.

Other useful pieces of literature are available at the following web sources:

- Sydney Water recycled water pipeline and overflow abatement works carried out in the Georges River (www.sydneywater.com.au/html/major_projects/Georges/eis.cfm)
- The methods to assess the ecological effects of chemicals on ecosystems can be looked up at (www.icsu-scope.org/downloadpubs/scope53/chapter01.html)
- Australian National Guidelines on Water Recycling, Managing Health and Environmental Risks and Impact Assessment are available at www.ephc.gov.au/pdf/EPHC/Water/DraftGuidelines_Oct05.pdf
- Florida Department of Environmental Protection provides information on projects related to wastewater and reclaimed water use (www.dep.state.fl.us/water/reuse/index.htm)
- The American Argonne Laboratory, Environmental Science Division, provides navy guidance for conducting ecological risk assessments processes (www.ead.anl.gov/ecorisk/process)
- The U.S. EPA offers a complete study of risk assessment downloadable at www.epa.gov/oswer/riskassessment/risk-management.htm
- Information on health and environmental risk assessment provided by Cambridge Environmental at www.cambridgeenvironmental.com/services/health.htm
- Four-level ecological risk assessment process developed by Oregon Department of Environmental Quality (www.deq.state.or.us/wmc/cleanup/ecocover.htm)

- Oak Ridge National Laboratory – ORNL Environmental Sciences Division case studies of completed Ecological Risk Assessments www.esd.ornl.gov/programs/ecorisk/assess_examples.html

6. IMPACT ON POPULATION, INDUSTRY, AGRICULTURE AND ENVIRONMENT

In this section the impacts (main benefits and constrains) of the different proposed alternatives of water reuse on population, industry, agriculture and environment from different range scopes (social, environmental and economical ones) will be pointed out.

Moreover, at this preliminary stage of the water reuse project a community consultation process is recommended in order to know the public willingness and acceptance to the different reclaimed water options. Consequently, the main outcomes of this consultation process should be carefully analysed.

Accordingly, the next sections deal with both subjects. In section 6.1 different benefits and potential disadvantages of direct water reuse are summarised. Moreover, (27) key (social, environmental and economical) indicators are proposed and main assessment methodologies described. In section 6.2 the different stages to perform and the actors involved in a community consultation process are indicated. Furthermore, the main tools to be used in each step and useful supporting information and references are provided.

6.1 Socio-environmental and economical impacts

Using reclaimed water in place of fresh water for existing uses can free up existing water supply system capacity to cater for new water needs. This results in savings in the cost of developing new water sources, water transfers and treatment and distribution systems. It can also result in significant improvements in downstream river water quality.

The different **socio-environmental and economical benefits** that could result from water conservation and reuse might comprise (Anderson, 2003):

a) agriculture benefits

(i) reduced diversion costs

(ii) value of a secure "drought proof" supply of reclaimed water

(iii) increased farm production

(iv) value of reclaimed water nutrients = savings in fertiliser applications and pesticides

b) urban water supply benefits

(i) savings in the capital cost of diversion structures, drought storage, transfer systems and water treatment

(ii) savings in distribution, operation and maintenance costs including pumping energy, and treatment chemicals

c) urban wastewater benefits

(i) savings in discharge pump stations and pipelines

(ii) savings in treatment and nutrient removal costs required for discharge to sensitive waters

(iii) savings in operation and maintenance costs (heat recovery, chemicals)

d) environmental water quality benefits

(i) reduction in freshwater diversions

- more river flow for downstream users
- better downstream water quality

(ii) reduction in pollutant discharges

(iii) better downstream water quality

- reduced environmental impact and improved river aesthetics
- reduced impacts on fisheries and aquatic life
- improved public health for downstream users
- lower water treatment costs for downstream users
- improved recreational values of waterways

(iv) reduction of the potential salinity intrusion risk in groundwater aquifers

(v) improvement of the ecosystem and increase of the fauna and flora species due to the creation of new recreational zones, parks, gardens and green areas

(vi) improvement of the quality of the seawater and beaches

e) Increase in the tourist activity due to the good quality of the seawater and beaches and quantity of golf courses, sport fields, swimming pools, recreational zones, etc.

f) Decrease in raw materials, reagents, and water or heat consumption due to industrial water recycling linked to a decrease in the environmental penalties that these industries should pay for wastewater discharge.

g) Increase of the quality of life of the population due to

(i) the increase of recreational zones, parks, gardens, sport fields, golf courses, etc.

(ii) the improvement of the sanitary and health quality of the water (decrease of the diseases related to the water)

(iii) the improvement of the environment

(iv) the decrease or restrain in the water price due to the non needed water diversion infrastructures

(v) the increase of the employment due to the new jobs created related direct and indirectly with water reuse: new employments related to the increase of the tourist activity in the zone, the increase in agricultural activity, the maintenance of these new green areas (parks, gardens and recreational zones) and those directly connected to the operation and maintenance of the wastewater treatment plants, water engineering companies, suppliers of systems, equipment and chemicals for wastewater treatment and water reuse.

All of these social and environmental benefits and those potential disadvantages (production of wastes, noises, odours, failures in the supply…) associated to water reuse projects are considered externalities. These externalities must be carefully planned in the evaluation of the different water reuse proposed alternatives (Haruvy, 1996; Seguí, 2004).

There is a real difficulty in giving a specific weight (a real number) to these externalities. In each case the awarded value will vary depending on the particular situation. Thus, if for example there is a very acute water scarcity or the reclaimed water will be used for indirect potable uses the weight of the social aspects will be high. Conversely, when the reclaimed water will be discharged in an environmental protected zone, e.g. wetlands, the environmental relative weight will be high. However, in general the highest relative weight corresponds to the economical aspects (internalities) with an average value higher than 80%.

Within AQUAREC different **indicators** (27) have been proposed **to evaluate** these **social, environmental and economical aspects associated to water reuse**. They have been classified into social indicators - SI (7), economical indicators - EI (5) and environmental indicators – EVI (15) indicators and comprise the following items:

- Social indicators (SI)

  1. Employees in the water treatment plant
  2. Number of acceptable bathing areas accessible per inhabitant
  3. Concern about water as resource and welfare base
  4. Social willingness to the use of reclaimed water
  5. Volume of water supply per inhabitant
  6. Technology failures causing incidences in the water supply
  7. Quality and health risk in population using reclaimed water

- Economic indicators (EI)

1. Total saving in water supply treatment and distribution (referred to process costs) per inhabitant and year
2. Direct savings from reclaimed water use in main water reuse applications
3. Water supply infrastructure needs
4. Economical increase linked to water resources consumption
5. Economic welfare

- Environmental indicators (EVI)
    1. Water Quality Index (WQI)
    2. Saline intrusion decrease
    3. Increase in pesticides
    4. Nitrate exceeding legal limits
    5. Increase of microelements
    6. Presence / increase of pathogens
    7. Biological Monitoring Working Party (BMWP)
    8. Riparian Habitat Quality Index (QBR)
    9. Marine Biotic Index (MBI)
    10. Increase in heavy metals
    11. Increase in micronutrients
    12. Changes in soil infiltration capacity
    13. Changes in cation exchange capacity
    14. Decrease of macrofauna
    15. Decrease of microflora.

The specific aspects to be measured by each one, their units and some supporting references are enclosed in Annex III.

Some of these proposed indicators can be very easily quantified, like water supply. However, many others are very difficult to measure directly as they depend on many other factors. For instance, surveys, enquiries and specific studies should be specifically conducted to quantify aspects like social willingness or water quality index.

The main function of an indicator is to supply quantitative information about a specific benefit or problem and provide assistance in monitoring the improvements achieved by the different initiatives. Indicators can be classified as follows (Smeets, 1994):

Descriptive indicators: they try to describe the current situation with regard to the main wastewater reuse related issues.

Performance indicators: They contrast actual conditions with a specific set of reference conditions. They are based on the distance to the target assessment, measuring the "distance" between the current environmental situation and the desired situation or target.

Efficiency indicators: they provide an insight of the efficiency of products and processes in terms of resources used.

Next, a brief description of the different assessment methodologies for social and environmental validation is provided.

Assessment methodologies

Two types of assessment methodologies are normally addressed:

1. Semi-quantitative assessment

When evaluating the potential impact of a water reuse project, and in particular when addressing the calculation of social and environmental indicators, even there is an established measurement unit for each of them, it might not be feasible or easy to quantify all of them. Thus, a more visual and simpler method could comprise their representation in a table associating their individual impact with a colour. Each colour would correspond to a range, covering all the scale from very negative impacts to very positive ones. Thus, a fast glimpse through the table may provide a quick conclusion on the general impact of the water reuse project or proposal. Moreover, a numerical value could also be associated to each colour, reaching negative figures when causing negative impacts in specific indicators. Table 6.1 shows an example of a possible classification of the produced impacts considering both approaches.

Table 6.1 Classification of impacts of indicators addressed in water reuse projects using semi-quantitative assessment (AQUAREC)

	Range (Produced impact)	Value
(red)	Very negative	-2
(yellow)	Slightly negative	-1
(white)	No change	0
(cyan)	Slightly positive	1
(green)	Very positive	2

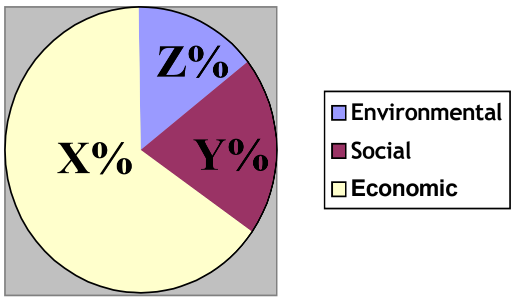
However, even the overview of the impacts of all indicators could give an idea of the general assessment of the reuse project or proposal, it would be only a preliminary guiding information. In the case of using colours, their majority gives an impression of the general impact of the project. However, the absence of weights in the indicators can give rise to risky conclusions (e.g. exclude a social indicator with very negative impact from a list with majority of blue results). In the case of using numbers, the final result is even more difficult to evaluate. One can compare the final results of two options and go for the one with the highest score, but no reference values are provided.

Therefore, the main elements required to face a semi-quantitative assessment using key indicators in water reuse projects would be:

- To count with an expert knowledge to evaluate the impact reflected in the result from each indicator, and/or
- To establish a tentative reference assessment scale for measuring the feasibility of each project (e.g. values in the range of 50 to -50). It is assumed beforehand that all indicators have identical weight, which is a simplistic approach.

In any case, the ranking within the tentative reference assessment scale is not easy to determine. It is closely related to the weights assigned to main indicators' categories (environmental, social and economical) that should be established by the project promoters and decision makers by giving specific values to the variables, as shown in Figure 6.1.

Figure 6.1 Distribution of the weights assigned to the different concepts considered in water reuse (AQUAREC)



Alternatively, instead of defining standard weighting factors per category, they could be established within each project according to inherent characteristics such as:

- Local conditions of shortage of water
- Use purposes (agricultural, drinking…)
- Social acceptance and willingness
- Fragility of the surrounding ecosystems
- Others

This way, the weighting factors will reflect several local conditions that will lead to a more adequate and well-balanced decision.

2. Quantitative assessment

Alternatively, a quantitative assessment could be addressed to evaluate the influence of different items according to the scores achieved by the related indicators. The key elements are the reference values to be considered when performing the evaluation. These reference values could be based on:

- Legal references and requirements (for example, water quality indicators)
- Average data at European, national or local level
- Expert knowledge

For example, the social indicator SI2 addressing quality of life issues makes reference to the compliance of the guiding values of the Bathing Water Directive. Thus, the optimal value of the indicator (full Directive compliance) should be 100%, and the reference scale - with the corresponding scores - could be established as follows (Table 6.2):

Table 6.2 Example of score rating for indicators addressed in water reuse projects using quantitative assessment (AQUAREC)

Score	0	1	2	3	4	5	6	7	8	9	10
SI2	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

This should be performed for all the 27 different indicators proposed (7 social, 5 economical and 15 environmental presented in Annex III) and thus no specific expertise should be needed to assess and evaluate the individual effects. The weight for each indicator is implicitly included in its individual reference scale. Accordingly, considering all proposed indicators the total score in a water reuse feasibility study would range from 0 to 270 points. Moreover, an internal ranking or a threshold reference value should be established to define the degree in which the feasibility of the study is accepted.

In summary, the assessment using the semi-quantitative method requires technical expertise in the indicator evaluation whereas the quantitative methodology, once the references scales are completed for each indicator, can be easily followed.

Integral indicators

When performing the assessment of the feasibility of water related projects the use of general indicators integrating different individual indicators is recommended.

Indicators have usually a subjective character and although different ranges and quality standards are established, there is a real difficulty to obtain a result applicable to different environments and circumstances. Thus, the same quality criteria is used to range the river quality no matter its location (cold industrialised countries or warm low industrialised countries).

Among the literature regarding integral indicators, the proposed interrelation of Driving Force-Pressure-State-Impact-Response – **DPSIR** used by the European

Environmental Agency (EEA) in its assessments stands out. This interrelation would mean that the driving force (usually economical) provokes a pressure on the resources, affecting their state and generating an impact (e.g. pollution, overexploitation…). The response to this impact is defined as the social reaction (research, infrastructures, protection programmes…). However, no social or environmental stimuli or driving forces are foreseen.

Likewise, the Pilot 2006 Environmental Performance Index (**EPI**) developed by the Columbia University and Yale University (www.yale.edu/epi) considers environmental, economical and social aspects.

In addition, the Water Sustainability Index (**WSI**) was developed by the Canary Water Centre (www.fcca.es). This index, involving 13 principal indicators (PI) subdivided into 92 secondary indicators (SI), is a guiding value to measure water sustainability and allows a quick and real overview of the current and future situation when facing water related projects. The 13 WSI main indicators (PI) comprise: economical aspects, water quality, water quantity, use of natural resources, risks, water pollution, protection and conservation, water supply infrastructures, sewage infrastructure, efficiency of water use, energy saving and consumption, research and education as well as social and institutional capacity.

Additional information about this index and some examples comparing different alternatives using the proposed semi-quantitative assessment method can be looked up the AQUAREC project web site.

A final step after assessment based on indicators entails the redaction of some suggestions for the improvement of those weak points reflected by the followed methodology. The type and orientation of these suggestions will depend on each case study.

6.2 Community consultation process and outcomes. Public acceptance

Community and stakeholder consultation is a very important issue on water reuse. Consultation components and activities to be performed should include: project summary document, free telephone information lines, newsletters, fact sheets, web site, press advertisements, community information sessions, stakeholder meetings, planning focus meeting and community focus group research.

Regarding the existing European regulation on community consultation and participation on environmental issues, in 1998 the European Community and its 15 Member States signed the UN/ECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (referred to as 'the Århus Convention'). The aim of the Convention is to allow the public to become more involved in environmental matters and to actively contribute to improved preservation and protection of the environment.

The three pillars of the Århus Convention, namely access to information, public participation in decision-making and access to justice in environmental matters, confer different rights and must be applied both to Member States and Community institutions and bodies.

With regard to legislation applicable to the Member States, two directives have been adopted covering the first two pillars (Directives 2003/4/EC and 2003/35/EC respectively) and a third directive proposal concerning access to justice in environmental matters (COM(2003) 624) has been submitted to cover the third pillar of the Convention.

In order to improve the social acceptance of water reuse, information about the different benefits (environmental, economic: tourism, water price) of water reuse and organisation of an information session about the different terms (water, wastewater, reclaimed water, water treatment, water quality, etc) would be needed, as information has been proved to have a positive influence in users' willingness. In some cases, aspects like religious issues might have a negative influence on users' acceptance. Moreover, this water reuse public acceptance is needed not only in the area where the project will be implemented but also where the products irrigated with reclaimed water are sold. For example, in Jordan products irrigated with reclaimed water are well accepted but they have problems to sell these products in other countries due to that fact.

Moreoever, some apparently not very significant issues like the denomination given to the treated wastewater can have a great influence on its social acceptance. Thus, currently in California the treated water is named as "recycled water" and in different Eastern countries (e.g. Singapore) is called "new water". These terms have been proved to have a more positive influence on public acceptance.

Among the different studies on final users' willingness and opinion about using recycled water, those carried out by Tsagarakis (2003), Abu Madi (2003), Tubail (2003) and Hartley (2003) stand out. A commonly used model for aiding satisfactory decision-making and conflict avoidance is the **stakeholder satisfaction triangle**, formed by three major components:

- Substance: is the technical, scientific and factual content of the process
- Process refers to the management steps involved in the decision making
- Relationship means how positive networks are developed between the individuals involved who have either a direct/indirect interest in, or some influence over, the overall process of management and decision making

The seven basic principles put forward by the Institute of Environmental Assessment regarding public involvement to improve environmental decision making are that participation should be inclusive, open and transparent, interactive, timely, relevant, credible and able to generate a response (Robinson, 2003).

Public participation shall begin from the first stage of water reuse planning as on one hand population stakeholders can provide early indications regarding which reuse program will be best accepted on a community-wide level, and on the other hand it can help to identify and solve potential problems before they occur and bring new ideas and alternatives more profitable for the community (US EPA, 2004). Thus, a two-way communication will produce advantageous results for all the parts and will ensure the adoption of a water reuse program that will fulfil real user needs and generally recognised community goals.

Depending on the project, public involvement can need limited contact with a number of specific users, or can be expanded to include the formation of a formal advisory committee or task force. Often, public information efforts begin by targeting the most impacted stakeholders and in a more advanced phase will broaden to include the public at large.

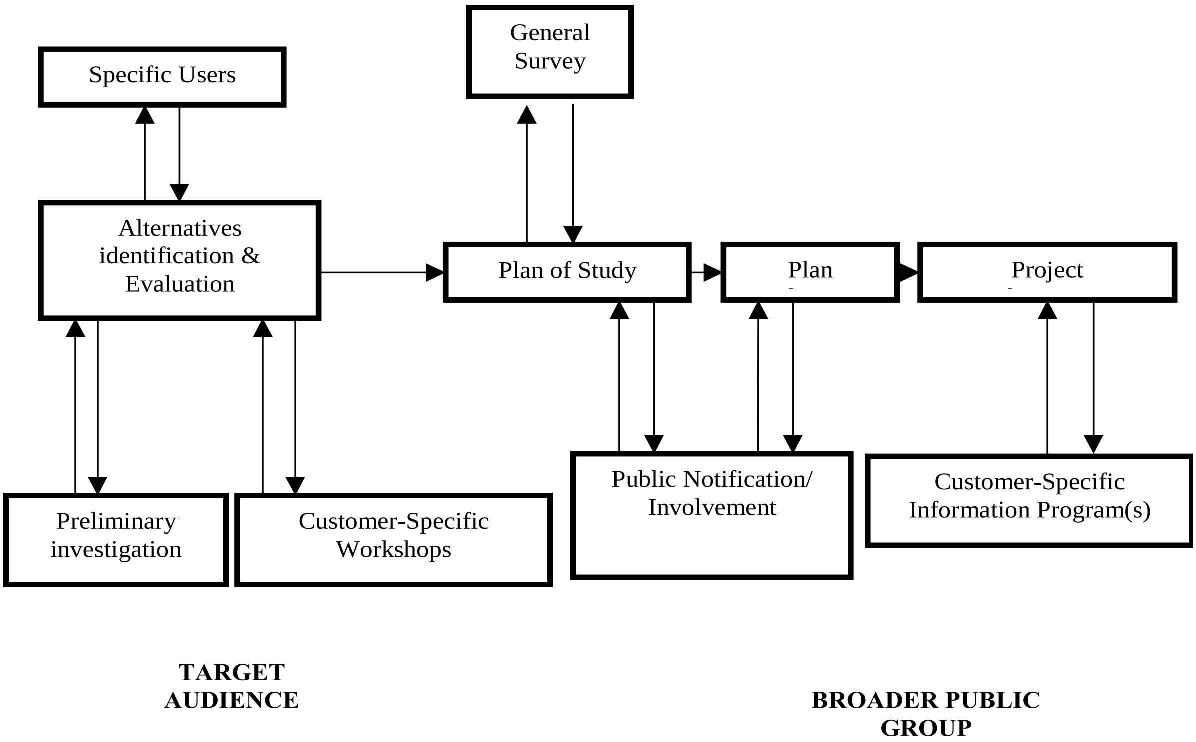
Different types of groups should be addressed for public consultation such as: residents, families, school children, teachers, religious representatives, local councillors, care professionals, hospitals & clinics, scientists, journalists, local community groups, land owners, farmers, lawyers, local businesses, trade associations, consumers associations, trade unions, planners, ecologist groups, national NGOs, local and national government representatives and developers.

The US EPA tools and purposes to be used in a public involvement program are summarised in Table 6.3, while its model scheme of the public involvement program for a water reuse system planning is represented in Figure 6.2.

Table 6.3 Tools used to evaluate social willingness towards water reuse projects (U.S. EPA, 2004)

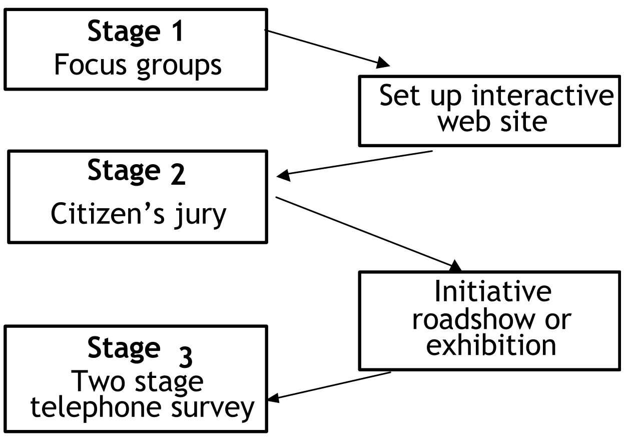
PURPOSE	TOOLS
Community-wide Education/Information	News media, editorial boards, program web site, travelling exhibits, brochures, educational videos, school programs, open houses
Direct Stakeholder or Citizen Contact	Neighbourhood meetings, speeches and presentations to citizen/stakeholder groups, direct mail letters and surveys, program "hotlines" for answering information or managing construction complaints
Formalised Process	Public workshops, public meetings, presentations to elected bodies, public hearings, advisory committees, especial task forces

Figure 6.2 Public Participation Program for Water Reuse System Planning (U.S. EPA, 2004)



Within AQUAREC a *Handbook of principles, tools and guidance for participative planning for water reuse projects* has been developed covering positive and negative features of some of these US EPA tools. Thus, in Figure 6.3 the proposed AQUAREC participation protocol is shown, comprising three central stages and combining elements of focus groups, interviews, citizen's panels (or juries) and deliberative polling.

Figure 6.3 Representative participative planning process (AQUAREC)



An example of questions used in the focus discussion groups is provided in Table 6.4. Some of the questions at the different stages concern details of the specific scheme while others are about more general issues of water reuse, water management and social and environmental values.

Table 6.4 Examples of questions used to promote group discussion on water reuse (AQUAREC)

Topic	Example Issue
Science	Do we have enough knowledge of the behaviour of those physical systems involved in water recycling?
Risk	How risky do we consider reuse to be in terms of public health?
Trust	Which bodies should be trusted to set and monitor reuse quality standards?
Responsibility	Where does responsibility lie for setting and monitoring reuse quality standards?
Cost	What length of payback period would be acceptable for a water recycling unit?
Education	Would a public education programme promote acceptance of reuse schemes? How should it be designed and at whom should it be targeted?
Technology design	Would you consider having this technology situated in your garage/basement?
Technology scale	Would you consider using your own treated bath water for toilet flushing? Would you use your next door neighbour's bath water?
Ownership	How does/should the ownership of water/wastewater change as it flows from mains supply to sewer?
Standards	Should reuse standards be based on water quality criteria or on minimum treatment requirements?

In this framework, the European Union of National Associations of Water Suppliers and Waste Water services (EUREAU) performed a water reuse survey in 2004 and sorted the 95 most important reuse issues according to the perceived key priorities compiled (www.eureau.org). Similarly, Hartley (2003) reviewed three in depth case studies to better understand public perception and options to address more constructively public participation options. He suggested five underlying principles contributing to shaping public perception:

1. Manage information for all
2. Maintain individual motivation and demonstrate organisational commitment
3. Promote communication and public dialogue
4. Ensure fair and sound decision-making and decisions
5. Build and maintain trust

Furthermore, in his opinion no checklist of "to-do's" can exist for establishing public confidence and trust, as each case study is different.

In general, some of the main issues raised during the consultation program comprise noise, access problems to different places, damage to structures and properties, level of treatment of the recycled water, health impacts related to the inadvertent consumption of the treated water, possible problems in the case of crops irrigation, price of the recycled water, system connection issues and availability of product and experience of other schemes (Nexus Australia, 1999).

In summary, to improve the social acceptance of water reuse, an information session about its benefits and main terms (water, wastewater, reclaimed water, water treatment, water quality, etc.) would be needed, as information has been proved to have a positive influence in users' willingness. In this sense in some reuse communities, a sense of community pride has been noted in the literature. For the developer, the study area could be marketed as an "environmentally aware" community.

Some other important statements to be considered in order to obtain the social acceptance of the proposal would include:

- Consider public consultation from the first steps of a Water Management or Water Reuse project, as the higher is the public involvement the higher is the social acceptance of the proposal.
- A higher level of income and education are positively correlated with a respondent's willingness to use recycled water and with a potential user's sensitivity to information on the advantages of using non-conventional water resources. Overall, extra information on the advantages of recycled water has a statistically significant impact on reported degrees of willingness to use recycled water.
- The information given to the users has to be detailed, timely, accurate and ongoing so that the knowledge of recipients will be periodically refreshed and kept updated.
- Usually users see cost savings as the main benefit; only some of them plump for the environmental and saving natural resources.
- Although the great majority of the interviewed users are usually willing to pay for treated wastewater, to increase the use of reclaimed water and the social willingness the price of reclaimed water should be lower than the price of potable water.
- Though water reuse may be environmentally beneficial, the project success mainly depends on considering costs and risks. A risk assessment will focus on the identification of sources, pathways, receptors and levels of harm.
- To finish, next 13 short pieces of advice or maxims useful in promoting public acceptance (AQUAREC) are summarised:
    - ♦ Initiate participation early
    - ♦ Careful explanation and description can help others to understand the most complicated concepts and information. Diagrams, pictures, charts or graphs can be used to good effect.
    - ♦ Try not to generalise or hypothesise. Talk about specific issues and processes

- ♦ Try and be transparent in your dealings with other actors
- ♦ If progress is slow or hampered by specific issues, seek the support of a facilitator
- ♦ Avoid using specialist language or acronyms
- ♦ Identify the sources of your information and data
- ♦ If a decision or agreement is to be made, ensure that a means of implementation has been identified
- ♦ Seek to agree on what the sources of any disagreement are
- ♦ Establish a system for sharing information
- ♦ Try not to pre-judge specific issues or questions
- ♦ Use unimposing and informal surroundings for meetings where possible and
- ♦ Demonstration projects usually increase public acceptance on water reuse projects.

6.3 Supporting references

To conclude, next some web links and reports widening the information provided in this sub-heading are listed.

- Canadian Information System for the Environment (www.cise-scie.ca/english/home.cfm)
- Queensland Water Recycling Strategy (www.epa.qld.gov.au/environmental_management/water/water_recycling_strategy)
- EEA Technical Report No. 64 (2001) on participatory methods of Integrated Environmental Assessment (IEA), downloadable from reports.eea.eu.int/Technical_report_no_64/en/Technical_Report_64
- EEA water indicator-based assessment (reports.eea.eu.int/topic_report_2003_1/en/Topic_1_2003_web.pdf)
- EEA core set of indicators guide (reports.eea.eu.int/technical_report_2005_1/en/CSI-tech1_2005_FINAL-web.pdf) and individual water indicators fact sheets (themes.eea.eu.int/Specific_media/water/indicators)
- UK Department for Environment, Food and Rural Affairs – DEFRA report on biodiversity indicators (www.defra.gov.uk/wildlife-countryside/ biodiversity/biostrat/indicators/pdf/indicators031201.pdf)
- Sustainable Measures web page (www.sustainablemeasures.com) developing indicators for the environment, amongst others.

- Ecole Nationale du Génie Rural des Eaux et des Fôrets – ENGREF's publication *Performance indicators for the regulation of the water and sewerage services: the French experience* (www.engref.fr/labogea/Melb_e20005aV2.pdf)
- Performance Indicators used in Lithuania in the water sector (www.ib-net.org/wb/bench/Lithuania2002.xls)
- Overview of the IWA system on performance indicators (PI) for water supply services (www.iwahq.org.uk/documents/pi_workshop/Highlights.pdf), as part of the IWA Manual of Best Practice Series including performance indicators for water supply and sanitation (www.iwapublishing.com/template.cfm?name=series_2)
- Information on the Columbia and Yale University Environmental Performance Index (EPI) and Environmental Sustainability Index (ESI) (www.yale.edu/esi)
- Examples of performance indicators of water and sanitation utilities in different countries provided by the World Bank (wbln0018.worldbank.org/mna/mena.nsf/0/BB37100F8EABA7B78525694A00527E47?OpenDocument)
- Performance indicators (types, data, units) of water resources used by Jerusalem Water Undertaking Company (www.jwu.org/bench/indicators.html)

7. COMPARISON OF CURRENT AND PROPOSED SYSTEMS

7.1 Selection of alternatives

In this section, the evaluation and comparison of the different proposed alternatives for water reuse will be performed. Evaluation criteria will vary depending on the scope (economic, technical or socio-environmental) and might basically address project costs, risks, reliability and related aspects. The selection of the optimum option must be carried out from a multidisciplinary point of view. Aspects already considered in section 4.2 (advantages and disadvantages) will be also helpful to reach a decision.

The cost effectiveness of water reuse projects is directly related to the volume of reclaimed water used: the more water utilised, the more cost-effective the project. In this sense irrigation generally provides the highest potential of water reuse. In opinion of Vergés (1998), Director of the Sanitation Department of the Spanish Water Company AGBAR (Aguas de Barcelona), depending on the need of the resource there is a minimum flow to consider a water reuse project as cost-effective. This level, although difficult to specify, could be in the range of a flow corresponding to 10,000-20,000 inhabitants-equivalents, or what it is the same the water needed to irrigate a golf course or a crop extension of 3,500,000 m^2.

The different water reuse options should be compared to the non-reuse existing alternative. In most cases not a single option is the most suitable one. Two different types of treatments and water reuse applications might be the most suitable option. This is the case for example of the water reuse project in the Pineda II Waste Water Treatment Plant in Valencia (Spain), where after the conventional secondary treatment a physico-chemical treatment (for phosphorous removal for marsh enhancement) and UV disinfection UV are applied. Depending on the reclaimed water final application, the physico-chemical polishing option is by-passed (e.g. for agricultural irrigation - 93,000,000 m^3y^{-1} - where nutrients are preferable) or not (e.g. for marsh enhancement - 31,000,000 m^3y^{-1}) (Generalitat Valenciana, 2003).

Besides the treatment costs, other aspects such as the decrease in the discharge environmental penalties or the increase in the crop yield due to irrigation with treated water (or decrease in the needed fertiliser amount) should be considered. In summary, the characteristics of the different options should be compared in a data sheet with a tentative simplified structure as shown in Table 7.1 to finally score and rank the different options considered.

Table 7.1 Cost- benefit analysis reference table

		OPTION 1	OPTION 2		OPTION n
Costs	Financial				
	Tangible				
	Intangible				
Benefits	Financial				
	Tangible				
	Intangible				
Other	Risk rating				
	Issues rating				
	Project duration rating				
	Other issues				
	TOTAL SCORE				

Next, some useful Internet-accessible information supporting the selection of cost-effective water reuse alternatives is offered:

- UNDP - World Bank Discussion Paper *Reuse of wastewater in agriculture: a guide for planners* downloadable from www-wds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid=000009265_3961006165519)
- New Jersey Department of Environmental Protection Technical manual for reclaimed water for beneficial reuse (www.state.nj.us/dep/dwq/techmans/reuseman.pdf)
- New Jersey Cape May County Municipal Utilities Authority – CMCMUA wastewater reuse feasibility study report (www.cmcmua.com/FORMS%20AND%20DOCUMENTS%20PAGES/Docs/Feasibility_Study1.pdf)
- San Diego City water reuse study (www.sandiego.gov/water/waterreusestudy/pdf/aa1wp.pdf)
- Redwood City (California) water recycling feasibility study report (www.ci.redwood-city.ca.us/publicworks/pdf/Final%20Report%20-%20TEXT%20ONLY%20-%20LOW%20RES.pdf)
- Aquatlan European Interreg project (www.itccanarias.org/aquatlan) addressing the situation regarding agricultural use of wastewaters in the Atlantic areas and favouring the exchange of technological experience.
- Florida Department of Environmental Protection water reuse technical documents provision (www.dep.state.fl.us/water/reuse/techdocs.htm).
- South Africa Thukela Water Project (www.dwaf.gov.za/thukela/Reports)
- Romanian SAMTID infrastructure development programme guidelines for applicants (www.mie.ro/Pdr/Engleza/mdp_mie_en/development/phare/phare2002/samtid/guidelines_for_applicants.pdf)

7.2 Results of computer network modelling analysis

There is a varied computer software offer that can be used for the analysis of the different proposed systems such as the Kentucky´s network modelling program - KYPIPE (Turner Collie & Braden Inc., 1991), Expert Systems (Economopoulou, 2003), the Economical Internal Rate of Return - EIRR (Ali El-Saie, 2001), the Desalination Economic Evaluation Programme - DEEP (Gowin, 1999) and the WTCost© for membrane treatments (Moch & Associates, Inc.). Moreover, within AQUAREC a software specially focused on water reuse projects (WTRNet) has been developed.

These modelling programmes allow the accurate determination of required pump sizes, waterline sizes, water supply requirements and ground and elevated storage tank volumes necessary for given demand conditions. Resulting distribution system pressures, water velocities, and head losses are then computed and tabulated relative to the demands. Extended period simulation (EPS) techniques allow simulation varying water demands throughout a specified analysis period, which often is a 24-hour day.

Another interesting methodology commonly used to compare and assess the different water reuse options is the Multicriterion Decision Analysis (MCDA) method (Ganoulis, 2003). As specific MCDA techniques the ELECTRE-3, ELECTRE-4, Compromise Programming (CP) and BOOT/BOT (Build, Own, Operate and Transfer) methods stand out (Avlonitis, 2002; Bazza, 2003). They are used to rank alternative strategies and find out the most sustainable one. This methodology considers not only technical and economical aspects of wastewater reuse but also environmental and social ones (Haruvy, 1996; Seguí, 2004). Alternative strategies are formulated by combining elements such as different treatments, different disposal sites, type of irrigation schemes, crop pattern, water pricing, use of fertilisers, etc.

For instance, the criteria used to evaluate the most sustainable strategy in the case of water reuse for irrigation should include (i) public health and environmental factors, that pose risks on human health, water pollution during and after irrigation, efficiency of water use, (ii) economic factors, including the water cost, the initial cost of the irrigation system, maintenance costs and crop profitability, and (iii) social issues including the employment of rural labour.

7.3 Summary of probable costs and cost-effectiveness analysis

When performing feasibility studies a summary of the costs and a cost-effectiveness analysis of the finally selected option(s) has to be performed. The main issues to be considered under this sub-heading include:

- General issues (introduction and main issues to be considered).

- Summary of probable project capital costs: investment (e.g. land purchase), construction (e.g. advanced treatment facilities, pumping facilities, distribution pipelines, storage tanks, on site-plumbing conversions), design, services during construction, etc.
- Summary of probable O&M costs: chemicals and other materials, power, labour costs, equipment replacement, waste disposal, others...
- Other costs.
- Calculated price of the reused water.
- Cost-effectiveness analysis. Current situation and future trends (e.g. increase of water consumption, increase of population, decrease of water resources…).

The estimation of the price of the obtained reclaimed water as well the price that final users are ready to pay for are two key issues to be very carefully analysed.

To support the calculation of the cost of a water reuse project the following publications might be helpful:

- *Guidelines for preparation of reuse feasibility studies for consumptive use permit applications* (Reuse Coordinating Committee of Florida, 1996), downloadable from www.dep.state.fl.us/water/reuse/docs/feasibility.pdf. It addresses three aspects of a water reuse project feasibility: environmental feasibility, technical feasibility, and economic feasibility, including a present value cost analysis. In particular, further to explain the way to estimate the present value analysis of using current source and reclaimed water, a practice example is shown.
- *Guidelines for preparation of reuse feasibility studies for applicants having responsibility for wastewater management* (Florida Department of Environmental Protection, 1991), downloadable from www.dep.state.fl.us/water/reuse/docs/ reuse_final.pdf. This is a very complete document where all the most important issues to carry out a water reuse feasibility study are tackled.
- "Planning and Analysis of Water Reuse Projects", Chapter 2 of the book *Wastewater Reclamation and Reuse* (Asano, 1998). It offers very useful information to carry out a feasibility study, explaining general concepts of economic and financial analyses. Furthermore, different examples are given and project optimisation and influence of subsidies are shown.

The **probable cost** of implementing a water reuse alternative requires the investigation of four primary cost components:

- Distribution of the reclaimed water

- Additional treatment at the wastewater treatment plant, if required, above the requirements necessary to achieve water quality standards for conventional effluent discharge
- Storage systems and pressure maintenance of the regenerated water
- Water quality monitoring and additional administration for maintaining two water systems.

They include both capital construction costs and operation and maintenance (O&M) costs, framed within the Internal Costs appendix. Table 7.2 intends to help ranging the different items to be considered in treatment costs calculation.

Table 7.2 Treatment train costing parameters (AQUAREC)

Description	Calculation
Basis for calculation	**Sum of Unit Processes Construction Costs**
Costing evaluation period	20 years
Costing discount rate	8%
Piping (inter-process)	8% of Total Unit Processes Construction Cost
Control and Instrumentation	8% of Total Unit Processes Construction Cost
Site electrical	9% of Total Unit Processes Construction Cost
Site development (landscaping, roads, drainage)	8% of Total Unit Processes Construction Cost
Site works (excavation, base preparation)	6% of Total Unit Processes Construction Cost
Sub-total	**Total Treatment Train (TT) Construction Cost**
Engineering and construction supervision	12% of Total TT Construction Cost
Contingency	15% of Total TT Construction Cost
Total	**Total Facility Capital Cost**

Comparison of these costs with a similar compilation of costs for a freshwater supply system provides a measure of cost-effectiveness of a reuse project.

Potentially, there are additional costs that may be incurred by end users of a reuse system. Examples include additional treatment and monitoring for use of reclaimed water in cooling towers or other industrial uses, retrofitted plumbing or installation of additional plumbing in new constructions if considering toilet flushing water reuse or steps needed to ensure workers' safety.

Potentially offsetting these costs is the possibility of a lower overall water system cost, either due to a reduction in the sizes and capacities of facilities or to lower debt costs, especially if grants or low-interesting financing are available to assist in project funding. An increase in the surface water conversion to fresh water might also be delayed indefinitely with effective implementation of this and other reuse projects, resulting in substantial savings to future water users.

On the other hand, as previously mentioned in this booklet there are certain intangible items (**externalities**), both benefits and detriments, which must be weighed and valued in considering a reuse project. Changes in normal personal routines, for instance, restricted access to irrigated areas, or control of volume and frequency of irrigation can be considered negative impacts.

Price of water is also a key point in the implementation of water reuse projects.

Many methodologies have been used to analyse the feasibility of water reuse projects, as shown in Table 7.3.

Table 7.3 Methodologies for assessing the feasibility of water reuse projects (adapted from Seguí, 2004 and AQUAREC's own elaboration)

APPROACH	DESCRIPTION	BIBLIOGRAPHY	MAIN IDEAS
Asano	Engineering Perspective Applicable in developed countries	Asano & Mills (1990); Asano (1991); Asano & Levine (1996); Asano (1998); Asano (2001)	Assess wastewater treatment needs Ascertain water supply and demand Study the market of reclaimed water Carry out a technical and economic analysis of the alternatives Design an implementation plan, based on a financial plan
WORLD BANK	Multi-discipline and Inter-discipline Perspective. Applicable in developing countries	Kalbermatten (1982); Khouri (1994); Marinio (1999)	Necessary coordination among specialists, health experts, sociologists and economists
Standish-Lee	Develops Asano approach, more weight to social, legal and market aspects	Standish-Lee (1997)	Places great emphasis on social and legal aspects
Seguí	Based on previous contributions	Seguí (2004)	Global perspective including technical, social, economical, financial, environmental and legal aspects
US EPA	Complete guideline on water reuse, indirect economical analysis	US EPA (2004)	Technical issues, water reuse regulations, legal and institutional issues, funding and public involvement programs
California Task Force on Water Reuse	Many recommendations for projects in water reuse	California Task Force (2003)	Economic feasibility analysis based on true benefits and costs, including non-market benefits and costs; develop appropriate benchmarks for comparing incremental costs of developing recycled water with cost of other options.
Multi-Criteria Decision Analysis: Boot, Electre…	Available practical methods for applying scientific decisions to multi-criteria problems	Rogers (1999)	Methods not formalised into a framework readily applicable to environmental projects.

Generally, the economical evaluation is based on a **Cost-Benefit Analysis** and often only Internal Costs (investment, operating and maintenance costs) are taken into consideration. A series of authors (Asano, 1990, Standish-Lee, 1997) defined economic analysis as a tool that enabled a water reuse project to be justified in monetary terms, providing total profits are greater than total costs. In this sense, it is important to take reclaimed water piping and distribution systems into account, as their cost are sufficiently high to question the economic feasibility of a project.

Next, and according to Seguí (2004), the most relevant subjects accounted for when addressing a water reuse project economic feasibility are summarised.

7.3.1 Supply and demand of reclaimed water

The supply of reclaimed water is mainly determined by the plant's productive capacity. If there are no restrictions on wastewater generation (influent), the reclaimed water supply can be considered constant and guaranteed.

Demand potentiality depends on whether or not alternative water resources exist and, should this be the case, on their price. This leads to analyse water availability in terms of the quantity and quality the user requires in each geographical area.

As a part of the tasks carried out in the AQUAREC project a study on the state of water supply and demand of reclaimed water in Europe has been performed, a estimation model developed and different key indicators (for reclaimed water demand and supply) proposed. All this information can be downloaded from the web site of the project (www.aquarec.org).

7.3.2 The cost of reclaimed water reuse

Reuse costs include both the internal costs of producing and distributing the reclaimed water, as well as external costs of an environmental or social nature (Louis, 2001; Renzetti, 2003). In general, only **internal costs** are regularly taken into consideration in water regeneration and reuse projects, consisting of:

1. Investment costs: land, civil works, machinery and equipment, facilities and connection works.

2. Financial costs, which result from financing the investment.

3. Operation and Maintenance (O&M) costs, which are divided into fixed and variable costs. The formers are incurred regardless of the volume of water reclaimed, whereas the latter are directly related to the output volume (Asano, 1998).

7.3.3 The price of reclaimed water

Some authors (Cuthbert, 1999; Ogoshi, 2001) believe that many companies' reclaimed water rates are based on a percentage of drinking water rates. While this strategy might help to encourage the usage of this type of water, there is general agreement that a water reuse project should aspire to recover its overall costs, always including distribution systems. In other words, the price of the water offered should be at least based on costs. This price should also include the value of the water itself, its environment effects and its own opportunity cost.

There is a real difficulty to give a range of prices for reclaimed water as they change very much form one country to another one. For example, in Morocco as the cost of personnel is cheap, the relative cost of civil works is low but on the other hand as the majority of the equipment is imported the relative cost of this item is high. Thus in Spain the CANARAGUA Company supplies reclaimed water (using membrane treatment) for agricultural irrigation with a total cost of 0.5 €.m^{-3} and in Mexico, to fulfil with WHO requirements (and including the sludge disposal and water distribution), the total cost is of 0.125 €.m^{-3}.

A recent experience in California indicates that approximately 3.52 million € in capital cost are required for each 1 million m^3 per year of reclaimed water made available for reuse. Assuming a facility life of 20 years and 9% interest rate, the amortised cost of this reclaimed water is about 0.44 €.m^{-3}, excluding operation and maintenance costs (Asano, 1998). This reclaimed water is normally too expensive for traditional agricultural irrigation in the United States and most other countries; only landscape irrigation and other urban applications can afford to pay for the water.

In Japan water reuse is directed toward urban reuse where higher costs can be born for reclaimed water. For instance, the reported production cost for reclaimed water in Fukuoka City is 1.76 €.m^{-3} compared to the drinking water cost of 1.67 €.m^{-3}. However, the price to consumers for reclaimed water averaged 2.64 €.m^{-3} compared to the drinking water price of 3.26 €.m^{-3} (Ogoshi, 2001).

7.4 Cost effectiveness analysis. Proposal of a methodology for studying the feasibility of a water reuse project

A thorough analysis combining capital construction costs for both the non-reuse and the different reuse alternatives annualised at different interest rates and annual O&M costs to compare the different alternatives on an equivalent annual cost basis is needed (Turner Collie & Braden Inc., 1991).

As far as a productive economy is concerned, the term **efficiency** is associated to the rational use of available resources. In other words, it is used to describe the optimal use of all the production factors in a production process, in accordance with the existing technology. There are different models to estimate the efficiency of different options, and can be divided into parametric and non-parametric ones.

Despite the widespread presence in the literature of empirical research based on efficiency analysis, contributions in the field of the environment and more specifically in the area of wastewater management remain scarce. Practically all existing papers have concentrated on either analysing changes in the productivity of a series of plants related to water in the urban environment (Marqués, 2003), or covering the impact of privatisation and regulation processes on the water industry in terms of efficiency (Saal, 2000 and 2001; Parker, 2002) and above all else, on the efficiency of water price fixing (García, 2004).

An efficiency analysis of wastewater treatment processes can supply vital information for valuing the potential for reusing wastewater, particularly in terms of costs. The efficiency in wastewater treatment processes can be considered as a basic requisite for the re-utilisation of these water resources to be satisfactory. Efficient performance, both in technical and cost terms, favours reuse possibilities and, therefore, increases the supply of the so-called non-conventional resources. Hernández and Sala (2005) have carried out an empirical research using an analytical benchmarking methodology known as **Data Envelopment Analysis** (DEA). As a result, the efficiency index has been obtained for different wastewater treatment plants (338) located in Valencia Region (Spain) concluding that the largest plants run more efficiently than smaller plants, as expected. Each plant was characterized by the presence of 1 output and 5 inputs: the output was the waste obtained from wastewater, calculated as the difference between effluent and influent in terms of Suspended Solids (SS), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD), whereas the five inputs were energy, labour, maintenance, waste management and other costs. Not only largest plants were more efficient than smaller ones, but also there was evidence that a series of representative variables in the treatment process were clearly linked to efficiency. Maintenance and waste management costs were the most important factors to explain the differences between plants in terms of efficiency. As a result, the benchmarking methodology (DEA) was confirmed as a very useful management tool for the study of the wastewater sector.

Next, a proposal of a **methodology** that could be used for studying the economical viability of water reuse projects is described.

The basic objective of all reuse projects is to maximise total benefits, which, in economic terms is the difference between income and costs. This result will show whether or not the project is feasible. When calculating total benefit, it is worth including internal benefit, benefits from externalities and opportunity cost. Another way to write the function to be maximised would be:

$$Max\ B_T = B_I + B_E - OC \qquad [1]$$

where

B_T = *Total Benefit (total income – total costs)*

B_I = *Internal Benefit (internal income – internal costs)*

B_E = *External Benefit (positive externalities – negative externalities)*

OC = *Opportunity Cost.*

7.4.1 Internal benefit

Internal benefit is obtained from the difference between internal income and internal costs. **Internal income** is obtained by multiplying the selling price of reclaimed water and the volume obtained. **Internal costs** are made up of the sum of Investment Costs (physical infrastructures), Operating Costs (labour, energy, chemical products and fungible materials), Financial Costs and Taxes.

Richard (1998) reported that cost estimation for a water reuse project should include projections of capital costs, annual operating and maintenance costs and life cycle costs. Life cycle costs enable the economic feasibility of various alternative projects to be compared over a specific period of time. This author calculates the overall cost of a project by taking into account the cost of construction, equipment and operating as well as maintenance costs. Preparing the land and electricity costs are considered to represent 10% and 15% of total costs, respectively. Annual O&M costs include personnel costs (depending on the size and complexity of the facilities), consumption of energy and chemical products and maintenance costs, which are estimated as a percentage of equipment costs. For example, maintaining pipes and storage tanks is estimated to be 2% of capital costs. It is important to underline the fact that maintenance costs represent the majority of costs in smaller plants, as an example of diseconomy of scale.

By calculating the project potential costs and income it is possible to appropriately assess its feasibility. Moreover, it must be remembered that these costs and income will vary over the useful life of the project. This methodology understands income as any benefit in well-being and cost as any loss of well-being or utility.

The cost of O&M of a water system is a composite of both fixed and variable system costs and is relative to the size of the water system. Fixed costs can be divided into O&M costs for the distribution system, including waterlines and elevated and ground storage, and O&M costs for water production including water well O&M or surface water treatment costs. Administrative costs are common to both components. Variable costs, on the other hand, are generally limited to the cost of treatment chemicals and pumping.

While capital costs are relatively straightforward to compute, O&M costs are more difficult to estimate for any particular system, due primarily to the variability in age of components and differing sources of water supply. In either a groundwater or surface water system, a utility with the new system components has relatively lower O&M costs, whereas operators of the older water system are often faced with increasing O&M costs as more components require repair or replacement. If considering two separate distribution systems, the difficulty in estimating O&M costs becomes more complex. O&M costs for the reuse system alternatives can increase by at least a factor of 1.5 to 2 with regard to the non-reuse alternative.

When analysing **operating costs**, the main items to be addressed are described next (Mancini, 2003).

- Staff. Manpower requirements depend on the plant design, the treatment complexity or the automation level. Personnel Costs associated to each plant size are calculated on the basis of necessary working hours assuming a labour cost of 20.66 € h^{-1}. A cost reduction per Equivalent Inhabitant (E.I.) is observed when the plant size is increased.

- Energy. It normally represents the most important part of the Operating Costs. It is very variable depending of the typology of the treatment plant, mainly in reference to the sludge treatment. A energy average price is 0.07 € kWh^{-1}.

- Sludge disposal. It is a function of the quantity of sludge generated and also depends of transport and disposal costs. A unitary average cost of transport and disposal could be of 0.21 € kg^{-1} of dry solids.

- Maintenance. Its costs are expressed as percentage of the initial investment. In fact, 0.5% of initial investment is considered for maintenance of the civil works, while 3% is assumed as maintenance of the electromechanical equipment. It is also assumed that 80% of the equipment needs to be substituted every 10 years.

In the literature different valuable data about the cost for different items (energy, staff…), systems (pipes, tanks…), process types or plant sizes can be found (Richard, 1998; Hidalgo, 2004; Mancini, 2003; Sipala, 2003; EWATRO web page www.dica.unict.it/users/fvaglias/EWATRO). As an example, estimated cost curves for different treatment alternatives assuming a discharge of 300 L/d per Equivalent Inhabitant are shown in Table 7.4.

Table 7.4 Cost curve as function of treatment plant size (Sipala, 2003)

TREATMENT ALTERNATIVES	X < 30,000 E.I.	X ≥ 30,000 E.I.
Primary Treatment	$Y = 0.317 - 9 \cdot 10^{-6} \cdot X$	$Y = 0.132 - 5 \cdot 10^{-7} \cdot X$
Secondary Treatment	$Y = 0.474 - 7 \cdot 10^{-6} \cdot X$	$Y = 0.309 - 4 \cdot 10^{-7} \cdot X$
Filtration	$Y = 0.507 - 7 \cdot 10^{-6} \cdot X$	$Y = 0.342 - 4 \cdot 10^{-7} \cdot X$
Nitrification/denitrification + filtration	$Y = 0.559 - 8 \cdot 10^{-6} \cdot X$	$Y = 0.369 - 5 \cdot 10^{-7} \cdot X$
Nitrif./Denitrif. + P removal + filtration	$Y = 0.602 - 8 \cdot 10^{-6} \cdot X$	$Y = 0.393 - 5 \cdot 10^{-7} \cdot X$
Coagulation-flocculation	$Y = 0.939 - 2 \cdot 10^{-5} \cdot X$	$Y = 0.471 - 5 \cdot 10^{-7} \cdot X$
Carbon adsorption	$Y = 1.132 - 1 \cdot 10^{-5} \cdot X$	$Y = 0.730 - 5 \cdot 10^{-7} \cdot X$
Reverse Osmosis	$Y = 1.503 - 2 \cdot 10^{-5} \cdot X$	$Y = 0.907 - 5 \cdot 10^{-7} \cdot X$

Y indicates the unit costs in € m^{-3}; X indicates the number of Equivalent Inhabitants (E.I.)

Given the lack of a market for reclaimed water, it is difficult to obtain a price for this product. In order to overcome this problem, the cost per cubic meter should supposedly be equal to the minimum selling price. In this way, covering costs is guaranteed. Following Seguí (2004), **Current Net Value** (CNV) **criteria** are used to obtain this price. The minimum selling price is that which makes the CNV equal zero. After having established the target quality for reclaimed water, the next step is to find the most suitable technology to achieve it. When there are several technological alternatives, the one that offers the lowest cost per cubic meter will be chosen (Hartwick, 1998; OECD, 2002). The following scheme shows the steps to be taken:

$$CNV = -I_0 + \sum_{n=1}^{n} \frac{NB_n}{(1+i)^n} \qquad [2]$$

$$NB_n = (AVWR * MSPWR) - (IC_n + OMC_n + T_n + FC_n) \qquad [3]$$

where

CNV = Current Net Value

I_0 = Initial investment

NB = Net Benefit

i =Discount Rate

n = Year

IC = Investment Cost

OMC = Operating and Maintenance Costs

T = Taxes

FC = Financial Costs

AVWR = Annual Volume of Water Reclaimed

MSPWR = Minimum Selling Price of Water Reclaimed

This methodology provides the cost per cubic meter, but is not enough to determine the feasibility of a project. In order to achieve this, Total Benefit (B_T) must be calculated according to the equation [1]. Therefore, internal benefit is given by:

$$B_I = \sum_{n=0}^{n} \left[(AVWR_n * SPRW_n) - (IC_n + OMC_n + T_n + FC_n) \right] \qquad [4]$$

where

SPRW = Selling Price of Reclaimed Water

The Tax variable refers to tax payments derived from tax benefits obtained for the activity.

Providing internal benefit is always positive, the project will be economically and financially viable, always from an internal point of view.

Once water has been reclaimed, it can be used for a large number of activities such as irrigating farmlands and gardens, refilling water-bearing resources, industrial process, etc. The quality this water demands depends on its final use and its potential exposure to people. One problem associated to water reuse projects is the lack of integrated planning, which often makes its real price much higher than that estimated when it was being designed. When the wastewater treatment and reuse system has been built and is running, the quality of the water to be reused must be monitored continuously in accordance with the parameters that the law establishes for each usage.

7.4.2 External impacts

Project impacts are considered as any consequence (positive or negative, intentional or random) that can be calculated and that is derived from the project. An example of possible externalities that could be considered in a water reuse project is shown in Table 7.5.

Table 7.5 Identification and valuation of externalities (adapted from Seguí, 2004 and AQUAREC's own elaboration)

GROUPS	EXTERNALITIES	
	IDENTIFICATION	UNIT
Water Infrastructures	Avoids constructing facilities to capture and store freshwater	Euros
	Avoids water purification costs	Euros
	Avoids constructing pipes and water distribution costs	Euros
Reuse of Pollutants	Reuse of Nitrogen in agriculture	Kg of N
	Reuse of Phosphorous in agriculture	Kg of P
	Reuse of sludge in agriculture and gardening	Kg.
	Reuse of thermal energy	Watt
Uses of the Resource	Increases the quantity of water available	m^3
	Guarantees supply in times when there is a shortage	% Confidence
	Water quality adapted to different uses is obtained	Kg waste
Public Health	Biological risks associated to wastewater reuse	People exposed
	Chemical risks associated to wastewater reuse	People exposed
Environment	Increase in the level of rivers	m^3
	Avoids overexploitation of water-bearing resources	Meters Aquifer level
	Avoids water pollution	Kg Waste eliminated
	Allows wetland and river habitat to be recovered	Users
	Increase in pollution due to smell and noise	People exposed
	Decrease in the value of land nearby	Euros
Education	Raises social awareness of a new water culture	Number of people

While some of the impacts identified can be directly calculated in terms of monetary units, biophysical and social aspects demand the definition of units of measurement. In order to homogenise results, an annual reference is proposed. A monetary value can be obtained from the calculation of each impact. However, there are a series of external impacts, for which no explicit market exists. In these cases economic valuation methods are used, which are based on hypothetical scenarios or patterns observed in related markets.

Following Louis (2001) and Renzetti (2003), all projects need, apart from internal benefit, to calculate the value of positive and negative externalities derived from the water treatment and reuse project.

External benefit would be given by:

$$B_E = \sum_{n=0}^{n} (PE_n - NE_n) \quad [5]$$

where

B_E = External Benefit
PE = Positive Externalities
NE = Negative Externalities

As there is plenty of information on economical assessment of projects considering internalities but it is not usual to include the externalities calculation in this economical assessment, next a full description on the different methods and the different items that can be considered as externalities on water reuse projects is given.

The objective of **environmental valuation methods** is to ascertain how much importance people give to the functions the environment performs. For this reason, the valuation of environmental goods is an extremely useful method of economic analysis in the following cases:

- A complete cost-benefit analysis can be carried out, which will provide more information to the public-sector decision maker and will make it possible to prioritise the assessment of the various possible alternatives for one same project.
- It can be useful for groups and organisations that defend natural resources, as it makes it possible to ascertain how much people value the natural resource heritage they defend.
- Information obtained can be used by courts of justice to calculate compensation for damage inflicted upon the environment.
- Results obtained can be interesting for third world countries where natural resource heritage is an important source of income.

The main methods for valuating for environmental goods, are presented in Table 7.6.

Table 7.6 Methodologies of valuation for environmental goods

INDIRECT VALUATION METHODS	DIRECT VALUATION METHODS
Hedonic prices (HP)	Contingent valuation (CV)
Travel cost (TC)	
Restoration cost (RC)	

Indirect valuation methods are those based on the presence of a complementary relationship between environmental goods and other private goods with a market and, therefore, the value of environmental goods can be indirectly deduced. These methods' sphere of application is more limited than that of direct methods, as there must be a complementary relationship between the environment good and the private good with a market. In addition to this, only the value of use can be estimated, whereas that of existence and option cannot.

In table 7.6, some of the externalities generated by these water supply systems and the most suitable methods for their economic valuation are shown. It must be taken into account that not all the externalities mentioned always occur, but rather depend on the area where the system will be implanted, on the purpose for which water is used, and on the water quality requirements (no treatment, secondary or tertiary treatment).

Moreover, next some interesting Internet-available documents giving examples of calculation of externalities associated to water reuse projects are listed:

- Spanish Consorci de la Costa Brava paper (Sala, 2004) titled *Towards sustainability in water recycling*, downloadable from www.iwaponline.com/wst/05002/0001/ 050020001.pdf
- Australian CSIRO Land and Water report on the economics of water first use, reuse and return to the environment, downloadable from www.clw.csiro.au/publications/consultancy/2004/economics_of_water_reuse_report.pdf
- Water conservation, reuse and recycling procedures interacademy workshop (Tunisia, 2002), proceedings readable at newton.nap.edu/books/0309092930/html

Table 7.7 Externalities related to water reuse systems and methods for their valuation

SECTION	EXTERNALITIES	
	IDENTIFICATION	VALUATION METHOD*
Infrastructure	Avoids water purification costs	MP
	Building of pipes for water distribution	MP
	Infrastructure costs from regenerating and reusing water will depend on the purpose the water is used for	MP
Pollutants	Avoids drawn out treatment processes to eliminate certain useful compounds such as fertilisers	MP
	Nitrogen reuse in agriculture	MP
	Phosphorous reuse in agriculture	MP
	Reuse of already digested mud for agriculture	MP
	Reuse of thermal energy	MP
Public Health	Monitoring and controlling biological pollutants present in regenerated water	MP
	Cost of monitoring and controlling chemical pollutants present in regenerated water	MP
	Risks associated to the spread of illnesses and disease	MP and CV
Environment	Avoids energy consumption and, in turn, gas emissions	MP and CV
	If the regeneration plant is far from the area of consumption and long pipes are required, habitat fragmentation and a loss of biodiversity can arise	CV and TC
	Decrease in nitrate pollution of aquifers	MP and CV
	Decrease in the eutrophication of waste water discharge areas	MP and CV
	Noise and smells from the regeneration plant	HP, RC and CV
	Increase in water quality	MP and CV
	Increase in the ecological flow rate of rivers, contributing to the maintenance of biodiversity and preventing floods	CV, TC and MP
	Avoids over-exploitation of aquifers, decreasing land cave-ins and prevents salt from entering coastal area.	MP and RC
	Decrease in water pollution and increase in the aesthetic quality of the water, allowing it to be used for recreational purposes	MP, TC and CV
	Change in the use of land (transforming dry land to irrigated land) and its environmental impact	MP and CV
	Increase in the quality of beach water If located in a coastal area	MP and TC
	Decrease in the value of nearby land	MP
Education	Enhances social awareness of a new water culture	CV
	Personnel expenses in order to convince local inhabitants of the quality of the water used	MP

*MP: Market price; CV: Contingent valuation; TC: Travel cost; HP: Hedonic prices; RC: Restoration cost

Externalities simply measured by market price (MP) would be the easiest to include in the cost-benefit analysis, but they have been included Table 7.7 as they are frequently omitted.

For the rest of externalities, one of the methods mostly applied is contingent valuation (CV), above all for externalities related to the environment, as willingness to pay makes it possible to deduce both the use and non-use value of these marketless assets.

Travel cost (TC) is applied almost exclusively to the valuation of natural reserves with a recreational function and restoration cost (RC) to those impacts that can be, in one way or another, restored or depleted by means of goods with a market.

Next, some specific issues and their methodologies are dealt with:

- When addressing risks associated to the spreading of illnesses and disease we can value the expenses incurred by a farmer due to disease by means of MP, as pesticides and medicine are needed to combat it. Health costs stemming from illnesses suffered by people and in the extreme case of death, the price of a life, could be valued by means of CV.
- When arriving to evaluating the avoidance of energy consumption and, as a result, gas emission, energy consumption is valued directly by MP, but CV would make it possible to ascertain the willingness to pay of inhabitants in the area for a cleaner atmosphere, thereby avoiding respiratory and other types of problems.
- Habitat fragmentation and loss of biodiversity: CV can be used to determine how much local inhabitants value the natural environment. However, if the area has unique ecological characteristics or other features, it could attract tourists. In this case, the externality could also by valued by CV.
- Decrease in nitrate pollution of aquifers: if this type of pollution is reduced, water from aquifers could be used in the future and would be a good with a market. CV could be used to determine it as the most "ecological" value of this water.
- Decrease in eutrophication: MP can be used to determine the use value of this water and CV can be used to value the maintenance of the ecosystem.
- Noise and smells from the regeneration plant: houses in the vicinity of the regeneration plant would lose value. HP can be used to determine this loss and in order to avoid noise inside houses, they will have to be conditioned, the cost of which can be measured by RC. The only way to value noise and smells outside houses is CV.
- Increase in water quality: a higher price can be demanded for water, as it can be used for different purposes. This is valued by means of MP, but also CV, as some people want high quality water per se.

- Increase in the ecological flow rate of rivers, contributing to the maintenance of biodiversity and preventing floods: CV can be used to determine the value of biodiversity, but flood prevention has a market price, as we can determine the costs incurred as a result of the flood.
- Avoiding over exploitation of aquifers, decreasing land cave-ins and prevents salt from entering coastal areas: MP can be used to value water from aquifers, but in addition to this, RC determines the cost of avoiding cave-ins and salt intrusions.
- Increase in the aesthetic quality of the water, allowing it to be used for recreational purposes: MP can be used to determine the direct benefits that this use of water has on the area, but TC and CV can determine the existence value people assign to the recreational area. Willingness to pay for a degraded recreational area would be different if water is less polluted and therefore of higher quality.
- Change in the use of land (transforming dry land to irrigated land) and its environmental impact: the transformation of dry land into irrigated land can be valued by MP, as profits obtained from crops on irrigated land are different to those obtained from crops on dry land. In addition to this, more water will be available for other uses, such as industry, which can be valued by MP. However, these changes also mean alterations in the environment, such as a loss of biodiversity, alteration of natural ecosystems etc, which could be valued by means of CV.
- Increase in the quality of beach water: this externality would be related to the recreational use of water.
- Enhances social awareness of a new water culture: a portion of the population would be willing to pay a certain amount of money in order to make the rest of the population aware of environmental problems, allowing future generations to enjoy nature in a state that is at least as well conserved as it is today.

7.4.3 Opportunity cost

In Pearce (1983) the opportunity cost is defined as the value of a good in terms of a lost alternative use of that good. Thus for example, in the case of water treatment and reuse projects, the benefit associated to the use of the land that the plant occupies for other more profitable uses should be considered.

By substituting the previous equations in the general equation [1] initially proposed, the following expression emerges,

$$Max\ B_T = \sum_{n=0}^{n} \left[(AVWR_n * SPRW_n) - (IC_n + OMC_n + T_n + FC_n) + (PE_n - NE_n) - OC_n \right]$$

It is worth remembering that in this type of analysis, while having a suitable methodology is important, so is the quantity and quality of the data used. The combination of both elements is what gives validity to the feasibility study.

7.4.4 Sensitivity analysis

To end the study, it would be necessary to assess the feasibility of the project when faced by possible changes in a series of significant variables. The objective is to determine how sensitive the result of the project assessment is to changes in some of the parameters used in the analysis, such as the discount rate, financing conditions, energy costs or the price of reclaimed water itself. Once the changes in Total Benefit have been analysed for each of the scenarios proposed, the robustness or true feasibility of the project under study can be evaluated.

7.5 Financial analysis and financing options

Investment costs range from 45% to 75% of the total cost of a water reuse project (Asano, 1998). Both, obtaining financing as well as its cost in terms of interest, are crucial for the project to be carried out. Although these projects have traditionally been state-financed, publications by the International Finance Corporation - IFC (www.ifc.org/ifcext/publications.nsf/Content/BySubject) and the US Environmental Protection Agency (US EPA, 2004) show that more and more privately funded initiatives are arising. Furthermore, public sector participation can take many forms, ranging from investment subsidies to long term loans or from interest rebates to risk guarantees.

In Sancho (1999), a series of financial approaches that can be applied to water reuse projects in different countries is described. As far as public funding is concerned, three models can be distinguished:

- the first consists in the recipient returning part of the cost of the investment over its useful life, in other words, over a period of 25-50 years
- the second model, known as the "German Model", involves private financing that, once the project is executed, it is paid for by the State
- the third option, the so-called "shadow tolling", means that the private sector finances both the project's construction and running costs in exchange for a state concession over a specific period of time. This model has been used in countries such as Great Britain through plan entitled Private Finance Initiative.
- with regard to the so-called mixed financing, it is worth mentioning the role played by State-run companies, which enable decision-making to be less centralised and also allows income to be earned by means of selling their services. In this case some resources are obtained which are not included in the calculation of public deficit.

The different aspects to be considered for the financing analysis should comprise:

- Funding overview
- Potential programs for financing capital improvements (local, national and European programs)
- Funding requirements
- Return on investment

Funding and management of a water reuse system is a key element of a feasible implementation. Without a workable funding and management component, any capital development program obviously remains only a plan.

In Europe, in most cases, the construction of waste water treatment plants and implementation of water reuse projects have been funded by different Administrations, Statements and Private Agents at different scale. Thus, the different types of sources of funding can come from the European Union, National administration, Regional administration, Local government, public stakeholders (Water Agencies, Water Consortiums) and in some cases private funding (e.g. farmer's associations).

The EU does not have specific subsidies to encourage water reuse; however, there are six European programmes or organisations that are likely to finance water recycling projects: European Investment Bank (EIB), Short and Medium-term Priority Environmental Action Programme (SMAP), Financial Instrument for the Environment (LIFE), Community Initiative of the European Regional Development Fund (especially, Urban II), Structural Funds (FEDER), Cohesion Funds and the Interreg Programme. Furthermore, economic disincentives are also used to encourage water recycling and water conservation, the major being the effluent charges and water abstraction taxes. In the EU the major difficulties to project funding arise from demand risk, regulatory risk and technology risks. More information about water reuse funding can be found in the *Manual of engagement of water reuse systems in the implementation/operation phase* prepared within the AQUAREC project.

Next, Table 7.8 provides a non-exhaustive list of possible funding agencies and the specific areas covered by the subsidies.

Furthermore, the European Commission has developed a web site containing fact sheets about each type of grants and the department managing them (europa.eu.int/comm/secretariat_general/sgc/info_subv/index_en.htm). Each of those grant programmes has their own rule regarding eligibility criteria and application processes, which differ according to the department that manages the programme.

Table 7.8 Summary of types of funding and main characteristics (AQUAREC)

Type of Funding Organism	Country	Type of funding	Characteristics/ Remarks
European Union		Cohesion Funds	Up to 80% of the investment The Cohesion Funds cover only two sectors, environment and transport and only four countries: Spain, Portugal, Ireland and Greece. (-Note: from 2004 the ten new member states will also be eligible. The budget for 2000-2006 is foreseen to be 18 Mill €. For the period 2007-2013 the total funds (FEDER and Cohesion Funds) will be of approximately 330 Mill € (75% for the 10 new members countries).
European Union		Structural Funds	Structural Funds are non-reimbursable grants given to projects intended to boost the economic development of underdeveloped regions throughout all of Europe.
European Union		RETEX Funds	
European Union		LIFE (LIFE +)	The financial instrument for the Environment of the European Commission. Supporting innovative and demonstration type projects
European Union		ISPA funds	Structural Funds for accession countries, in the form of non-reimbursable grants to projects intended to boost the economic development, including water related facilities
European Union		FEDER Funds	
Local Administration	Spain		Up to 20% of the total investment when Cohesion funds are been obtained
Regional Government (Basq Government)	Spain		Up to 50% of the total investment (the other 50% is provided by the local Water Company)
Regional Water Agency (Consorcio de la Costa Brava) (Catalonia)	Spain		Up to 20% of the total investment when Cohesion funds are been obtained
Regional Government (Madrid), Town Council (Madrid) and Local Water Agency (Canal Isabell II)	Spain		The total amount funding by these Organisms in Madrid (1995-2005) is 627.8 Mill €
Spanish Government	Spain		The Ministry of Environment funds specific works of general public concern (water supply and wastewater treatment) by 25%
Spanish Government	Spain		The total investment foreseen by the Spanish Government in its Water Policy for the next years is the following: Andalucia: 579 Mill € Comunidad Valenciana: 1,219 Mill € Cataluña: 1,110 Mill €
Local Government (Queensland Region)	Australia		Total funding up to 50% Funding for projects is considered on a case by case basis and is available primarily for the project's benefit to the community and its viability

The process of grants acquisition may take a long period, thus it may delay the project implementation of several months (or even years). It is for this reason that it is recommended to screen the funding possibilities during the early planning phase, to package the project for legislative funding (e.g. pointing out similarities to past legislative funded projects) and to already provide answers to all possible questions that could be asked to the applicant. Often, once a capital funding is obtained by one agency, other agencies will follow.

Beside direct grants, governments may provide other financial incentives like tax exempt financing, taxable financing, mandatory up-front contribution of end users or long-term loans. Alternative types of funds, such as for instance water credits, are also emerging.

According to AQUAREC, the funding mechanisms can be ranged in two categories

1. Financing of up-front costs (i.e. initial capital investment)
2. Financing of ongoing operating costs (i.e. revenue programmes during the operation to cover debt service and operation and maintenance costs).

Besides, the alternatives to cover up-front costs can be basically split in four categories:

1. Water reuse subsidies
2. Debt financing
3. Non-debt financing
4. Mobilisation of private sector funds (equity rising).

The future trend in the European Union moves forward to financing only a portion of the up-front cost through grants (generally up to 50% of the approved cost).

Subsidies in Europe usually cover planning, technical assistance and research (pilot studies, etc.), construction costs and some actions aimed at regional objectives got on. They do not cover operation and maintenance costs. It is for this reason that in many cases after building a wastewater treatment plant thanks to the different funding plans, the plant does not operate appropriately (failures in the system, low yields…) as no correct maintaining programmes are followed.

Up to now, and due to the big amount of water used in agriculture, the price of water for this use is usually a symbolic price or free. That it is a very common practice in the South European countries. For example in Spain the price of water for agricultural purposes is 0.006-0.012 € m^{-3}, the price of tap water is 0.77 € m^{-3}, the cost of desalinated water is around 0.6 € m^{-3} and the cost of wastewater treatment (tertiary treatment included) is around 0.6-0.8 € m^{-3}; so reclaimed water should be subsidised in order to spread its implementation or water prices for both (household and agriculture) uses should be incremented.

Water price is a very important issue that must be profusely studied. Likewise, Water Framework Directive (WFD) establishes the "cost coverage principle" for water. It proposes cost recovery pricing for certain kinds of water uses. Some European countries actually do have even a system of full-cost-recovery in place. Cost recovery pricing is recommended for water services and includes abstraction, distribution and consumption of waters and pollution of surface water, wherever the source lies. This is closely connected to wastewater treatment cost and water reuse. Problems such as the calculation of the total costs for water-pricing, whether or not the resource (water) itself should be valued and included and the possible raise of water charges, especially for agricultural users, have led to a turn from the original full-cost recovery proposal to this compromise of cost coverage.

In this sense, water users have to be split up into household, industrial and agricultural parts. In general, water charges still have to be based on this cost-coverage principle. Possible exceptions may be granted to supply households for a reasonable price and for some specific European areas.

Another European requirement plays an important role in this context. If states keep subsidising the water price and private companies suffer because of that, then European competition policy and its laws on state aids may apply and bring to an end cross-subsidies and any unjustified different treatments (Sellner dissertation, www.dundee.ac.uk/iwlri/Documents/StudentsMaterial/FalkoJosefSellner/PDFs/Dissertation.pdf).

In the case of USA, in opinion of the Recycled Water Task Force of the State of California one of the requirements to obtain funds from the Government for a water reuse project should be counting with the social acceptance of the proposal.

On the other hand, in Australia water companies subsidise reclaimed water through the price of fresh water. This could be a common mechanism in case of being the same distributor or could be considered a regulated water pricing structure.

In some cases water reuse for agricultural applications is being carried out with no control, using wastewater with very low or without treatment. In order to increase the implementation of water reuse projects different alternatives can be followed:

1. Funding the water reuse offering a very competitive (low) price of this kind of water,
2. Forbid the use of fresh water in cases where regenerated water can be used (legislation need),
3. Increase the price of tap water.

In any case, the chosen option will be basically a political decision. In this sense, in Spain the previous political party in the government considered the best option to solve water scarcity in Spain the diversion among water basins, but the current government bets on desalination and water reuse so implementation of water reuse projects is expected to have an important increase for the next years in this country.

To finish, in the case of water reuse in the industry, there are different types of industries that need very big amounts of water than could use recycled or treated water. Textile, pulp and paper, and power industries are different industrial sectors where water reuse has been successfully applied. In this case, most of the financing is private.

8. CONCLUDING SESSION OF A FEASIBILITY STUDY REPORT

Main conclusions for each section in the feasibility study need to be summarised in a brief and clear way. In addition, essential supporting information like the one considered in the next appendices needs also to be included.

8.1 Schedule and recommendations

The proposed schedule for the implementation of the water reuse project has to be included and consequences of possible delays on the execution schedule foreseen. This schedule will be closely linked to the final approval of the funding and the financing plan.

Many times, the biggest risk of delays in achieving recycled water use is not in the design and construction of facilities, but in obtaining customer agreements and getting site delivery systems planned and ready to accept recycled water (Kennedy&Jenks Consultants, 2002).

In this section recommendations to carry out the implementation of the proposed project will be described. For example, if key provisions were acceptable, a public meeting to solicit comments from the general public would be of convenience. Once the final decision is taken, a demonstration project using the selected option should be carried out.

Main obtained recommendations will be summarised, e.g. changes in the monitoring plan, proposed changes in the schedule, necessity of any additional infrastructure (road, access…), proposed public information campaigns, etc. (Turner Collie, 1991).

Some web-available reports and links supporting the development of this section include:

- Queensland Government *Manual for Recycled Water Agreements in Queensland*, downloadable from www.epa.qld.gov.au/environmental_management/water/manual_for_recycled_water_agreements, including a model recycled water agreement.
- New Jersey Department of Environmental Protection – NJDEP technical manual Reclaimed water for beneficial reuse, downloadable from www.state.nj.us/dep/dwq/techmans/reuseman.pdf
- World Bank Group guide for planners for reuse of wastewater in agriculture, downloadable from www-wds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid=000009265_3961006165519

- Guidelines for the preparation of reuse feasibility studies downloadable from the technical documents page of the Florida Department of Environmental Protection (www.dep.state.fl.us/water/reuse/techdocs.htm)

8.2 Other aspects to be considered

This section will cover the main characteristics of the agreements and contracts that have to be signed, responsibilities among the different agents (enterprises, water companies, and administrations) involved in the project (who is the responsible of delivering reclaimed water to the end-point, assurance plan of appropriateness quality and quantity of the supplied water, who is the responsible of fixing treated water prices, etc.), consequences of breach of contracts, etc.

8.3 References

In this section, after the literature survey and review, main references of already implemented water reuse projects with similar characteristics (geographical, applications, flows, water quality and public health risks, etc.) to the evaluated project will be summarised. The most relevant aspects and conclusions to be considered in the proposed feasibility study will be pointed out.

In different reports of the AQUAREC project, an extensive survey and review of water reuse projects all over the world has been performed (www.aquarec.org). Furthermore, in many of the recommended web sites in this handbook, relevant publications, documents and reports as well as inventory of implemented water reuse projects and examples are compiled.

8.4 Annexes

In any feasibility study, there is a section where the different annexes are included. Some of the aspects included as annexes will be the following: drawings, plan of site, maps, tables (water qualities, regulations, water prices, population distribution, different alternatives comparison analysis…), graphs (precipitation, temperature…), flow-sheets, plans of the proposed system, etc.

9. CONCLUSIONS

The aim of this *Handbook on feasibility studies for water reuse systems* performed in the framework of the AQUAREC project has been to develop and provide a useful and practical document, easy to read and understand, as brief as possible and complete, to assist the different stakeholders (administration, engineering companies, water management bodies, etc.) involved in the preparation and implementation of a water reuse programme.

The final decision and success of a water reuse project depend on many different aspects such as geological, technical, economical, environmental, sociological, political and quality as well as risks issues. It is for this reason that this manual has been tackled from a multidisciplinary scope. Logically, due to the great number of aspects to be considered, only the key points and main information to be studied in each one have been addressed. Moreover, for most of these issues, main references and links to obtain more information if desired are included. In addition, some key sections such as environmental assessment, economical evaluation or social issues, have been developed more profusely.

Attached to the main handbook core chapters, three supporting annexes are included with a variety of information, basically extensive tables, useful when tackling a feasibility study on water reuse.

To finish, this handbook aims at being a useful and practical tool to assist potential involved actors in the preparation and implementation of a water reuse programme, and at least its utility has been proven within the AQUAREC project in the accomplishment of three different case studies on water reuse feasibility studies.

1. Filter backwash water reuse of a Water Treatment Plant for cooling water purposes in Romania
2. Reuse of a domestic effluent from natural treatment systems in remote areas in Hungary, and
3. Reuse opportunities in South Moravia in Czech Republic for industrial and agricultural uses.

Full information coming from these case studies is available at the project web site (www.aquarec.org). We aim at extending the handbook usefulness to the different stakeholders outside AQUAREC consortium intereseted in water reuse issues and encourage them to address such a promising alternative for a rational and integrated water management within and outside Europe.

10. REFERENCES

Abu Madi M., Braadbaart O., Al-Sa'ed R. and Alaerts G. (2003). Willingness of farmers to pay for reclaimed wastewater in Jordan and Tunisia. *Wat. Sci. Tech.: Water Supply*, 3 (4), 115-122.

Alegre, H., Hirner, W., Melo Baptista, J. and Parena, R. (2002). Highlights of the IWA system of performance indicators for water supply services. IWA workshop *Views and Experience Gained Through Implementing the IWA Performance Indicators Project* (www.iwahq.org.uk/documents/pi_workshop/Highlights.pdf**).**

Ali El-Saie M.H., Ali El-Saie Y.M.H., Deghedi Moneer A. (2001). Financial, economical and technical aspects of establishing remote desalination plants. *Desalination*, 135, 25-42.

Anderson J. (2003). The environmental benefits of water recycling and reuse. *Wat. Sci. Tech.*: *Water Supply*, 3 (4), 1-10.

AQUAREC (2004) Report on the survey on conducted of feasibility studies (D2).

AQUAREC (2004). General maps on water supply and demand (D3).

AQUAREC (2004). Review Report on Wastewater Treatment Unit Operations (D6).

AQUAREC (2004). First draft of guidelines and interactive instruments for stakeholder involvement (D9).

AQUAREC (2004). Management Review Report (D10).

AQUAREC (2004). Participative Planning for Water Reuse Projects. A handbook of principles, tools and guidance (D18).

AQUAREC (2004). WTRNet Simulation Software User Manual (M8.2).

AQUAREC (2005). Report on the water supply and demand indicators and wastewater treatment status (D12).

AQUAREC (2005) Guideline for quality standards for water reuse in Europe (M2.2).

AQUAREC (2005). Feasibility study methodology (M4.2).

AQUAREC (2006). Handbook of principles, tools and guidance for participative planning for water reuse projects.

Armitage, P.D., Moss, D., Wright, J.F. and Furse, M.T. (1983). The performance of a new biological water quality score system based on macroinvertebrate over a wide range of unpolluted running-water sites. *Wat. Res.*, 17, 333-347.

Asano, T. and Mills R. (1990). Planning and Analysis for Water Reuse Projects. *Journal American Water Works Association*. 82 (1), 38-47.

Asano, T. (1991). Planning and implementation for Water Reuse Projects. *Water Science and Technology*, 10 (9), 1-10.

Asano, T. and Levine A. (1996). Wastewater Reclamation, Recycling and Reuse: Past, Present and Future. *Water Science and Technology*, 33 (10-11), 1-14.

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

Asano, T. (2001). Water from (waste)water - The dependable water resource (The 2001 Stockholm Water Prize Laureate Lecture). *Water Science & Technology*, 45 (8), 23-33.

Avlonitis, S.A., Pulios, I., Vlachaki, N., Tsitmidelis, S., Kouroumbas, K., Avlonitis, D. and Pavlou, M. (2002). Water resources management for the prefecture of Dodekanisa of Greece. *Desalination*, 152, 41-50.

Barbour, M.T., Stribling J.B. and Karr, J.R. (1996). The multimetric approach for establishing biocriteria and measuring biological condition. In: W.S.Davis & T.P.Simon (eds), *Biological assessment and criteria: tools for water resource planning and decision making*. Lewis Publishers, Boca Raton, Florida.

Bazza, M. (2003). Wastewater recycling and reuse inthe Near East Region: experiences and issues. *Wat. Sci. Tech.*: *Water Supply*, 3 (4), 33-50.

Bis, B. (2002). Ecological integrity assessment as a strategic component of sustainable water management. In: M. Zalewski (ed.) *Guidelines for the Integrated Management of the Watershed - Phytotechnology and Ecohydrology*. UNEP- IETC, Freshwater Management Series, 5:157-167.

Bis, B., Zdanowicz, A. and Zalewski, M. (2000). Effects of catchment properties on hydrochemistry, habitat complexity and intermediate community structure in a lowland river. *Hydrobiologia*, 422/423, 369-387.

Bis, B., Usseglio-Polatera, P. and Niesiolowski, F. (2004). Functional modifications of macroinvertebrate community structure: how do species traits vary in the stream gradient? *The 29th Congress of the International Association of Theoretical and Applied Limnology* (Societas Internationalis Limnologiae - SIL), 8-14 August 2004, Lahti, Finland.

California Code of Regulations (1978). Title 22.

California Recycled Water Task Force (2003). Final Report: Water Recycling 2030 (www.owue.water.ca.gov/recycle/docs/TaskForceReport.htm).

Calow, P. (1998). Handbook of Environmental Risk Assessment and Management. Blackwell Science Ltd., pp. 590.

CATCHWATER (2002). Management guidelines for the implementation and operation of water reuse cycles.

CIRIA (1994). Environmental Assessment. Special Publication 96.

City of San Diego Water Department (2004). City of San Diego Water Reuse Study 2005, American Assembly Workshop I, Water Reuse Goals, Opportunities and Values (www.sandiego.gov/water/waterreusestudy/ pdf/aa1wp.pdf).

CMCMUA (2000). Feasibility study for reuse of wastewater effluent (www.cmcmua.com/FORMS%20AND%20DOCUMENTS%20PAGES/Docs/Feasibility_Study 1.pdf).

Commission of the European Communities COM (2003) 624. Proposal for a Directive of the European Parliament and of the Council on access to justice in environmental matters.

Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (85/337/EEC).

Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment.

Council Directive of 21 May 1991 concerning urban wastewater treatment (91/271/EEC).

CSIRO (2004). The economics of water: taking full account of first use, reuse and return to the environment (www.clw.csiro.au/publications/consultancy/2004/ economics_of_water_reuse_report.pdf).

Cuthbert, R. and Hajnosz, A. (1999). Reclaimed Water Rates. *Journal of the American Water Works Assoc.*, 91 (8), 50-57.

DEFRA (2003). A biodiversity strategy for England. Measuring progress: baseline assessment.

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy – EU Water Framework Directive (WFD).

Directive 2003/4/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC.

Directive 2003/35/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice Council Directives 85/337/EEC and 96/61/EC.

Dulay, M. (2002). Cost-effective wastewater planning: integrating GIS and HYDRA™ with custom-scripted programs (gis.esri.com/library/userconf/proc02/pap0263/ p0263.htm).

EC (2003). Guidance Document nº 8. Public participation in relation to the Water Framework Directive. *Common Implementation Strategy for the Water Framework Directive.*

Economopoulou, M.A. and Economopoulous, A.P. (2003). Expert system for municipal wastewater management with emphasis in reuse. *Wat. Sci. Tech.*: *Water Supply*, 3 (4), 79-88.

EEA (1999). Environmental indicators: typology and overview. Technical Report No 25.

EEA (2001). Participatory integrated assessment methods – An assessment of their usefulness to the European Environmental Agency. Technical Report No. 64 (reports.eea.eu.int/Technical_report_no_64/en/Technical_Report_64).

EEA (2003). Europe's water. An indicator-based assessment. Topic Report No. 1/2003.

EEA (2005). EEA core set of indicators guide. Technical report No. 1/2005 (reports.eea.eu.int/technical_report_2005_1/ en/CSI-tech1_2005_FINAL-web.pdf).

Engelman, R. and LeRoy, P. (1993). Sustaining water. Population and the future of renewable water supplies. *Population Action International*.

European Commission (1996). Technical guidance document in support of Commission Directive 93/67/EEC on risk assessment on new notified substances and Commission Regulation (EC) 1488/94 on risk assessment for existing substances.

European Commission (2003). Common Implementation Strategy for the Water Framework Directive Guidance document No. 9. Implementing the Geographical Information System Elements (GIS) of the Water Framework Directive.

FAO (1995). Environmental impact assessment of irrigation and drainage projects. (Eds)T.C. Dougherty, A.W. Hall, HR Wallingford, United Kingdom.

FAO (2003). Review of world water resources by country (ftp.fao.org/docrep/fao/005/y4473E/y4473e00.pdf).

Florida Department of Environmental Protection (1991). Guidelines for preparation of reuse feasibility studies for applicants having responsibility for wastewater management (www.dep.state.fl.us/water/reuse/docs/ reuse_final.pdf).

Ganoulis J. (2003). Evaluating alternative strategies for wastewater recycling and reuse in the Mediterranean area. *Wat. Sci. Tech.: Water Supply*, 3 (4), 11-19.

García, S. and Reynaud, A. (2004). Estimating the benefits of efficient water pricing in France. *Resource and Energy Economics*, 26 (1).

Generalitat Valenciana (2003). Ampliación de la estación depuradora de aguas residuales de Pinedo II (Valencia).

Giupponi, G., Mysiak, J. and Fassio, A. 2004. An Integrated Assessment Framework for Water Resources Management: A DSS Tool and a Pilot Study Application. Fondazione Eni Enrico Mattei, Milano.

Gowing P.J. and Konishi T. (1999). Nuclear seawater desalination – IAEA activities and economic evaluation for southern Europe. *Desalination*, 126, 301-307.

Greenberg A. (1999). Standard Methods for the Examination of Water and Wastewater. 20th Edition. American Water Works Association Publishing.

Guerin-Schneider, L. and Brunet, E. (2002). Performance indicators for the regulation of the water and sewerage services: the French experience, *Enviro 2002 IWA World Water Congress*, Melbourne (www.engref.fr/labogea/Melb_e20005aV2.pdf).

Hampton G. and Russell S. (2005). Challenges in understanding public responses and providing effective public consultation on water reuse. *International Conference in Water Recycling*, Wollongong (Australia).

Hartley, T.W. (2003). Water reuse: Understanding public perception and participation. IWA publishing.

Hartwick J. and Olewiler (1998). The economics of natural resource use. 2' edition. Addison- Wesley. USA.

Haruvy, N. (1996). Wastewater reuse-regional considerations. *36th European Congress ETH* Zurich, Switzerland 26-30 August 1996.

Hauser, B. (1996). Practical hydraulics handbook. CRC Press. USA.

Henderson, F. (2002). An integrated water management GIS for Broward County, Florida.

Hernández, F. and Sala, R. (2005). Technical Efficiency in Wastewater Plants: Evidence from a Spanish Case Study. *IWA International Conference on Water Economics, Statistics, and Finance* Rethymno, Greece.

Hidalgo, M.D. and Irusta, R. (2004). Reutilización de agua residual tratada de origen municipal en agricultura, *VII Congreso Nacional del Medio Ambiente*, Madrid (Spain).

Hochstrat, R., Wintgens, T., Melin, T. and Jeffrey, P. (2005). Wastewater reclamation and reuse in Europe: a model-based potential estimation, *Water Science & Technology: Water Supply*, 5 (1), 67-75.

IPTS (1998). Special Euro-Mediterranean Issue report.

IWMI (1998). World water demand and supply, 1990 to 2025: scenarios and issues (www.iwmi.cgiar.org/pubs/PUB019/REPORT19.PDF).

Jain, R.K., Urban, L.V., Stacey, G.S., Balbach, H.E. and Webb, M.D. (2001). Environmental Assessment, McGraw-Hill.

Jouravkova, O. (2003). On problems and perspectives of GIS applications for transboundary water management in Europe: a case study of the Daugava/Zapadnaya Dvina, Master Thesis, Kungl Teksniska Högskolan, Department of Land and Water Resources Engineering, Sweden (www.lwr.kth.se/Publikationer/PDF_Files/ LWR_EX_2003_03.PDF**)**.

Kalbermatten, J., Julius, J., Gunnerson, S. and Mara, D. (1982). Appropriate Sanitation Alternatives: A Planning and Design Manual. *World Bank Studies in Water Supply and Sanitation nº*2. The International Bank for Reconstruction and Development, World Bank, Washington, USA.

Kamizoulis, G., Bahri, A., Brissaud, F., Angelakis, A.N. (2003). Wastewater recycling and reuse practices in Mediterranean Region: Recommended guidelines (www.med-reunet.com/05ginfo/04_references.asp).

Kennedy & Jenks Consultants (2002). Water recycling feasibility study for the Redwood shores area (www.ci.redwood-city.ca.us/water/)

Khouri, N., Kalbermatten, J., and Bartone, R. (1994). The reuse of wastewater in agriculture: a guide for planners. *Water and Sanitation program report series; no*. 6. The International Bank for Reconstruction and Development. World Bank. Washington, USA.

Lazarova, V. (2001). Role of water reuse for enhancing integrated water management in Europe. CatchWater Project (ENV4-CT98-0790), final report.

Louis, G. and Siriwadana, M. (2001). A Procedure for Calculating the Full Cost of Drinking Water. CEWorld-a virtual, *American Society of Civil Engineers* (www.ceworld.org).

Lunz, R. (2002). An integrated assessment framework for combinig general systems and organizational levels. Proccedings of the International Conference *Integrated Assessment and Decision Support*, (ed.) S.M. Cuddy, CSIRO, Australia, 103-108.

Malcolm Pirnie (2000). Feasibility study for reuse of wastewater effluent. Cape May County. Final Report.

Mancini, G., Sipala, S. and Vagliasindi, F.G.A. (2003). Criteria for marginal water treatment and reuse under drought conditions, *International Workshop on Water Management under drought conditions*, Valencia (Spain).

Marinio, M. and Boland J. (1999). An Integrated Approach to Wastewater Management. The International Bank for Reconstruction and Development. World Bank. Washington, USA.

Marques, R.C. and Monteiro, A.J. (2003). Measuring productivity and efficiency of water and sewerage utilities. A total factor productivity approach, *II International Conference: Efficieny use and management of urban water supply*, Tenerife, Canary Islands, Spain.

Massena, P.A. (2001). Valorisation des eaux usees en irrigation localisée (mrea_jo.org/Documents/Eauxusees-EI1003.pdf).

Miller, J.R., Clibum, D.C., Feddema, J.J. and Slocum, T.A. (2003). Modeling and visualizing uncertainty in a global water balance model. *Proceedings of the 2003 ACM symposium on Applied computing*, 972-978.

Mills, R.A., and Asano, T. (1996). A Retrospective Assessment of Water Reclamation Projects, *Water Science & Technology*, 33 (10-11), 59-70.

Munawar, M., Hanninen, O., Roy, S., Munawar, N., Karenlampi, L. and Brown, D. (1995). Bioindicators of Environmental Health. SPB Academic Publishing, Amsterdam.

Nexus Australia (1999). Education needs background report, *Study Report One prepared for the Queensland Water Recycling Strategy* (www.epa.qld.gov.au/ publications/p01286aa.pdf/Education_needs_background_report_/_prepared_on_behalf_of_Queensland_Water_Recycling_Strategy_by_Nexus_Australia.pdf)

NFSMI (2002). Writing a feasibility study, in *A Guide to Centralized Foodservice Systems*, 55-62.

NJDEP (2005). Reclaimed water for beneficial reuse (www.state.nj.us/dep/dwq/ techmans/reuseman.pdf).

NZWERF (2002). New Zealand Municipal Wastewater Monitoring Guidelines (ed. D.E. Ray). NZ Water Environment Research Foundation. Wellington, New Zealand.

OECD (1993). OECD core set of indicators for environmental performance reviews. *Environment monographs* 83 (lead.virtualcentre.org/en/dec/toolbox/Refer/ gd93179.pdf)

OECD (2002). Handbook of Biodiversity Valuation. A guide for policy makers. OECD Publications. Paris, France (www.oecd.org).

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

Parker, D., Saal, D. and Weyman-Jones, T. (2002). Longitudinal and comparative productivity measurement in the English and Welsh water and sewerage industry, *Easter 2002 Workshop on Efficiency and Productivity Analysis*, University of Leicester Management Centre (ULMC), Leicester, UK.

Pasqual, J. (1999). La evaluación de políticas y proyectos, criterios de valoración económicos y sociales. Ed. Icaria editorial S.A., Barcelona, Spain.

Pearce, D.W. (1983). The Dictionary of Modern Economics. General Editor. The MIT Press. Cambridge, Massachusetts, USA.

Pearce, D.W. and Atkinson, G.D. (1993). Capital Theory and the Measurement of Sustainable Development: An Indicator of weak sustainability. *Ecological Economics*, 8, 103-108.

Perry, R.H. and Green, D.W. (1992). Perry's Chemical Engineers' Handbook. Mc GRAW-HILL.

Queensland Government EPA (2004). Public consultation draft: Queensland Guidelines for the Safe Use of Recycled Water.

Queensland Government EPA (2005). Manual for recycled water agreements in Queensland (www.epa.qld.gov.au/environmental_management/water/manual_for_recycled_water_agreements).

Recycled Water Task Force (2002). Department of Natural Resources, California (USA) (www.owue.water.ca.gov/recycle/taskforce/taskforce.cfm).

Redwood City California (2002). Water recycling feasibility study for the Redwood shores area (www.ci.redwood-city.ca.us/publicworks/pdf/Final%20Report%20-%20TEXT%20 ONLY%20-%20LOW%20RES.pdf).

Renzetti, S. (2003). Full Cost Accounting for Water Supply and Sewage Treatment: A Case Study of the Niagara Region, Canada. World Bank's Water Resources Management Group on Economic Instruments (worldbank.org)

Resh, V.H. and Jackson, J.K. (1993). Rapid assessment approaches to biomonitoring using benthic macroinvertebrates. In: D.M. Rosenberg and V.H. Resh (editors). *Freshwater biomonitoring and benthic macroinvertebrates*, Chapman and Hall, New York, USA, 195-233.

Resh, V.H., Norris, R.H. and Barbour, M.T. (1995). Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology,* 20, 108-121.

Reuse Coordinating Committee (1996). Guidelines for preparation of reuse feasibility studies for consumptive use permit applicants (www.dep.state.fl.us/water/reuse/docs/feasibility.pdf).

Riley, J. (2001). Multidisciplinary indicators of impact and change: Key issues for identification and summary. *Agriculture, Ecosystems and Environment*, 87 (2), 245-259.

Robinson, M. and Bond, A. (2003). Investigation of different stakeholder views of local resident involvement during environmental impact assessments in the UK. *Journal of Environmental Assessment Policy and Management*, 5 (1), 45-82.

Rogers, M., Bruen, M. and Maystre, L. (1999). Electre and Decision Support: Methods and Applications in Engineering and Infrastructure Investment, Kluwer Academic Publishers.

Saal, D. and Parker, D. (2000). Productivity and price performance in the privatised water and sewerage companies of England and Wales, RP0029. Aston Business School, Aston University, Birmingham, UK.

Saal, D. and Parker, D. (2001). The impact of privatisation and regulation on the water and sewerage industry in England and Wales: A Translog Cost Function model, RP0103. Aston Business School, Aston University, Birmingham, UK.

Sakthivadivel, R., Thiruvengadachari, S., Amerasinghe, U., Bastiaanssen, W.G.M. and Molden, D.et al. (1999). Performance evaluation of the Bhakra Irrigation System, India, using remote sensing and GIS techniques, International Water Management Institute, Research Report No. 28 (www.iwmi.cgiar.org/pubs/pub028/RR028.htm)

Sala, L. and Serra, M. (2004). Towards sustainability in water recycling, *Water Science and Technology*, Vol. 50, No. 2, pp. 1-7 (www.iwaponline.com/wst/ 05002/0001/ 050020001.pdf).

SAMTID Programme (2003). Guidelines for Applicants to Call for Proposals (www.mie.ro/Pdr/Engleza/mdp_mie_en/development/phare/phare2002/samtid/guidelines_for_applicants.pdf).

Sánchez Durón, N. (1988). Mexican experience in using sewage effluent for large scale irrigation. In: *Treatment and Use of Sewage Effluent for Irrigation*, M.B. Pescod and A. Arar (eds.). Butterworths, Sevenoaks, Kent.

Sancho, T. (1999). Nuevos Sistemas de Financiación Las Sociedades Estatales. *III Congreso Nacional de Ingeniería Civil*. Madrid, España, 1999.

SCOPE 53 (1995). Methods to Assess the Effects of Chemicals on Ecosystems, (eds.) R.A. Linthurst, Ph. Bourdeau and R.J. Tardiff, 436 (SGOMSEC 10-IPCS 23).

Seguí, L. (2004). Sistemas de Regeneración y Reutilización de Aguas Residuales. Metodología para el Análisis Técnico-Económico y Casos. Tesis Doctoral. Universidad Politécnica de Cataluña, Barcelona, Spain.

Sellner, F.J. (1999). The proposed European Water Framework Directive, its main features and possible impacts on the regulation of water in England, Wales and Germany.

Shephard, R.W. (1970). Theory of Cost and Production Functions, Princeton University Press, Princeton.

Sipala, S., Mancini, G. and Vagliasindi, F.G.A. (2003). Development of a web based tool for the calculation of costs of different wastewater treatment and reuse scenarios. *Water Supply*, 3 (4), 89-96.

Smeets, E, Weterings, R. (1994). Environmental indicators: typology and overview. Technical Report 25. European Environment Agency.

Standish-Lee, P. (1997). Planning a water reuse project". Conferencia Utilización de aguas regeneradas y biosólidos. Abril 6-7 de 1997. Malaga, Spain.

Thomas, J.S., Durham, B. (2003). Integrated Water Resource Management: looking at the whole picture. *Desalination*, 156, 21-28.

Tsagarakis, K.P. and Georgantzis N. (2003). The role of information on farmers' willingness to use recycled water for irrigation. *Wat. Sci. Tech.: Water Supply*, 3 (4), 105-113.

Tubail, K.M., Al-Dadah, J.Y. and Yassin, M.M. (2003). Present and prospect situation of wastewater and its possible reuse in the Gaza Strip. Med Reunet case study. (www.med-reunet.com/05case/01.case.asp)

Turner Collie & Braden Inc. (1991). Feasibility study for the implementation of a water reuse project in Fairfield Village. Final Report.

Turon, C., Poch, M. and Cortés, U. (2004). A methodology for knowledge reuse: application in the automatic generation of operational protocols for wastewater treatment plants. *iEMSs 2004 International Conference Proceedings*.

UNDP-World Bank (1994). Reuse of wastewater in agriculture: a guide for planners, *UNDP Water and Sanitation program report series No. 6* (www-wds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid=000009265_3961006165519).

UNEP (2002). Environmental Impact Assessment Training Resource Manual, ETB Publications: 573.

United Nations (2003). Wastewater treatment technologies a general review. Economic and Social Commision for Western Asia. Report number 03-0695, New York.

US EPA (2003). Environmental Finance Program (www.epa.gov/efinpage)

US EPA (2004). Guidelines for Water Reuse. EPA/625/R-04/108, U.S. Environmental Protection Agency, U.S. Agency for International Development, Washingthon, DC. (www.epa.gov/ORD/NRMRL/pubs/625r04108/ 625r04108.htm).

Verdonschot, P.F.M. (2000). Integrated ecological assessment methods as a basis for sustainable catchment management. *Hydrobiologi*a, 422/423, 389-412.

Vergés, C. (1998). El agua regenerada como nuevo producto en el mercado del abastecimiento y saneamiento de las aguas. Technical Conference *La gestión del agua regenerada,* Palamós, Costa Brava, Spain.

WHO (1989). Health guidelines for the use of wastewater in agriculture and aquaculture. *WHO Technical Report Series* No. 778.

WHO (1999). Guidelines for drinking-water quality. Vol. 2, second edn. Health criteria and other supporting information. Geneva.

WHO (2002). Guidelines for the safe use of wastewater and excreta in and aquaculture: Measures for public health protection.

World Bank (2003). Water resources and environmental. Technical Note F.3 – Wastewater reuse. World Bank, Washington D.C, USA.

WS-DH (1997). Water Reclamation and Reuse Implementation. Washington State Departments of Health and Ecology. Final Report to Washington State Legislature.

ANNEX I

INFORMATION ON DATA COLLECTION

Table I-A. Summary of the extent and methodology for input data collection in a feasibility study on water reuse (AQUAREC)

	Aspect	Methodology	Scope	Sources and means of verification	Assumptions
BACKGROUND INFORMATION	**Zone characteristics**				
	Geography & Topography	- Data collection - Use of GIS tool	- Characteristics of the zone (flat/mountainous), unevenness of the soil, type and classification of soils, mapping. - Main types of plants, vegetation, trees, and animal species	- Previous Studies - Socio-Economic Statistics - Institutions with Planning, Monitoring and Control functions	Data available
	Climate	- Data collection - Use of GIS tool	- Total and average precipitation data for the last 20 years (or at least 10 years). - Mean net and gross annual evaporation - Average temperature and average annual high and low temperatures. - Other aspects such as main type of winds, climate associated risks, etc.	- Previous Studies - Institutions with Planning, Monitoring and Control functions such as Environmental Agencies - Socio-Economic Statistics.	Data available
	Surface and Groundwater resources	- Data collection - Use of GIS tool	- Analysis of current and forecasted surface and groundwater resources in the area with the forecast schedule of the main changes to be carried out. - Current and possible risks such salt intrusion, pollution of surface and groundwater wells, etc.	- Previous Studies - Institutions with Planning, Monitoring and Control functions - Existing or Potential Water Resource Planning Areas - Reports from FAO, EEA, World Resources Institute, etc.	Data available Useful web page with links to water reference web sites: www.fcca.es/Docs/2LINKS%20(040604).htm
	Land use projections	- Data collection - Use of GIS tool	- Analysis of studies on land use projections - Analysis of crops and volume of land used for each - Irrigation volumes and projectoions of possible changes in the agricultural sector - Projected development should include single-family, multifamily, commercial, and institutional uses. - Schedule of the expected development should be included.	- Studies of land use projections at municipal, regional and state scale - Institutions with Planning, Monitoring and Control functions - Land use plan	Data available
	Population projections	- Data collection - Use of GIS tool	- Population projections and forecast for the study and surrounding area - Consider expected changes in single-family and multifamily connections, commercial, and institutional uses.	- Urban and Rural Demography - Socio-Economic Statistics; - Institutions with Planning, Monitoring and Control functions	Data available

Aspect		Methodology	Scope	Sources and means of verification	Assumptions
BACKGROUND INFORMATION	**Water supply**	- Data collection - Use of GIS tool	- Sources and quality characteristics of each type of water supply - Description of main water supplying facilities - Water consumes trends - Forecast of future needed plants - Groundwater management / problems - Current and future costs of tap water, funding and water prices	- General Outline of Existing Water Infrastructure in and Around Zone - Potential for System Linkages and Shared Projects Between Zones - Existing or Recommended Planning Areas for Water Infrastructure	Data available
	Water sanitation	- Data collection - Use of GIS tool	- Wastewater treatment plants. Treatment types, flows and costs. Quality of waste and reclaimed water. Variability (flow, quality). - Forecast of future needed plants / re-vamping of existing ones. - Need of pollutants control program for water reclamation. - Current applications of water reuse. Users, flows, actual agreements, price rates of regenerated water. Problems and improvements.	- General Outline of Existing Sewer and Wastewater Infrastructure in and Around - Potential for System Linkages and Shared Projects Between Zones - Existing or Recommended Planning Areas for Sewer and Wastewater Infrastructure - Data from National and Regional Environmental Agencies - Consultation to stakeholders (Water Agencies, Water Companies, Municipal Administrations)	Data available
	Reclaimed water quality standards	- Legislation revision - Data collection - Risks analysis and monitoring programmes	- Water quality and health protection regulations. Up to now, there is no European legislation for water reuse; each country establishes the limits and quality standards when appropriate. However, in some countries, like Spain, there is not a common national legislation but region-specific guidelines (e.g. Catalonia, Andalusia or Balearic Islands) - Water quality will depend on the water reuse application	- Guidelines available at EWATRO Project web site (www.dica.unict.it/users/fvaglias/EWATRO). - Reference guidelines for most European countries: California Legislation (Title 22), WHO recommended microbiological guidelines for agricultural reuse and the U.S.EPA guidelines - AQUAREC reports (D1, D15, M2.1, M2.2 and M2.3)	Data available

Aspect		Methodology	Scope	Sources and means of verification	Assumptions
BACKGROUND INFORMATION	**Potential users of reclaimed water**	- Data collection - Market analysis - Enquiries - GIS tool	- Inventory of potential users and volumes of water reuse. Potential for irrigation (agricultural, landscaping, golf courses…), grey water and cooling reuse and other potential reuses (industrial recycling or reuse, environmental uses…).	- Previous Studies - Institutions with Planning, Monitoring and Control functions - Urban and Rural Demography - Socio-Economic Statistics - Market analysis - Enquiry to users	Data available
	Literature review	- Review of papers, books, internet sites/ documents, conference proceedings, reports, stakeholders consultation…	- Types of reuse - Water quality and public health risks - Education and reuse - Case studies - Treatment technology	- Significant water reuse projects - AQUAREC reports D2 and D10 - MedReunet web page (www.med-reunet.com) - Catchwater project reports, U.S. EPA guidelines report	Data available
PROPOSED SYSTEMS	**Description**	- Data collection - Analysis of possible treatments/ treatments trains	- Water quality provided/requested - Wastewater volumes - Reclaimed water demands and needs for different uses. - Types of possible treatments and treatment trains - Main characteristics and requirements (power, land, maintenance…)	- AQUAREC D2 report and WP6 and WP7 contributions - EWATRO project web page www.dica.unict.it/users/fvaglias/EWATRO - Catchwater project reports - U.S.EPA guidelines report	Data available
	Advantages/ disadvantages	- SWOT analysis (Strengths, Weaknesses, Opportunities and Threats)	- Evaluation of advantages and disadvantages of the different systems considering economic, technological and environmental issues, amongst others.		Data available
	Requirements	- Evaluation of components and O&M specifications	- Additional wastewater treatment needs - Storage & place requirements, distribution lines, pressure maintenance, security needs, auxiliary power, special considerations. - Personnel needs, cleaning/chemicals needs, systems to minimise pipeline and irrigation systems obstruction (e.g. sprinklers), legal and administrative constraints…	- AQUAREC D2 report and WP6 and WP7 contributions	Data available

Aspect		Methodology	Scope	Sources and means of verification	Assumptions
PROPOSED SYSTEMS	**Basic layout**	- Figures, flow charts, design, requirements, location of components	- Main treatment and distribution system characteristics - Design values for the different parameters	- Engineering and Equipment Companies	
	Equipment needs and costs	- Data collection on investment and O&M costs	- Capital costs of the treatment system: design, materials (technology and equipment needs), construction and assembly (distribution systems, storage tanks, infrastructure needs…) - Running costs: O&M needs (Monitoring and control, chemical additives, power…) - Waste disposal needs and costs - Other costs - Comparison with conventional and unconventional water resources	- Data on conventional and unconventional water resource.	Treatment costs not usually well documented. Daily per-capita discharge of 300 L/p.e/d, with average treatment unit costs (Sipala, 2003). Wide variations in reported water reclamation costs.
	Site possibilities	- Analysis of the possibilities - GIS tool	- Advantages and disadvantages of each alternative - Proximity to potential users - Final decision taken by regional administrations (governments)	- Previous studies - Institutions with Planning, Monitoring & Control functions. - Socio-Economic statistics.	
	Environmental impact statement	- Environmental Impact Assessment (EIA) Studies - Life Cycle Assessment (LCA) - Use of biotic and abiotic indicators	- Ecological effects (water resources improvement, salt intrusion decrease, marsh enhancement, development of recreational lakes, restoration or increase of streams flow, vegetation increase - parks, recreational zones, ecological flows, changes on land characteristics, biodiversity changes). - Air quality. Hazard and risks (mosquitoes, odours, noise, possible groundwater pollution…). Human health. Visual impacts. Heritage.	- Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment and its amendment in Council Directive 97/11/EC: • Define Scope of full Environmental Impact Assessment • Preliminary Assessment and Mitigation Measures	EIA example for water reuse available at www.sydneywater.com.au/html/major_projectsGeorges/eis.cfm for the recycled water pipeline and overflow abatement works carried out in the Georges River in Sydney (Australia).

Aspect		Methodology	Scope	Sources and means of verification	Assumptions
PROPOSED SYSTEMS	**Impact on population, industry, agriculture, tourism, hygiene, and water quality**	- Analysis of cost savings. - Analysis of water quality improvements - Community and stakeholder consultation	- Socio-economical benefits: o Analysis of cost savings in water supply, treatment and distribution o Environmental benefits: Analysis of improvements in downstream river water quality o Agriculture benefits: reduced diversion costs, secure "drought proof" supply of reclaimed water, increased farm production, nutrients load in water, i.e. savings in fertilisers o Analysis of increase in the tourist activity, public welfare, employment, decrease in power and raw materials needs, increase in crops production, decrease in shortage episodes… - Public-acceptance for the different proposed systems and alternatives	- Data on: • Agriculture benefits • Urban water supply benefits • Urban wastewater benefits • Environmental benefits: improvements in receiving water quality • Increase in the tourist activity due to good water quality, quantity of golf courses, recreational zones, etc. • Decrease in raw materials, reagents or heat consumption due to water recycling in industry. Lower environmental penalties for industries linked to wastewater discharge. • Increase of population quality of life due to increase of recreational zones, sport fields, golf courses, etc. - Public participation, perception and acceptance are covered by Hartley (2003), Tsagarakis (2003), Abu Madi (2003) or Tubail (2003), U.S.EPA report (2004) and Hampton & Russell (2005).	

	Aspect	Methodology	Scope	Sources and means of verification	Assumptions
CURRENT vs. PROPOSED SYSTEMS	**Selection of alternatives**	- Evaluation and comparison - Cost-benefit analysis (www.method.123.com/documents/feas_study.doc)	- Evaluation criteria (cost, risks, reliability…). - Evaluation and comparison of options (included the current situation) - Consideration of additional aspects such as environmental improvement, increase of crop yield, etc.	- Information from AQUAREC WP6 and WP7 reports - Other related documents such as Khouri (1994) report, World Bank´s methodology for projects investments, information requirements set by EBRD (CFFPDA, 2001) and information described in the SAMTID Programme.	Cost effectiveness will increase with the volume of reclaimed water used Demonstration projects can be needed before taking a final decision
	Computer network modelling analyses	- Computer analysis/ modelling programmes (ELECTRE-3, ELECTRE-4, CP, KYPIPE, BOOT…)	- Find out the most sustainable alternative with modelling programmes that go from treatment definition down to determination of pump and waterline sizes, water supply requirements, storage tanks, etc. - Consideration of different criteria: technical, economical, environmental and social aspects of wastewater reuse.	- Multicriterion Decision Analysis (MCDA) methods: ELECTRE-3, ELECTRE-4 and Compromise Programming (CP) - University of Kentucky´s KYPIPE network modelling program - BOOT (Build Own Operate and Transfer)/BOT analysis ranking alternative strategies (Avlonitis, 2002, Bazza, 2003) - AQUAREC WTRNet design support and simulation software for reuse systems	Modelling and solving a problem with two or more non-commensurable and conflicting objectives (e.g. environmental quality, sustainable development): MCDA
	Costs and cost-effectiveness analysis	- Cost analysis summary	- Probable project costs. It comprises four primary cost components: o reclaimed water distribution o additional treatment at the WWTP o water storage and pumping o water quality monitoring - Probable O&M costs. - Other costs - Price of the reused water - Cost-effectiveness analysis. Current situation and future trends.	- Guidelines for reuse feasibility studies (Reuse Coordinating Committee of Florida, 1996, (Florida Department of Environmental Protection, 1991) - "Wastewater Reclamation and Reuse" (Asano, 1998) - AQUAREC D2 references and D6 general information - EWATRO project web page - DEA modelling methodology (Haruvy, 1996)	Costs have to be compared with a similar compilation for a freshwater supply system. Capital costs relatively straightforward to compute, O&M costs more difficult to estimate.

Aspect		Methodology	Scope	Sources and means of verification	Assumptions
CURRENT vs. PROPOSED SYSTEMS	**Financing options**	- Analysis of financing options from: • own sources • bank credits • state or local budget founds • special founds • external credits	- Funding overview - Potential programs for financing capital improvements (local, national and European) - Funding requirements - Return on investment	- International donors programmes and rules - Local financial legislation - AQUAREC D10 full information on funding options - U.S.EPA guidelines (2004) with information on funding options in the U.S.A.	Funding and management of a water reuse system is a key element for a feasible implementation
CONCLUSIONS AND FINAL	**Conclusions and final recommendations**	- Data / info analysis	- Conclusions - Recommendations	- Other considerations and accompanying measures such as infrastructure needs and improvements (new roads and other civil works…), agreements and contracts, responsibilities among the different agents (enterprises, water companies and administrations) involved in the project, etc.	
PROPOSED PROJECT SCHEDULE	**Project schedule**	- Schedule and deadlines for each phase of the proposed project	- Study phase (covered by the feasibility study + additional necessary information) - Planning phase (partially covered by the feasibility study) - include financial and contractual agreements - Demonstration phase (case studies derived from the application of the feasibility study conclusions) - Execution phase (starting up and operation of the proposed strategy)		It will be as a guiding schedule as the real schedule will depend on many variables (political decisions and alliances, funding, public acceptance…).
ANNEXES	**Supporting documents**		- References - Drawing part: • plan of site, • flow-sheets, • plans of the proposed system…		

ANNEX II

INFORMATION ON WASTEWATER TREATMENT TECHNOLOGIES

Table II-A Key indicators for the different treatment processes (AQUAREC M8.2)

No.	Selection Criteria (Key indicators)
1	Cost of treatment
2	Effluent quality achieved and intended reuse application
3	Reliability
4	Land required
5	Ease of operation and maintenance
6	Resources requirement
7	Quantity and quality of sludge (waste) produced
8	Adaptability to upgrade
9	Adaptability to varying flow rate
10	Adaptability to varying quality
11	Ease of construction
12	Ease of demonstration
13	Impact on environment (power requirements, chemical requirements, odour generation, impact on groundwater, impact on the soil, receiving river)
14	Power requirements
15	Chemical requirements
16	Odour generation
17	Impact on the soil
18	Impact on the receiving source (river, mash, groundwater)
19	Impact on health, risks
20	Improvement on public welfare
21	Improvement on economy (employment, increase on production yield)
22	Solution to the population needs
23	Decrease in the price of water
24	Social acceptance

Table II-B Removal range for different wastewater treatment processes (AQUAREC D6)

Type of treatment	Range of removal estimation (%)							
	COD/ BOD	P	N	SS	Patho gens	Viruses+ Helm.	Micropol lutants	Salts
Primary Treatment (after bar racks & screens)								
A) Sedimentation								
a) without coagulant	0-35	0-35	0-35	0-70				
b) with coagulant	0-35	35-100	0-70	35-100				
B) Dissolved air flotation								
a) without coagulant	0-35	0-35	0-35	0-70				
b) with coagulant	0-35	35-100	0-70	35-100				
C) Coarse media filtration								
a) without coagulant	35-70	0-35	0-35	70-100				
b) with coagulant	0-35	35-100	0-70	35-100				
D) Direct membrane filtration	0-35	0-35	0-35	70-100				
E) Magnetic separation	35-70	70-100		70-100				
F) Actiflo™-Process	35-70	35-100	0-35	70-100				
G) A-step								
a) without coagulant	35-100	35-70	0-35	35-70				
b) with coagulant	35-100	35-100	0-35	35-70				
H) Denitrifying A-step	70-100	35-70	0-35	35-70				
I) UASR-reactor	0-70			35-100				
Secondary biological Treatment								
I) Activated sludge +sec. sedimentation	70-100	35-100	35-100	70-100	0-100	70-100		
II) Trickling filters + sec. sedimentation	35-100	35-70	35-70	70-100	70-100	0-100		
III) Rotating biological contactors	70-100	35-70	35-70	70-100	70-100			
IV) Submerged aerated filters	70-100	35-70	35-70	70-100	70-100			
V) Stabilisation ponds	35-100	0-100	0-100	0-100	70-100	70-100		
VI) Constructed wetlands	35-100	0-100	35-100	70-100				
VII) Membrane bioreactors	70-100	35-100	35-100	70-100	70-100	70-100		
Tertiary treatment								
1) Filtration over fine-porously media	0-70	35-70		35-100				
2) Surface filtration				35-100				
3) Membrane filtration	0-35	0-35	0-35	70-100	70-100	35-100	0-100	0-100
4) Adsorption							70-100	
5) Gas stripping			70-100					
6) Ion exchange			70-100					70-100
7) Advanced oxidation	70-100							
8) Disinfection					70-100	70-100		

Table II-C Comparison of different disinfection treatments (Lazarova, 1999)

Characteristics /Criteria	Chlorination/ dechlorination	UV	Ozone	MF	UF	NF
Safety	+	+++	++	+++	+++	+++
Bacteria removal	++	++	++	++	+++	+++
Virus removal	+	+	++	+	+++	+++
Protozoa removal	-	-	++	+++	+++	+++
Bacterial regrowth	+	+	+	-	-	-
Residual toxicity	+++	-	+	-	-	-
By-products	+++	-	+	-	-	-
Operating costs	+	+	++	+++	+++	+++
Investment costs	++	++	+++	+++	+++	+++

-: none; +: low; ++: middle; +++: high

Table II-D Comparison among the different wastewater treatments for the different key indicators (AQUAREC)

	Indicator																								
Type of treatment	**1 C**	**1 OM**	**2**	**3**	**4**	**5** [b]	**6**	**7**	**8**	**9**	**10**	**11** [b, d]	**12** [b]	**13** [a]	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23** [c]	**24**
Primary Treatment																									
A) Sedimentation																									
a) without coagulant	+	+	+	+	+++	+++	++	+	+	+	+	++	+	+	+	+-	++	+	+++	+++	+	+	+		+
b) with coagulant	++	+	++	++	++	+++	++	++	+	+	++	+++	++	++	++	++	+	++	++	++	++	+	+		++
B) Dissolved air flotat.																									
a) without coagulant	+	+	+	+	+++	++	+++	+	+	+	+	++	+	+	+	+-	+++	+	+++	+++	+	+	+		+
b) with coagulant	++	+	++	++	++	++	+++	++	+	+	++	+++	++	++	++	++	++	++	++	++	++	+	+		++
C) Coarse media filtration																									
a) without coagulant	+	+	+	+	+++	++	++	++	+	+	++	++	+	+	+	+-	++	+	++	+++	+	+	+		+
b) with coagulant	++	+	++	++	+++	++	++	++	+	+	++	+++	++	++	++	++	+	++	+	++	++	+	+		++
D) Direct membrane filtration	++	++	+- +++	+++	+	++	++	+	+++	+++	+++	++	+++	+	++	+	+	+	+	+	+	+	+++		+++
E) Magnetic separation	+	+	+	+	++	+	++	++	+	++	++	+	+++	+	+++	+	+	+	+++	++	+	+	+		++
F) ActifloTM-Process	++	+	++	++	+	++	++	+	+	++	++	++	++	++	++	+	++	+	++	+	+	+	+		++
G) A-step																									
a) without coagulant	+	++	++	++	++	++	++	++	+	++	++	++	++	++	++	+-	++	+	+++	++	+	++	+		+
b) with coagulant	++	++	++	++	++	++	++	++	+	++	+++	+++	++	+++	++	+++	++	++	++	+	++	++	+		++
H) Denitrifying A-step	++	+	+	+	++	++	++	++	++	++	++	++	++	++	++	+	+++	+	+++	+	+	++	+		++
I) UASR-reactor	+	+	++	++	++	+	++	++	++	++	++	++	++	++	++	+	+++	+	+++	+	+	++	+		++
Secondary biological Treatment																									
I) Activated sludge +sec. sedimentation	++	++	++	++	+++	++	++	+++	++	++	++	++	++	++	++	+	+++	+	++	++	++	++	++		++
II) Trickling filters + sec. sedimentation	++	++	++	++	+++	++	++	+++	++	++	++	++	++	++	++	+	+++	+	++	++	++	++	++		++
III) Rotating biological	+	++	++	++	++	++	++	+++	++	++	++	+	++	++	++	+	+++	+	++	++	++	++	++		++

	Indicator																								
Type of treatment	**1 C**	**1 OM**	**2**	**3**	**4**	**5 [b]**	**6**	**7**	**8**	**9**	**10**	**11 [b, d]**	**12 [b]**	**13 [a]**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23 [c]**	**24**
contactors																									
IV) Submerged aerated filters	++	++	+	++	++	+	++	++	++	+	++	+	+	+++	++	+	+	++	+++	+++	+	+	+		+
V) Stabilisation ponds	+	+	+	+	+++	+++	+	+	+	+	+	+	+	+++	+	+	+++	+++	+++	+++	+	+	+		+
VI) Constructed wetlands	++	+	+	+	+++	+++	+	+	+	+	+	+	+	+++	+	+	+++	+++	+++	+++	+	+	+		+
VII) Membrane bioreactors (MBR)	+++	+	+++	+++	+	++	++	++	+++	+++	+++	++	+++	++	+++	+	+++	++	+	+	+++	+++	+++		++
Tertiary treatment																									
1) Filtration over fine-porously media	++	++	++	++	++	++	++	+++	+	+	++	+	+	++	++	+	+	+	+	++	++	+++	+		++
2) Surface filtration	+	++	++	++	++	+++	++	+++	+	+	++	+	++	+	++	+	+	+	++	++	++	+++	+		++
3) Membrane filtration	+++	++	+++	+++	+	++	++	+	+++	+++	+++	++	+++	+	+++	+	+	+	+	+	+++	+++	+++		+++
4) Adsorption	++	++	++	++	+	++	++	++	+	+	+	+	+++	+	++	+++	+	+	++	++	++	+++	++		++
5) Gas stripping	++	+	++	+	+	++	+	+	+	+	+	++	+++	++	+++	+	+++	+	++	++	++	+++	++		+
6) Ion exchange	++	++	+++	++	+	++	++	+++	+	+	+	+	+++	++	++	+++	+	+	++	++	++	+++	++		++
7) Advanced oxidation *(ozone, UV, Fenton)	+++	++	+++	+++	+	++	++	+	+++	+++	+++	++	+++	++	+++	+-+++	+	+	+	+-+++	+++	+++	+++		+
8) Disinfection*	+++	+	+++	+++	+	++	++	+	+++	+++	+++	+-++	+++	+	+-++	+++	++	+	+	+-+++	+++	+++	+++		++

*: Under this heading different types and combinations of treatments are included.
Indicator No. 1 (Cost of treatment) has been divided (C): Capital cost and (O&M): Operation and maintenance (power, equipment replacement, chemicals, labour).
[a]Difficult to estimate because of the great number of different items that includes.
[b]For these indicators: +: very difficult, ++: medium, +++: very easy).
[c]The indicator number 23 has not been evaluated because it is very difficult to correlate the type of treatment used with the final price of water.
[d]It could be understood of different ways: time required to build it, easy because it does not require very high -tech technology,….
To range the different treatment types, the most common used treatment (activated sludge conventional biological treatment) has been taken as reference.
In all the cases of primary treatment with coagulant, the cost will be higher (chemicals) and produce more sludge, but treated water will have higher quality.
MBRs need more energy than activated sludge systems and the membrane cost (equipment and membrane replacement) is quite important; but they allow working with higher pollutant loads, higher inlet concentrations, flow fluctuations, need less land requirement, produce less waste, and provide more reliable and higher water quality.

Table II-E Summary of the main characteristics and references for different wastewater treatment processes (Adapted from AQUAREC D6)

Process	Design parameters	Energy consumption	Cost calculation Data	References
		Physical/chemical pre-treatment methods		
Coarse solids removal and Grit removal	Space between bars Number of chambers Chamber width Detention time Horizontal velocity Settling velocity Head loss in a control section Added length allowance for inlet and outlet turbulence	20,000 kWh.y^{-1} (for the same case of the cost calculation data)	Construction (C): 135,750 Electro-mechanical (EM): 226,250 Maintenance: % of C/EM (/year) 0.5/1.5 % Assumptions: Fine bar screen (diameter: 6mm, 3,000 m^3/h), designed for 100,000 PE WWTP (Population Equivalent Wastewater Treatment Plant), for C and EM investments an additional overhead factor of 0.7 is assumed	STOWA, 1998 Metcalf&Eddy, 2003
Fine screen	Surface load Required screen surface Submergence percentage Total screen surface per drum Max. length per drum Max. diameter per drum Screen surface per drum Required number of drums Screening diameter Total space requirements	71,180 kWh.y-1 plus 158,170 kWh.y-1 for cleaning procedures (for a flow of 1,500 m3.h-1)	Construction (C): 678.75 Electro-mechanical (EM): 1,357.5 Maintenance: % of C/EM (/year) 0.5/2.5 % Assumptions: Fine screen (1,500 m3.h-1) for C and EM investments an additional overh ead factor of 0.7 is assumed	STOWA, 1998 Metcalf&Eddy, 2003
Mixing and flocculation	Hydraulic retention time Height Velocity gradient stirrers (for the mixing tank and flocculator)	Rapid mixing: 124,400 kWh.y-1 Flocculation mixing: 20,200 kWh.y-1	Construction (C): 450 /m3 Electro-mechanical (EM): 340 /m3 Maintenance: % of C/EM (/year) 0.5/1.5 % Energy (electricity) costs for a flocculator (rapid mixing 8,710 and flocculation mixing 1,415 /year) Assumptions: 100,000 PE WWTP. For C and EM investments an additional overhead factor of 0.7 is assumed Price of electricity: 0.07 /kWh)	Van Nieuwenhuijzen, 2002
Sedimentation and Settling/Precipitation	Hydraulic surface loading Tank height (circular configuration) Flocculant dose	Consumption per clarifier (kWh per year) 35,000 Consumption for primary and	FeCl3 (41%): 150 /m3 Anionic polymer: 5.6 /kg 5.5 /kg for cationic polymer 3.1 /kg for anionic polymer Final sludge disposal: 0.4 /kg dry solids	STOWA, 1998

Process	Design parameters	Energy consumption	Cost calculation Data	References
		secondary sedimentation (kWh per year) 70,000	Staff labour: 36,500 per staff member/year Construction (C): 270 /m2 (90 /m2 cover primary sedimentation tank) Electro-mechanical (EM): 70 /m2 Maintenance: % of C/EM (/year) 0.5/1.5 % Assumptions: Fine screen (1,500 m3.h-1) for C and EM investments an additional overh ead factor of 0.7 is assumed	
Flotation	Hydraulic surface loading Tank height Recycle flow Pressure recycled flow Yield of aeration pump Flocculant dose	27,083 W (237,250 kWh/year) (24 h per day, 365 days per year)	Construction (C): 1,130 /m2 Electro-mechanical (EM): 2,260 /m2 Maintenance: % of C/EM (/year) 0.5/2.0 % Assumptions: For C and EM investments an additional overhead factor of 0.7 is assumed Energy consumption: 16,610 /year (0.07 /kWh)	STOWA, 1998
Direct influent filtration Direct coarse media filtration	Filtration rate Bed height Column (diameter and number) Backwashing (Frequency, time and volume)	40,000 kWh/year	Construction (C): 3,600 /m2 Electro-mechanical (EM): 3,400 /m2 Maintenance: % of C/EM (/year) 0.5/2.0 % Assumptions: For C and EM investments an additional overhead factor of 0.7 is assumed	STOWA, 1998 Van Nieuwenhuijzen, 2002
Membrane filtration	Type of membranes (material, cut-off) Configuration Flux Transmembrane pressure (TMP) Recovery Membrane surface Installation (modules, vessels, stacks) Cleaning system	Microfiltration (MF) Dead end: 0.04 kWh.m-3 (284,700 kWh/year) Cross flow: 0.4 kWh.m-3 (2847,000 kWh.y-1)	Construction (C): 680 /module (655,500 /installation) Electro-mechanical (EM): 1,730 /module (1,667,700 /installation) Membranes (M) (MF): 1,600 /module)(1,542,400 /installation) Maintenance: % of C/EM/M (/year) 0.5/1.5/1.5 % Assumptions: For C and EM investments an additional overhead factor of 0.7 is assumed Energy consumption: 16,610 /year (0.07 /kWh)	STOWA, 1998
Magnetic separation	SIROFLOCTM-process Surface loading Magnetic particle size			STOWA, 1998
ActifloTM-Process	Micro sand particle size Surface loading			STOWA, 1998
Others (Micro screens and wet oxidation)	Micro screens: screen size, hydraulic loading rate, head loss through screen, drum submergence, drum diameter, drum speed, backwash requirements			

Process	Design parameters	Energy consumption	Cost calculation Data	References
Pre-treatment steps based on bio-flocculation and separation				
A-step/ A-step with sludge regeneration	Depth Hydraulic retention time F/M ratio Sludge volume index (Surface, volume)	Aeration: 479,000 kWh.y-1	Construction (C): 270 /m3 Electro-mechanical (EM): 180 /m3 Maintenance: % of C/EM (/year) 0.5/1.5 % Assumptions: For a 100,000 PE WWTP. For C and EM investments an additional overhead factor of 0.7 is assumed	STOWA, 1998 Van Nieuwenhuijzen, 2002
A-step with dosing of chemicals to enhance floc formation	Depth Hydraulic retention time F/M ratio Sludge volume index (Surface, volume Chemicals dosage	Aeration: 479,000 kWh.y-1	Similar to the previous one	STOWA, 1998
Denitrifying A-step	Depth Hydraulic retention time F/M ratio Sludge volume index (Surface, volume)	Lower than 479,000 kWh.y-1	Similar to the previous one (A-step)	STOWA, 1998
Upflow anaerobic solid retention	Hydraulic retention time Upward velocity		Construction (C): 270 /m3 Electro-mechanical (EM): 135 /m3 Maintenance: % of C/EM (/year) 0.5/2.0 % Assumptions: For C and EM investments an additional overhead factor of 0.7 is assumed Cost: US$ 4 per PE (for a plant of 50,000 PE capacity)	STOWA, 1998; Rose, 1999
Biological unit operations				
Activated sludge systems (high loaded systems)	Hydraulic retention time F/M ratio Sludge concentration V/Q Qras/Q	15-25 kWh/(PE.year) 0,2-0,3 kWh.m-3	Capital investment: 100-1000 /PE Operation and Maintenance: 10-40 /(PE.year) Investment and operational costs are strongly dependent on the size of the installation, especially for small and mid-size installations. The figures refer to typical Western Europe installations for respectively 100,000 PE and 500 PE. Above 100,000 PE the positive economies of scale are limited, while below the 500 PE the economies of scale are significant. Operation costs (depreciation included) in US $ (1996) for different flows: 0.72 (for 3,800 m3.d-1), 0.39 (for 19,000 m3.d-1), 0.34 (for 38,000 m3.d-1)	Aya, 1994; Massena, 2001; Stephenson, 2000; Rose,1999; Final report of the CatchWater Project, 2002

Process	Design parameters	Energy consumption	Cost calculation Data	References
			Secondary treatment by activated sludge +filtration: 0.85 (for 3,800 m3.d-1), 0.44 (for 19,000 m3.d-1), 0.43 (for 38,000 m3.d-1) Secondary treatment by activated sludge +Title 22: 0.85 (for 3,800 m3/d), 0.44 (for 19,000 m3.d-1), 0.43 (for 38,000 m3.d-1) Secondary treatment by activated sludge +filtration +carbon +reverse osmosis: 2.05 (for 3,800 m3.d-1), 1.47 (for 19,000 m3.d-1), 1.42 (for 38,000 m3.d-1) Other data (Stephenson gives data of all the items but the total figures are the following ones): Treatment costs (/m3): 13.2 (for 2,350 PE plant) and 4.9 (for 37,500 PE plant) Cost (Source: Rose): US$ 8 per PE (for a plant of 50,000 PE capacity)	
Activated sludge systems (low-loaded systems)	Hydraulic retention time F/M ratio Sludge concentration V/Q Qras/Q	15-25 kWh/(PE.year)	Capital investment: 150-1,000 /PE Operation and Maintenance: 10-40 /(PE.year) Investment and operational costs are strongly dependent on the size of the installation, especially for small and mid-size installations. The figures refer to typical Western Europe installations for respectively 100,000 PE and 500 PE. Above 100,000 PE the positive economies of scale are limited, while below the 500 PE the economies of scale are significant.	
Activated sludge systems (EBPR systems)	The same that for the activated sludge systems plus the anaerobic activated sludge system plus the ones for chemical precipitation	Additional energy consumption –0.5 kWh/(PE.year)	Additional Capital investment *: 3-10 /PE *This includes the capital investment for chemical precipitation, as chemical precipitation is generally built as stand-by treatment (chemicals are added whenever the EBPR process fails or doesnt meet the effluent consent). Additional Operation and Maintenance: 0.2-1 /(PE.year) *If EBPR does not need to be combined with chemical precipitation with metal salts.	
Activated sludge systems (P-precipitation systems)		0.1 kWh/(PE.year)	Additional Capital investment *: 0.25-2.5 /PE *Significant positive economies of scale Additional Operation and Maintenance: 0.45-2.5 /(PE.year)	
Trickling filters	Hydraulic loading (m.h-1) BOD loading (kg BOD.m-3.d-1)			

Process	Design parameters	Energy consumption	Cost calculation Data	References
	Depth (m) Recirculation ratio (-) Effluent characteristics			
Rotating biological contactors (RBCs)	Hydraulic retention time Organic loading Effluent BOD Effluent NH4-N Surface loading secondary clarifier Rotational speed	7-30 kWh/(PE.year)	These data refer to an application range between 150 PE and 2,000 PE: Construction costs: 450 1300 /PE Recurring costs: 10 70 /(PE.year) Remarks: the unitary costs (i.e. costs per PE) are strongly dependent on the size of the installation (important positive economies of scale apply).	
Submerged aerated filters (SAFs)	Hydraulic retention time Organic loading Effluent BOD Effluent NH4-N Surface loading secondary clarifier Rotational speed	40-70 kWh/(PE year)	The cost calculation data refer to an application range between 150 PE and 2,000 PE: Construction costs: 500 1,000 /(PE.year) Recurring costs: 20 60 /(PE.year) Remarks: the unitary costs (i.e. cost per PE) are strongly dependent on the size of the installation (important positive economies of scale apply).	
Stabilization ponds	Pond size Depth Operation (Series or paralell) Flow regime Detention time PH BOD loading	Pumping of the influent: site specific Consumption for aeration, aerated lagoon: 10 20 kWh per PE per year (at 0.07/kWh: 0.7 1.5 per PE per year) Partial mixing system, when needed: 1 3 W/m‡	Construction costs: 200 1,200 /PE Remark: does not include the costs for the land, as it is very site-specific (while in some cases the costs of land can be very expensive, in others land is given for free). In urban/suburban areas of economically developed countries where little land is available, costs for the land can be a major cost/constraint. Recurring costs: 7 50 /(PE.yea r) of which 1 5 /(PE.year) are energy costs As a result of a number of local factors, it is not possible to derive generally applicable cost-per-hectare unit cost. The following is a range of costs that may be useful for an order-of-magnitude preliminary estimate only.	
Constructed wetlands	Specific area Length Width Depth Average grain size of soil Internal bed slope Root density	1-5 /PE.year	Capital investment: 500 1650 /PE Operation and Maintenance: 15 90 /(PE.year) of which 1 5 /(PE.year) for electricity consumption	

Process	Design parameters	Energy consumption	Cost calculation Data	References
Membrane bioreactors (MBR)	Type of membranes (material, configuration, cut-off) Transmembrane pressure Membrane area Aeration Cleaning system (backflushing, frequency) Sludge age F/M ratio Sludge production Volumetric load Sludge concentration Residence time Hydraulic residence time	3.4 kWh.m-3	Capital cost: CCMBR = 8,250 Q0.75 ($); Q in m3.d-1 O&M cost; O&MMBR = 0.4 (Q/1000)0.28 ($/m3); Q in m3.d-1 Considered items: energy, chemicals, membrane replacement, labour, maintenance Other data (Stephenson gives data of all the items but the total figures are the following ones): Treatment costs (/m3): 11.5 (for 2,350 PE plant) and 6.2 (for 37,500 PE plant)	Adham, 2000; Lozier, 2002 Aya, 1994
Soil aquifer treatment (SAT)	Flow Type of soil Depth	The secondary WWT, SAT, extraction and distribution 1,420 kWh.m-3(99.4 /m3) Only for extraction (20-40 /m3)		
Unit operations for physical/chemical and advanced (post)treatment				
Filtration over fine-porously media	Bed height (Top layer and bottom layer) Filtration velocity Total filtration surface Dimensions of unit Backwashing (velocity, duration, frequency)	73,000 KWh.y-1	Construction (C): 3,600 /m2 Electro-mechanical (EM): 3,400 /m2 Maintenance: % of C/EM (/year) 0.5/2.0 % Assumptions: For C and EM investments an additional overhead factor of 0.7 is assumed	STOWA, 1998
Surface filtration	Size of openings Hydraulic loading time Head loss Disk submergence Disk diameter Disk rotation speed Backwash requirements	2.5*10-3 kWh.d-1 per filter (for a standard effluent of 20 mg/dm-3 of suspended solids)	It will be very variable For a 165,000 PE WWTP it will cost 1.7 109	Metcalf&Eddy, 2003
Membrane filtration	Type of membranes (material, cut-off)	KWh.m-3	Capital Cost for MF and UF: The correlation for direct capital	Adham, 1996;

Process	Design parameters	Energy consumption	Cost calculation Data	References
	Configuration Flux Transmembrane pressure (TMP) Recovery Membrane surface Installation (modules, vessels, stacks) Cleaning system	MF: 0.15-0.4 (0.39 GonzÆez) UF: 0.15-0.4 (1.21 GonzÆez) NF: 2.5 RO: 5 (2.02 GonzÆez)	cost estimation of MF and UF has the form $CC_{MF-UF} = 5,600Q^{0.6}$ ($) O&M cost for MF and UF: To obtain O&M cost estimates the following items were considered. i) Energy, ii) Chemicals, iii) Membrane replacement, iv) Labour, and v) Maintenance. On the basis of literature data a representative value of 0.10 $/$m^3$ for unit O&M cost is suggested. Capital Cost for RO and NF: A feed water with a representative salinity of 1,000 g.m^{-3} of TDS (Total Dissolved Solids) was selected to obtain RO cost estimates for various product water capacities up to 50,000 $m^3.d^{-1}$. An 80% product water recovery was assumed for RO and 90% for NF. The following cost items were considered: i) Membranes, ii) Pressure vessels, iii) Electrical equipment, iv) Instrumentation and control, v) High pressure pumps, vi) Chemicals feeding equipment, vii) Cartridge filters, viii) CIP system. A correlation valid for both RO and NF was obtained of the form: $CC_{RO-NF} = 1109Q^{0.845}$ ($) The above correlation does not include costs for installation, site development, piping, electrical distribution, controls and service, and contingencies. O&M cost for RO and NF: A similar procedure was applied to obtain annual O&M cost estimates. The following cost items were taken into account: i) Energy, ii) Labour, iii) Chemicals, iv) Membrane replacement, v) Cartridge filter replacement, and vi) Maintenance. The calculated results suggest a relatively flat unit product cost of 0.14 $/$m^3$ and 0.12 $/$m^3$ for RO and NF respectively. Chemicals: 0.02 /m^3 (for MF and UF) and 0.13 /m^3 (for RO) Membrane replacement: 0.01 /m^3 (for MF and UF) and 0.07 /m^3 (for RO) Maintenance: 0.10 /m^3 for MF, 0.15 /m^3 for UF and 0.07 /m^3 (for RO) Investment costs (installation): 210 /m^3d for MF, 210 /(m^3d) for UF and 270 /(m^3d) (for RO)	Laine, 2000; Metcalf & Eddy, 2003; U.S.EPA-832-F-00-01, 2000; Lozier, 1998; Wilf, 1999; Lozier, 2002; Adham, 2000; Glueckstern, 2002; Chellam, 1998; Gere, 1997; Cote, 2001; retrieved data from www.usfilter.com ; Wilbert, 1999; GonzÆez, 2003

Process	Design parameters	Energy consumption	Cost calculation Data	References
Activated carbon adsorption	Volumetric flow rate Bed volume Cross-section area Length Void fraction GAC density Approach velocity Effective contact time Empty bed contact time Operation time Throughput volume Specific throughput Bed volumes	Considering filters of the same size, the pumping costs for activated carbon filters are similar to the cost for depth filters. For an activated carbon filter (GAC) with a bed 2m high and with a diameter of 4m, treating secondary effluent with a surface load of 5 m.h-1, an energy cost of 1,255,000 kWh.y-1 was found	Capital Cost: CCGAC = (1948.8Q0.74)*1.61 ($) O&M: OMGAC = (225.4Q0.83)*1.08 ($)	Clark, 1989 Van Nieuwenhuijzen, 2002
Stripping of Ammonia	Liquid loading rate Air-to-liquid ratio Stripping factor Allowable pressure drop Height-to-diameter ratio Packing depth Factor of safety Wastewater pH Approximate packing factors Berl saddles, raschig rings	1 buffer tank pump: 65,700 kWh.y-1 3 chemicals pumps: 31,536 kWh.y-1 2 blowers: 1,629,360 kWh.y-1 1 circulation pump: 30,660 kWh.y-1 1 process-water pump: 2,628 kWh.y-1 Total: 1,759,884 kWh.y-1	Capital cost 1,886,000 Energy 119,000 /year Chemicals 400,700 /year Analysis, sampling, etc. 54,500 /year Management 76,000 /year Manpower 18,000 /year Cost data for the handling of ion exchange brines by ammonia stripping for a 100,000 PE WWTP	STOWA, 2001; Metcalf&Eddy, 2003
Ion exchange			Investment costs (US$/m3); 54 (chemicals) and 52-29.6 (for manual and automatic ion exchange systems) Operational costs (US$/m3); 0.164 (chemicals) and 0.001 (for manual and automatic ion exchange systems) Other data: Cost of 2-5 US$/dm-3 of wet resin	Akal, 2004 Johnston, 2001

Process	Design parameters	Energy consumption	Cost calculation Data	References
Nitrogen removal	Loading phase: Grains size (mm) Bed height (m) Flow rate (m3h-1) PH NH_4-N influent concentration (mg/dm-3) Exchange capacity (meq/dm-3) Conditions of the backflush phase Conditions of the regeneration cycle	*Physical-chemical brine handling (NH_3 stripping) 2.4*106 KWh biological brine handling (KMT reactor) 1.7*106 KWh	Physical-chemical brine handling biological brine handling (NH_3 stripping) (KMT reactor) Investment costs 6.09 million 6.22 million Yearly operational costs1.18 million 2.1 million (Chemicals) (0.4 million) (0.29 million) / kg of N removed 2.95 3.63 Footprint 950 m2 1,950 m2 *: These costs are reported for the treatment of [NH_4^+-N] = 50 mg/dm-3 to a level of [NH_4^+-N] = 1 mg/dm-3 in the effluent, on a scale of 100,000 PE (STOWA, 2001)	STOWA, 2001; Metcalf&Eddy, 2003
Removal of heavy metals				
Advanced Oxidation Processes (AOPs)	This heading includes very different types of ttreatments: UV, ozone, UV/H_2O_2, Ozone/H_2O_2, wet oxidation, PhotoFenton, so each type of treatment will have different design parameters as for example H_2O_2 concentration, pH, air concentration, ozone concentration, catalyst type and concentration, contact time, UV dose, etc.	The energy consumption will vary very much depending on the type of treatment and characteristics of the considered wastewater but in general the consume of power is very high	The total cost of these types of treatments will vary very much depending on the size of the plant, water characteristics, discharge quality, etc. In general the capital cost is medium and the cost due to power, lamps replacement, and chemicals (if H_2O_2, or a catalyst is used) are quite high. Cost of a treatment with (ozone +activated carbon +reverse osmosis): 0.55 /m3 (The different concepts are described)	Marcucci, 2002; EPA Handbook, 1998
Unit operations for disinfection				
Chemical treatments for desinfection (ozone, peracetic acide, NaClO, Chlorine dioxide, Chlorine gas)			The same considerations that for the case above could be used. Currently the most used disinfection system is by NaClO addition (because of t its reliability and low cost) but in the presence of organic compounds, undesirable by-products (organochloride compounds) can be produced. Its is for this reason than other types of treatments as for example UV radiation, membranes and ozone are being implemented. Treatment by ozone: Cost of operation: 0.8-1.6 /kg of ozone Cost of investment and operation: 0.05-0.1 /m3 UV $\leq$ 0.04 /m3 UV/O_3 $\leq$ 0.05 /m3 The treatment by UV and membranes is economically	Lazarova, 1999

Process	Design parameters	Energy consumption	Cost calculation Data	References
			competitive but the great cost of the ozone only makes it competitive for large facilities.	
Physical treatments (UV radiation and membrane technology (UF, NF, RO)		For an UV dose of 40 mWs/cm2 0.001-0.004 /m3 (for a capacity of 91 and 6.814 m3/d respectively)	UV: UV ≤ 0.04 /m3 Equipment replacement: 0.001-0.004 /m3 Labour: 0.0002-0.0009 /m3	www.trojan.com

REFERENCES

Adham S., Gagliardo P., Boulos L., Oppenheimer J. and Trussell R. (2001). Feasibility of the membrane bioreactor process for water reclamation. ***Wat. Sci. Tech.***, 43 (10), 203-209.

Aya, H. (1994). Modular membranes for self-contained reuse systems. ***Wat. Qual. Int.***, 4: 21-22.

Lazarova V. (2001). Role of Water reuse for enhancing integrated water management in Europe. Catchwater Final Report.

Chellam, S., Serra, C.A. and Wiesner, M.R. (1998). Estimating Costs of Integrated Membrane System. *J. AWWA*, 90 (11), 96-104

Clark, R.M. and Lykins, B.W.Jr. (1989), *Granular Activated Carbon: design operation and cost,* Lewis Publishers, Chelsea, Michigan USA.

Cote, P., Buisson H. and Praderie M. (1998). Immersed membranes activated sludge process applied to the treatment of municipal wastewater. *Water Science and Technology,* 38(4-5): 437-442.

Degremont Water and Environment, *Water Treatment Handbook (6th edition),* available at www.degremont.fr.

Elarde, J.R., Bergman, R.A. (2001). The cost of membrane filtration for municipal water supplies. Chapter 1 in *Membrane practices for water treatment*. Edited by S.J. Duranceau. Denver: American Water Works Association.

EPA (1998). Handbook, Advanced Photochemical Oxidation Processes. EPA/625/R-98/004. December 1998.

Glueckstern, P. Comparative Cost of UF versus Conventional Pretreatment for SWRO Systems. *Israel Desalination Society Conference*. Haifa, Israel (2002).

IDS conference Integrated Desalination Systems, 12 13 December, Haifa, Israel.

Johnston, R., Heijnen, H. and Wurzel, P. (2000), Safe water technology. (www.who.int/water_ sanitation_health/arsenic/ArsenicUNRep7.htm)

Korkusuz, E.A. and Diamadopoulos, E. (2005). Manual of practice on constructed wetlands (CWs) for wastewater treatment and reuse in Mediterranean countries. *Med Reunet II Workshop*. Barcelona (Spain), 12-13/05/05.

Laine J.M., Vial, D. and Moulart P. (2000). Status after 10 years of operation - Overview of UF technology. *Desalination*, 131(1-3), 17-25.

Lazarova V, Savoye P, Janex ML, Blatchley ER, Pommepuy M. (1999). Advanced wastewater disinfection technologies: State of the art and perspectives. *Water Science and Technology* 40(4-5), 203-213.

Lozier, J.C., 2002

Malina, J.F. and Pohland, F.G. (1992). Design of anaerobic processes for the treatment of industrial and municipal wastes. Water Quality Management Library, vol. 7, Tecnomic Publishing Company, Inc., Lancaster, U.S.A.

Marcucci, M. and Tognotti, L. (2002). Reuse of wastewater for industrial needs: the Pontedera case. Resources, Conservation and Recycling 34, 249-259.

Massena P.A. (2001). Valorisation des eaux usees en irrigation localisee, available at www.mrea_jo.org/Documents/Eauxusees-EI1003.pdf.

Metcalf & Eddy. (2003). *Wastewater Engineering, Treatment and Reuse* (4th edition), New York.

Mulder, M. (1997). *Basic principles of membrane technology* (2nd edition, corrected), Kluwer Academic Publishers, Dordrecht.

Nieuwenhuijzen, A. F. Van (2002), Dissertation: Scenario studies into advanced particle removal in the physical-chemical pre-treatment of wastewater, DUP Science, Delft.

Rose, G. (1999). IDRC 01-09-1999 Final report. (www2.gtz.de/ecosan/download/rose.pdf).

Stephenson, T., Judd, S., Jefferson, B., Brindle, K. (2000). *Membrane Bioreactors for wastewater treatment*, IWA Publishing, London.

STOWA (1998), Fysisch/chemische voorzuivering van afvalwater, Utrecht.

STOWA [Verker, J.] (2001) Ionenwisseling voor stikstofverwijdering uit afvalwater, (Report number 19), Utrecht.

STOWA, (2001), Compendium rwzi-effluent als bron en Deel 4 bijlagen, Utrecht.

Wagner, J. (2001). Membrane Filtration Handbook. Practical Tips and Hints. Published by Osmonics.

United Nations (2003). Waste-water treatment technologies: A general review. Economic and Social Commission for Western Asia Report number 03-0695 (www.escwa.org.lb/information/ publications/edit/upload/sdpd-03-6.pdf).

Wilbert, M.C., J. Pellegrino, J. Scott and Q. Zhang (1999). Water Treatment Estimation Routine (WaTER) UserManual. Water Desalination Research and Development Programme Report No. 43. US Department of the Interior, Bureau of Reclamation.

Wilf, M. (1998). Reverse Osmosis Membranes for wastewater reclamation. In T Asano Ed., *Wastewater Reclamation and Reuse*, Technomic Publishing, Lancaster, PA.

WTCost© Software. I. Moch & Associates, Inc. y el US Bureau of Reclamation, Wilmington, USA.

ANNEX III

KEY INDICATORS FOR FEASIBILITY STUDIES ON WATER REUSE

Table III-A Key social indicators (SI) in water reuse projects (compilation of referenced and AQUAREC's proposed indicators)

<table>
<tr><th>Aspect to be measured</th><th>Indicator(s)</th><th>Unit</th><th colspan="3">Subindicators</th></tr>
<tr><td>Employment</td><td>SI1. Employees in the water treatment plant</td><td colspan="4">N°employees.yr^{-1}</td></tr>
<tr><td rowspan="2">Quality of life</td><td rowspan="2">SI2. Number of acceptable bathing areas accessible per inhabitant</td><td rowspan="2">N° areas/inhabitant</td><td colspan="2" rowspan="2">Inland -Coastal areas compliant with Bathing Water Directive: mandatory values (Vm) and guide values(Vg)[1]</td><td>% areas compliant Vm</td></tr>
<tr><td>% areas compliant Vg</td></tr>
<tr><td rowspan="5">Society awareness on water resources</td><td rowspan="5">SI3. Concern about water as resource and welfare base.</td><td rowspan="5">% Population concerned</td><td colspan="3">% Population aware of water scarcity</td></tr>
<tr><td colspan="3">% Population concerned about tap water quality</td></tr>
<tr><td rowspan="3">% Population "worried" about water pollution (Av)[2]</td><td>Seas - coast</td><td>% Population "worried"</td></tr>
<tr><td>Underground water</td><td>% Population "worried"</td></tr>
<tr><td>River - lake</td><td>% Population "worried"</td></tr>
<tr><td>Public acceptance</td><td>SI4. Social willingness to the use of reclaimed water</td><td colspan="4">% acceptance (opinion poll)</td></tr>
<tr><td>Water supply</td><td>SI5. m^3 of water supply per inhabitant</td><td colspan="4">W= m^3 water.$inhabitant^{-1}$.yr^{-1}</td></tr>
<tr><td rowspan="3">Technology / health risks (failures in the system)</td><td rowspan="2">SI6. Technology failures causing incidences in the water supply and quality</td><td rowspan="2">% Failure:
N° failure hours*100
Total running hours</td><td colspan="2">Water supply interruption (%)</td><td>Σ interruption duration (h) per total running time (h)</td></tr>
<tr><td colspan="2">Water quality decrease (%)</td><td>Σ water quality decrease (h) per total running time (h)</td></tr>
<tr><td>SI7. Health risk in population using reclaimed water</td><td colspan="4">N° infectious cases.yr^{-1}</td></tr>
</table>

[1]European Environmental Agency. Bathing Water Quality: themes.eea.eu.int/Specific_media/water/indicators/WEU11%2C2004.05/index_html
[2]EUROBAROMETER 58.0. The attitudes of Europeans towards the environment

Table III-B Key economical indicators (EI) in water reuse projects (AQUAREC's compilation and proposal)

Aspect to be measured	Indicator(s)	Unit	Subindicators		
Supply savings	EI1. Total saving in water supply treatment and distribution (referred to process costs) per inhabitant and year	C_2-C_1 (EUR.inh^{-1}.yr^{-1}) C_2= costs in current year facing water reuse C_1= costs in previous year, not facing water reuse	Wf	Fresh water consumption.inhabitant^{-1}.yr^{-1}	
			Wr	Reclaimed water consumption.inhabitant^{-1}.yr^{-1}	
			W = Wf + Wr	Total water consumption.inhabitant^{-1}.yr^{-1}	
			C = (Wf*Cf) + (Wr*Cr)	Total water supply cost.inhabitant^{-1}.yr^{-1} Cf = cost of fresh water potabilisation treatment and distribution Cr = cost of reclaimed water treatment (further than WWTP) and distribution	
Process / service savings	EI2. Direct savings from reclaimed water use in main water reuse applications	∆(EUR) = EUR2.Product2-1 - EUR1.Product1-1 2= current year facing water reuse 1= previous year, not facing water reuse	Agriculture	EUR.Kg^{-1} Product (water cost and fertiliser savings, etc.)	
			Green areas	EUR.m^{-2}	
			Tourism/sport areas	∆income (EUR)	
			Energy production	EUR.Kwh^{-1}	
			Other Industry	EUR.Kg^{-1} Product (water cost savings)	
Infrastructure needs	EI3. Water supply infrastructure needs	Forecast for water supply needs: Tf > W*I OK Tf ≤ W*I Tr or ∆Tf Tf+Tr ≤ W*I ∆Tf	W	Water consumption needs per inhabitant per year	
			Population coverage (I)	Inhabitants	
			Plant water supply capacity	Fresh water treatment capacity (potabilisation plant)	Tf = m^3.yr^{-1}
				Reclaimed water treatment capacity (post WWTP)	Tr= m^3.yr^{-1}
Economic development	EI4. Economical increase linked to water resources consumption	IPI per m^3 of fresh water IPI=Industrial Production Index (sectorial and regional values)	Agriculture	IPI per m^3 of fresh water	
			Green areas	IPI per m^3 of fresh water	
			Tourism/sport areas	IPI per m^3 of fresh water	
			Energy production	IPI per m^3 of fresh water	
			Other Industry	IPI per m3 of fresh water	
	EI5. Economic welfare	Per Capita Income per m^3 of fresh water			

Table III-C Key environmental indicators (EVI) in water reuse projects (compilation of referenced and AQUAREC's proposed indicators)

Aspect to be measured			Indicator(s)	Unit	Comments / References
Quality of natural resources	Changes in water composition (physical-chemical)	Fresh surface water	EVI1.Water Quality Index (WQI) Parameters to determine include: Dissolved oxygen, BOD, COD, TN, $N\text{-}NH_3$, TSS, pH, Faecal Coliforms, T, TP, Turbidity…	Excellent: 85-100 Very Good: 75-85 Regular: 65-75 Deficient: 50-65 Bad: 50	The calculation of WQI is based on a formula that refers to different water quality parameters. They can differ amongst authors. www.ecy.wa.gov/pubs/0203052.pdf www.ipcb.state.il.us/Archive/dscgi/ds.py/Get/File-12032
		Groundwater	EVI2. Saline intrusion decrease	$S=\frac{mg\ Cl/l_0 - mg\ Cl/l_t}{mg\ Cl/l_0} * 100$	Aquifer recharge with reclaimed water themes.eea.eu.int/Specific_media/water/indicators
			EVI3. Increase in pesticides	$R=\frac{\Sigma\ (pesticides\ (mg/l))(2)}{\Sigma\ (pesticides\ (mg/l))(1)}$ (1) Refers to previous year and (2) refers to the present year of the analysis	The EEA accounts for the following pesticides in groundwater: Atrazine, Simazin, Lindan, Diuron, Hexachlorobenzene, Isoproturon, Alachlor, Desethylatrazine, Endosulfan, Trifluralin, Chlorfenviphos, Chlorpyriphos and Bentazon. themes.eea.eu.int/Specific_media/water/indicators
			EVI4. Nitrate exceeding legal limits	mg NO_3/l	
			EVI5. Increase of microelements	$R=\frac{\Sigma (As)+(Ca)+(Cr)+(Hg)+(N)+Pb+(Se)+(Sb)+(Fe)+(Ag)+(Mn)+(Al)\ (ppm))(2)}{\Sigma (As)+(Ca)+(Cr)+(Hg)+(N)+Pb+(Se)+(Sb)+(Fe)+(Ag)+(Mn)+(Al)\ (ppm))(1)}$ (1) Refers to previous year and (2) refers to the present year of the analysis	
		Surface gndwate	EVI6. Presence / increase of pathogens	Total/Faecal Coliforms (CFU/100 ml)	
				Streptococcal (CFU/100 ml)	
				Enteroviruses (PFU /l)	

Aspect to be measured		Indicator(s)			Unit	Comments / References
Quality of natural resources	Ecological quality	Surface water	Fresh water	EVI7. Biological Monitoring Working Party (BMWP)	Good >120 (Class I) Acceptable: 101-120 (Class II) Fair: 61-100 (Class III) Bad: 36-60 (Class IV) Very Bad: 16-35 (Class V) Strongly contaminated: <15 (Class VI)	Standard ISO method representative of the organisms' tolerance to pollution. Implies collection of invertebrates from different habitats and river sites. Organisms are identified to family level and scored. lakes.chebucto.org/H-1/tolerance.pdf, www.silsoe.cranfield.ac.uk/iwe/projects/bzp/a7invert.pdf
			Fresh water	EV8. Riparian Habitat Quality Index (QBR)	Undisturbed >95 Some disturbance, good quality 75-90 Considerable disturbance, fair quality 55-70 Large alteration, bad quality 30-50 Extreme degradation, very bad quality <25	It measures the condition of riparian areas along the banks of rivers and streams. The metrics in the Index are: area covered by vegetation, types of vegetation and intensity of human-generated activities. www.epa.gov/maia/html/mah-st4.html, geographyfieldwork.com/riparian%20quality%20QBR%20index.htm, www.diba.es/mediambient/kqbr.pdf
			Sea/Brackish	EV9. Marine Biotic Index (MBI)	Not contaminated: <1,2 (BIi=0,1) Slightly contaminated: 1,2-3,3 (BI=2) Medium contaminated: 3,3-5 (BI=3,4) Strongly contaminated: 5-6 (BI=5,6) Extremely contaminated: >6 (BI=7)	It establishes the ecological quality of soft bottom benthos within European estuarine and coastal environments (Borja, 2000). cozone.org.uk/lymm/2_DJ.ppt, www.euskadi.net/r493352/es/contenidos/informacion/agua/es_7453/calidad_agua_ficha.html
Changes in the composition of soil	Changes in the composition of soil physical-chemical)			EV10. Increase in heavy metals	$R = \frac{\Sigma((As)+(Cd)+(Zn)+(Pb)+(Cr)+(Cu)+(Ni)(mg/l))(2)}{\Sigma((As)+(Cd)+(Zn)+(Pb)+(Cr)+(Cu)+(Ni)(mg/l))(1)}$ (1) Refers to previous year and (2) refers to the present year of the analysis	Based on the EPA 6010 Standard method
				EV11. Increase in micronutrients	$R = \frac{\Sigma((Bo)+(Cl)+(Fe)+(Mn)(ppm))(2)}{\Sigma((Bo)+(Cl)+(Fe)+(Mn)(ppm))(1)}$	
				EV12. Changes in soil infiltration capacity	SAR = Na/((Ca + Mg)/2)1/2 Concentrations in $meq.dm^{-3}$	Assess infiltration problems due to an excess of Na vs Ca and Mg www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/005/Y4263E/y4263e09.htm

Aspect to be measured		Indicator(s)	Unit	Comments / References
Changes in the composition of soil		EV13. Changes in cation exchange capacity	R=CEC (1)/CEC(2) (1) Refers to previous year and (2) refers to the present year of the analysis	Total of exchangeable cations that soil can absorb (CEC) is affected by factors including but not limited to: soil texture, amount of organic matter and kind and amount of clay.
	Ecological quality	EV14. Decrease of macrofauna	Species richness (decrease of number of species) Density of population (number.m^{-2}) Deformities in population (number.m^{-2})	
		EV15. Decrease of microflora	Species richness (decrease of number of species) Density of population (number.m^{-2})	