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**MITIGATION MEASURES TO ADDRESS ADVERSE IMPACTS OF FOUR ALTERNATIVE WATER SUPPLY OPTIONS**

**TASK 2 REPORT**

Author(s): Paul Campling (VITO), Leo De Nocker (VITO), Wim Schiettecatte (VITO), Ayis I. Iacovides (IACO), Thomas Dworak (Ecologic), Eleftheria Kampa (Ecologic), Cornelius Laaser (Ecologic), Rodrigo Vidaurre (Ecologic), Manuel Álvarez Arenas (TAU), César Cuevas Pozo (TAU), Owen Le Mat (ACTeon), Verena Mattheiß (ACTeon), Fabienne Kervarec (ACTeon)

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**EXTENDED SUMMARY**

The objective of Task 2 is to identify the most appropriate mitigation measures that resolve the adverse impacts associated with the four alternative water supply options, and assess their technical and financial feasibility. This is done on the basis of 14 case studies across Europe. They provide an overview a wide range of conditions in which alternative sources were used and mitigation measures were developed and operated.

**Overview of the case studies**

<table>
<thead>
<tr>
<th></th>
<th>Desalination</th>
<th>Waste water re-use</th>
<th>Rain water harvesting</th>
<th>Ground water recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>XX</td>
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<td></td>
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<tr>
<td>Cyprus</td>
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<td>Malta</td>
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<tr>
<td>France</td>
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<td>Germany</td>
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<tr>
<td>Belgium</td>
<td>X</td>
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</tbody>
</table>

We discuss the case studies by water supply option, giving a description of the local conditions, listing the risks and mitigation options, and discussing the lessons to be learnt.

**A review of mitigation measures associated with desalination**

**Case studies**

**Cyprus:** Cyprus, a Mediterranean island at the southernmost part of the EU, currently produces 93,000 m$^3$/d with two RO plants of the larger typical size operating for 7 and 11 years at the coast. The operation of these plants has helped in meeting the growing...
water demand due to tourism and to overcome water shortage due to an extended drought.

**Malta:** Desalination activities at a larger scale take place in Malta since the 1980s, alleviating the constant water scarcity problems on the island. Nowadays, three reverse osmosis seawater desalination plants provide around 50% of the public water supply of the island. In order to reduce its negative impacts efforts to increase energy efficiency have been undertaken. Furthermore, the use sea wells for feed water intake managed to decrease pre-treatment costs.

**Spain:** The AGUA Programme (Actuaciones para la Gestión y la Utilización del Agua – Water Management and Use Action Programme) run by the Spanish Ministry of the Environment and Rural and Marine Affairs (Ministerio de Medio Ambiente y Medio Rural y Marino) includes two lines of intervention: reinforcement of actions to improve water management through water re-use and saving, and implementation of desalination projects to increase available water. The AGUA Programme promotes desalination in coastal towns as a general criterion for ensuring the water quality and availability required to supply the local population.

**Spain:** The AQUASOL project is a unique R&D project (partially funded by the European Commission) that has demonstrated mitigation measures applied to a Multi Effect Distillation plant in Spain include an improved heat pump, an improved solar system and a solar dryer to produce salt from the brine.

The principle risks and negative impacts linked to seawater desalination are grouped into four categories:

- **Environmental risks** – include (i) aquifer contaminations (in the case that a desalination plant is constructed inland and seawater has to be transported through pipes that can have leakages), (ii) marine ecosystem damage due to brine discharge to the sea, (iii) noise pollution and (iv) spoiling the coastal landscape, (v) potential accumulation of boron.

- **Economical risks** – the high investment and recurrent costs, mainly linked to energy requirements. The cost to produce 1 m$^3$ of desalted water is often much more expensive than the direct abstraction of fresh water, ranging from around €0.70/m$^3$ (reverse osmosis) to more than €1/m$^3$ (thermal processes). Investments in an added distribution network arise if the desalination plant is located far from urban areas and the existing main water supply.

- **Social risks** – concerns about the palatability of desalinated water and the effect on household goods are now largely dispelled. The higher costs of desalted water will increase the global water price, which puts lower income households at risk.

- **Global warming risks** - Desalination is probably the option that has the highest green-house gas emissions amounts per m$^3$ of water produced. This is linked to the higher amounts of energy needed to desalt water (between 3.5 and 24 kWh/m$^3$ according to the technology), especially with thermal processes.

The mitigation measures that deal with the adverse impacts of seawater desalination include:

- **Plant location** – ensuring that the desalination plant is located in the most appropriate position so that noise pollution does not effect local residents, that areas of great natural beauty are not spoilt.

- **Discharge of brine** – if brine is discharged at sea the outlet should be positioned so that there is sufficient wave action and sea currents to disperse it. In the Aquasol project a solar dryer is used to produce salt from the brine for selling.

- **Improved efficiency** – in all steps of the desalination process is used to decrease the amount of energy needed and keep recurrent costs low. Improving the heat
Extended Summary

pump (e.g. double-effect absorption pump) reduces both costs and green house gas emissions. GHG impacts per kWh electricity can be further reduced using less CO$_2$-intensive fuels and renewables, which will depend on factors outside water supply management. Linking solar energy with desalination is a specific technology combination for this purpose.

Mitigation measures associated with desalination

Table A provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular.

Table A. Mitigation options identified in each case study concerned with desalination

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Desalination in Southern Spain</td>
</tr>
<tr>
<td></td>
<td>(AGUA and AQUASOL projects)</td>
</tr>
<tr>
<td></td>
<td>Desalination in Cyprus</td>
</tr>
<tr>
<td></td>
<td>Desalination in Malta</td>
</tr>
<tr>
<td>Reducing adverse impact on land use</td>
<td>X</td>
</tr>
<tr>
<td>Reducing adverse impact of brine discharge</td>
<td>X</td>
</tr>
<tr>
<td>Improved efficiency to reduce energy</td>
<td>X</td>
</tr>
<tr>
<td>Leakage control to rivers and aquifers</td>
<td>X</td>
</tr>
<tr>
<td>Use of sea wells for feed water intake</td>
<td>nr</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

nr = not relevant in that area

Discussion

A mitigation option to reducing the adverse impact of desalination plants on land use is used in Spain and Cyprus, but not in Malta. This could be related to the fact that in Malta, the options for locating a desalination plant are so limited that this is not a serious consideration. In Spain and Cyprus special planning permission has to be sought to ensure the location is appropriate, and is not contravening conservation laws for Natura 2000 sites.

There are also mitigation options to reduce the adverse impact of brine discharge in Spain and Cyprus, but not in Malta. In Cyprus a discharge pipe for brine is installed that transfers the brine to a point in the sea where it can easily disperse. In Malta a recent study (World Bank, 2004) indicates that the rapid dispersion at the sea outlet is rapid enough to ensure few environmental impacts. In Spain (Aquasol Project) an experiment is demonstrated to use a solar dryer to produce salt from the brine, which is then sold on the local market.

In all three case study areas there have been considerable efforts to improve (or upgrade) technology which is more efficient and so reduce the energy demand. There are a number of technical options implemented that improve plant efficiency. In some
cases the use of renewable energy sources (such as solar energy) has been investigated. The long term economic costs of using renewable energy instead of fossil fuels are difficult to estimate due to the large fluctuations and uncertainty in fossil fuel prices and the extent to which external environmental costs are recovered in the consumer prices. The estimation of the reduction in GHG emissions is more clear-cut. The European CASES project\(^1\) provides estimates of both internal and external costs of energy production for different energy sources for the period 2005 – 2010. Private costs for electricity from fossil fuels varies from 0.03 to 0.05 €/kWh (for hard coal, lignite and gas). The total costs of electricity from fossil fuels, including environmental damage costs are around 0.06€/kWh. The total costs of renewable electricity varies a lot between technologies. Total costs of electricity from wind or hydro are estimated to vary around 0.06 to 0.11 €/kWh. The total costs of electricity from solar systems are significantly higher, and especially for Photo Voltaic (0.36 €/kWh for PV open space). The costs of solar electricity from “parabolic through” are cheaper (0.12 €/kWh). Although the costs of solar are likely to decrease in the coming decades, they will still be up to an order of magnitude higher than conventional technologies (Reiss, 2008).

The control of leakages to rivers and aquifers is not listed as a mitigation option for the Lanarka case study in Cyprus because the plant is located on an area which is part of a salt lake – therefore this mitigation option is not relevant. Using sea wells for feed water intake is only relevant to Malta because of the specific geology of the area. The limestone substratum means that the sea water is filtered, reducing costs related to pre-treatment, and sea wells can be bored close to the desalination plant.

The general costs of desalination powered by electricity from the electricity grid have fallen in the past 10 to 15 years due to improvements in the energy efficiency of the adopted technology, but the price of electricity has also seen large rises and falls in the last years. In Cyprus the unit cost of desalinated water mixed with conventionally supplied mains water is €1.02/m\(^3\) and households pay €0.77/m\(^3\) (in 2007). In Malta the cost of producing desalinated water is €1.28/m\(^3\), but households pay only €0.38/m\(^3\) for the first 11m\(^3\) consumed (in 2008). In Spain the cost of producing desalinated water is €1/m\(^3\), with farmers charged between €0.3 to 0.4/m\(^3\) (in 2008).

Concern remains about the health impact if boron concentration levels reach too high, and more research is needed in understanding the marine ecology impact of discharging brine into the sea.

\(^{1}\) http://www.feem-project.net/cases/
Review of mitigation measures associated with wastewater re-use for irrigation

Case studies

Germany: In Wolfsburg, irrigation with wastewater takes place in a region of low soil quality index values requiring additional fertilisation to be able to support agricultural production. The Wolfsburg model of wastewater re-use is a case, where appropriate measures have been successfully taken to avoid and mitigate possible environmental and health risks as well as to avoid rejection by the public and farmers.

Malta: only about 10% of all wastewater has undergone treatment until recent times. The treated sewerage has been reused mainly in the agricultural sector, but quality problems in terms of high salinity content originating from saline groundwaters due to sea water intrusion have restricted its utilization. Three new wastewater treatment plants have recently been built and will provide four times as much effluent for re-use as before, making the need to address the quality issues more urgent.

Spain: Campo Dalías is one of the oldest and largest irrigation areas in south east Spain. It is located in Almeria Province and receives the lowest rainfall in Spain. Campo Dalías is characterised by a well developed intensive agriculture, mainly greenhouses (30.000 ha), which have partially exhausted the groundwater, resulting in the salinisation of the aquifers due to seawater intrusion. The local authorities drew up plans for wastewater treatment plants in Campo Dalías with the capacity to supply 320,000 population equivalents to be used for irrigation.

The principle risks and negative impacts linked to wastewater re-use are grouped into four categories:

- **Environmental risks** – include risks i) to human health via the indirect consumption of or exposure to pathogens, heavy metals and harmful organic chemicals contained within it, ii) to groundwater due to heavy metals, increased loads of nitrate and organic matter contained in it in areas where re-use for irrigation is practiced, iii) to the soil due to heavy metals and salt accumulation and acidification, iv) to crops due to the presence of certain substances in the wastewater in such concentration that are toxic, v) to the environment due to high concentration of toxic substances and vi) need to store treated wastewater during the season when irrigation is not practiced.

- **Economical risks** – the need to invest in a new water supply distribution (if used in households or industry) so that there is no mix with potable water.

- **Social risks** – farmers’ acceptance in using wastewater for irrigation, the training in such use and control, and the public acceptance of such practice.

- **Global warming risks** – are not great because in general wastewater use has to be treated in any case.

Major environmental benefits identified from the wastewater re-use include: i) conservation of freshwater sources, ii) recharge of aquifers through infiltration water (natural treatment), iii) use of the nutrients of the wastewater (e.g. nitrogen and phosphate) resulting to the reduction of the use of synthetic fertilizer and, to the improvement of soil properties (soil fertility; higher yields), iv) reduction of treatment costs: through the Soil Aquifer Treatment (SAT) of the pre-treated wastewater via irrigation, and v) reduction of environmental impacts (e.g. eutrophication and minimum effluent discharge requirements) from direct discharge.
The mitigation measures that deal with the adverse impacts of wastewater re-use include:

- **Legal standards** – to ensure that agricultural use of wastewater meet soil, crop and ground water protection and hygiene objectives (also adherence to Codes of Good Agricultural Practices).

- **Public and user awareness and acceptance** – awareness campaigns and training to improve the acceptance of waste water re-use for agriculture and promote best practices

In the future, when there is a better understanding of the impacts of endocrine disruptive and pharmaceutical substances, additional mitigation measures might be needed to limit these type of substances from wastewater intended for re-use.

**Costs of mitigation measures**
Some figures on costs of mitigation measures are given for the Wolfsburg case of wastewater reuse (costs for monitoring and public relations programme costs).

**Economical risks:**
In the Wolfsburg case of wastewater re-use, the costs of irrigation with waste water almost correspond to the costs that would be incurred if groundwater were to be used for irrigation instead (unfortunately no quantitative figures available). Costs of waste water irrigation even tend to be lower than for groundwater irrigation, because the pumping effort needed is lower.

**Environmental benefits:**
Through the re-use of waste water on agricultural land, it is avoided to discharge treated waste water directly into the natural water environment of the area.

**Discussion**
Table B provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular.

**Table B. Mitigation options identified in each case study concerned with wastewater re-use**

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Wastewater re-use in Campo Dalias (Southern Spain)</th>
<th>Wastewater re-use in Malta</th>
<th>Wastewater re-use in Pornic Golf course, France</th>
<th>Wastewater re-use in Cyprus</th>
<th>Wastewater re-use in Lower Saxony, Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal standards</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Public and user awareness</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Treatment improvements</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved efficiency</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Financial incentives</td>
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<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
In each case study there are legal standards and monitoring to ensure that treated wastewater in irrigation water meets several parameters and standards to protect soil, crops, groundwater and hygiene. There is not a European Directive specifying the standards for treated wastewater in irrigation – so each case study follows either national (Cyprus, Malta, Germany, Spain) or local laws (France). In addition in all case studies there have been public awareness campaigns to highlight the benefits of using treated wastewater in irrigation (not only to users, but also the general public), but also to make people aware of some of the public health risks. In this regard there are local laws to restrict public access to irrigation areas or recommendations to irrigate only at night. In some cases improved treatment techniques are introduced to either deal with a certain local problem (such as high salinity in Campo Dalias and Malta) or to test out a cheaper alternative techniques (such as in Pornic). To encourage farmers to use wastewater re-use in their irrigation systems (rather than conventional water supply) financial incentives have been introduced. In Cyprus the unit cost of producing waste water for irrigation is €0.146/m$^3$, whereas the tariffs that farmers pay is €0.068/m$^3$ (in 2007).

**A review of mitigation measures associated with rainwater harvesting**

**Case studies**

**Malta:** On the Maltese islands, the use of rainwater harvesting cisterns is established in law. Nevertheless, this regulation is hardly complied with. The main reasons are high investment costs for building new cisterns. Potential mitigation measures to reduce negative social impacts include therefore financial aids for the construction of rainwater harvesting cisterns as well as an educational campaign.

**Flanders:** The case study focuses on recent initiatives in the Flanders region of Belgium to promote the use of RWHS for households. The cornerstone is the obligation for all new houses and major renovations to install a dual water supply system linked with RWH tanks of minimum size. The case study deals with issues related to water quality and health impacts, enforcement of requirements and socio-economic considerations.

The principle risks and negative impacts linked to rainwater harvesting are grouped into four categories:

- **Environmental risks** – include risks to human health resulting from inappropriate management and maintenance practices of the harvesting systems. The quality of domestically collected rainwater is depending on the management of the roof as well as on the cleaning of the storage facilities.

- **Economical risks** – high investment costs for installing reservoirs and including an additional water distribution system.

- **Social risks** – high investment costs may mean that this technology is not a feasible option for lower income households or tenants.

- **Global warming risks** – this technology does not pose an additional risk to global warming – but its performance relies on the rainfall amount and distribution, which is related to climate change.

The mitigation measures that deal with the adverse impacts of rainwater harvesting include:

- **Legal standards** – to ensure that there are no dangers of rainwater harvesting water contaminating mains water.

- **Financial aids or tax breaks** – to provide incentives to invest in the technology.

**Discussion**
Table C provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular.

Table C. Mitigation options identified in each case study concerned with rainwater harvesting

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainwater harvesting in Belgium</td>
</tr>
<tr>
<td>Financial incentives</td>
<td>X</td>
</tr>
<tr>
<td>Education campaign</td>
<td>X</td>
</tr>
<tr>
<td>Regulations and standards</td>
<td>X</td>
</tr>
</tbody>
</table>

The quality of RW harvested and stored following good practise is good enough for non-potable uses, but surveys show that people may also use RW for personal hygiene and drinking water. In both countries, the focus of regulation and information is to encourage the use of RW for non-potable uses, both outside and inside the house.

In Belgium and Malta there are regulations and standards in place to ensure that rainwater harvesting systems are of good standard and that the mains water supply is not contaminated. In Malta rainwater harvesting is a very old technology that has been neglected in favour more modern options such as desalination. Therefore there is a potential to bring in financial incentives and an education campaign to support the technology in Malta. In the Flanders regions of Belgium rainwater harvesting is actively being promoted – not just to conserve mains water supply, but also to reduce urban storm runoff events. A regulation requires that all new houses constructed or renovated have to include a rainwater harvesting tank with a dual water distribution system so that toilets are flushed using rainwater instead of mains water. This regulation is enforced in two stages and is linked with building permits and control of mains water installations. The latter also ensures that RW cannot be used for uses where drinking water quality is required.

The case studies confirm that the costs of RWH are relatively high per m³ RW used, but the general costs of rainwater harvesting are quite different between Malta and Belgium. In Belgium a RWHS for private households requires a large investment and the price amounts to €1.8 to 4/m³ of RW used. The regulation specifies minimum requirements that aim at a cost-efficient introduction of RW. On the other hand, the savings amount to €1.7/m³ for avoided use of mains water. As with current regulations, the costs for sewage and sewage treatment are recovered on the basis of m³ of mains water used, the RW user benefits from an additional €2/m³ for avoided costs for sewage and sewage treatment. Little is known about the real impact of scenarios of more substantial RW use on the long term costs of mains water, sewage, storm water and sewage treatment.

In Malta the estimated cost of a rainwater harvesting system ranges between €5 to 11/m³ depending on the construction costs. This difference is mainly due to larger size of water supply tank required in Malta, which is in most cases constructed rather than pre-fabricated. The larger tank size needed is due to less and more unevenly distributed rainfall.

In Belgium, there is also a subsidy grant in place for households to retrofit a rainwater harvesting system, but its contribution to the penetration of RWH is very limited compared to the impact of regulation for new buildings. In Berlin, there is a storm water fee of € 1.7/m² of sealed surface (in 2008), and households that harvest and
store RW are exempted from this fee, which gives a large financial incentive for the promotion of RWHS, in addition to providing savings for main water.

**A review of mitigation measures associated with ground water recharge**

**Case studies**

**Germany:** The city of Berlin is considered a water scarce area where natural groundwater recharge is not high enough to make it the sole sustainable water supply source. Moreover, many contaminated sites in the urban area of Berlin make the use of natural groundwater a risky business. Therefore, Berlin turned to bank filtration a long time ago enhancing available water resources and making use of the natural cleaning process of the sub-soil passage. From the viewpoint of energy consumption, bank filtration in Berlin can be regarded a very low-energy drinking water production technology.

**Malta:** Artificial groundwater recharge finds so far only limited application in Malta. Dams constructed throughout the valleys are primarily used for supplying water to agriculture. A Storm Water Master Plan is currently under discussion and will – besides mitigating flood risks – consider the recharge of aquifers. Also the potential to use treated sewage effluent for groundwater recharge is discussed. Quality problems of the effluent will have to be addressed.

**Flanders:** In the Toreele project in the coastal region of SW Belgium, cleaned sewage waste water from the UWWT plant receives additional treatment and is then used as infiltration water for recharging groundwater that has been overexploited.

The principle risks and negative impacts linked to ground water recharge are grouped into four categories:

- **Environmental risks** – include risks to human health resulting from the introduction of pathogens or trace amounts of toxic chemicals into the groundwater, that is eventually to be consumed by the public. Extreme caution is warranted because of the difficulty in restoring a groundwater basin once it has been contaminated.

- **Economical risks** – where waste water is directly infiltrated high investment costs are needed to treat municipal wastewater to prevent the contamination of the groundwater.

- **Social risk** – there is a potential social barrier that people feel uncomfortable drinking water that –although rigidly purified- originates from municipal wastewater.

- **Global warming risks** – neither groundwater recharge via bank filtration nor via infiltration pose an additional risk to global warming – although treating municipal wastewater for direct infiltration is energy consuming. On the other hand, groundwater recharge via bank filtration relies on natural processes that need low energy. It therefore can even be considered as a mitigation measure for climate change.

The mitigation measures that deal with the adverse impacts of ground water recharge include:

- **Tertiary treatment** – such as a multiple barrier treatment process is the best approach to avoid environmental and health impacts of ground water recharge.

- **Treatment side streams** – where contaminants are all ‘concentrated’ in a small side stream of the process for later direct infiltration of the treated waste water.
• **Ensure minimum transition time** – sitting the extraction well at a distance to the river bank or infiltration site that ensures a minimum transition time of the water through the sub-soil passage and by this allowing all natural cleaning processes to take full effect.

• **Monitoring systems** – help to detect water and soil quality in time to take counter measures like post-treatment or altering abstraction schemes.

• **Minimising pollution from other sites** – ensuring a high quality where surface water is taken as source water. This can be achieved by establishing a good waste water treatment and minimising pollution input from further diffuse and point sources.

**Discussion**

Table D provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular. In Malta the intention is to only use harvested rainfall as input for recharging aquifers – so the mitigation options related to the Belgian coast and the Berlin case studies are not relevant.

Table D. Mitigation options identified in each case study concerned with ground water recharge

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground water recharge at Belgian coast</td>
</tr>
<tr>
<td>Tertiary treatment</td>
<td>X</td>
</tr>
<tr>
<td>Intensive process control</td>
<td>X</td>
</tr>
<tr>
<td>Treatment of side streams</td>
<td>X</td>
</tr>
</tbody>
</table>

The main concern in groundwater recharge is to ensure that there is no pollution of the aquifer. There are differences in the recharging process used in the Belgian coast and Berlin case studies. The Belgian coast case study uses treated waste water directly from the UWWT plant for recharging, whereas in Berlin use is made of surface waters from rivers to recharge aquifers using bank infiltration. Therefore the source of the water used for recharging is of differing quality. However in both case tertiary treatment has to take place and there is a need to monitor and control the system continuously. In the case of the Belgian coast case study an additional concern is the treatment of side streams out of the UWWT – which is bi-product of the technology.

The general costs of supplying drinking water in Berlin is 1.04 €/m³ (although consumers pay close to 2 €/m³) (in 2008). In the Belgian case study cost of producing water from ground water recharge is estimated to be 0.5 €/m³, which is cheaper than transferred water from outside the region (0.77 €/m³) (in 2007).
Conclusions

Overall, the case studies confirm the conclusions from the Task 1 report, that the four alternative water supply options are proven, reliable technologies. One still needs to take into account that the use of the produced water may not be suited for uses that require drinking water quality. The case studies also confirm that the list of environmental, economic and social issues identified in Task 1 Report covers the mains issues.

The case studies indicate that the mitigation measures used were successful to address potential and locally specific environmental concerns. Potential problems and mitigation options differ between locations and technologies – meaning that mitigation measures have to be designed to deal with local conditions. The case studies therefore do not provide a single set of best available mitigation options or recommendations for good practice, but rather provide check-lists of potential problems and a catalogue of potential mitigation options, with illustrations about successful applications.

The mitigation options are very diverse. They include case specific choice of location and ex-ante procedures (e.g. environmental impact studies) to define the framework and conditions for the water supply to operate. The following issues need to be addressed:

- Potential land-use and noise impacts from desalination and wastewater treatment plants;
- Impact of brine discharge on coastal and marine ecosystems;
- Contamination of soil and groundwater from treated wastewater which is reused.
- The added investment in distribution networks to transfer treated waste water from UWWT plants to agricultural land for irrigation, desalinated water from desalination plants to the mains water supply, harvested rainwater to toilets and washing machines (dual household distribution system).

This last issue needs extensive monitoring and control. One point of note is that there is still no EU wide directive on the use of treated wastewater for irrigation.

Mitigation measures to avoid public health impacts from misuse of rain water or treated waste water not intended for potable use include the setting up of national or local standards for water to be used or for equipment and installation procedures, defining guidance for good practise, labelling of tap points, information and education,... The case studies give examples of implementing monitoring or control, also in cases where many users are involved.

Compared to conventional water supply sources, some alternative water supply options require more energy (desalination) or more materials for equipment (rainwater harvesting) per m³ of water. This leads not only to higher costs, but also a higher burden on the environment. These issues are difficult to solve in the context of water supply decisions, and therefore need to be addressed in a wider environmental framework.

As desalination requires more energy compared to other conventional water supply sources, it will result in a higher carbon footprint, if it uses energy from fossil fuels directly or electricity from the mains grid generated by fossil fuel power stations. Although the designated use of renewables, such as solar or wind energy, may reduce the carbon footprint of desalination this problem, the current total costs of renewable energy per kWH are significantly higher. During 2008 the market price of crude oil peaked at 147 USD per barrel in July and then fell to 40 USD per barrel by December. Comparisons therefore between the short and long term economic costs of renewables and fossil fuels remain uncertain. It should also be remembered that desalination plants
need a steady supply of energy to function optimally - this means that renewable energy supplies from wind and solar, which fluctuate depending on wind and solar conditions, and therefore need to be backed up by the mains electricity grid (or a fossil fuel powered generator). An alternative set up is to power the desalination plant continuously from the mains electricity grid, that is powered partially by renewables connected by a "smart" grid. Therefore, the costs of renewables and the need for a steady energy supply have to be considered.

Rainwater harvesting systems require a relatively large investment in rainwater tanks, which is not only reflected in being an economic obstacle, but also in the relatively high environmental life cycle impacts embedded in material and energy use. There are no mitigation options to deal with this apart from guidelines to promote an optimal sizing of RW tanks.

Alternative water supply options may be more expensive then more conventional options, especially if water prices do not recover all private and environmental costs. The case studies illustrate that in these cases the promotion of alternative water supply options are likely to use subsidies to compensate for price differences. However, these may in the long term not be the best way to deal with this situation, as it does not promote overall efficiency of water use. Therefore, it is recommended that promotion of more expensive alternative water supply options is accompanied by a revision of water pricing towards a full recovery of all private and environmental costs.

Higher water prices give rise to concerns about the affordability of mains water for the low income groups. Furthermore, higher water prices also raise concerns about the affordability for agriculture and industries that have been used to having access to cheap, high quality water. Although subsidies can help these users in the transition towards a more sustainable use of water resources, the final goal should be to have sustainable water use where price of water reflects its true cost, efficiencies are improved, and water demand reduced.

The case studies illustrate that the mitigation measures addressed have allowed alternative water supply options to be established. However, as the knowledge and experience on a number of issues is limited, further research on potential impacts and mitigation options are required. This is the case for:

- Discharge of brine into marine and coastal ecosystems;
- Accumulation of boron from desalinated water in the water system and ecosystems;
- Contamination of soil and groundwater from treated wastewater;
- Scopes to improve energy efficiency of desalination;
- Scope for more cost-efficient use of rainwater harvesting systems, including upgrading of existing tanks and use in collective systems;
- Net costs of rainwater harvesting systems, accounting for short- and long term impacts on investments for mains water supply and distribution, sewage and sewage treatment and storm water management;
- Risks for human health of dual water supply systems and re-use of treated wastewater for irrigation;
- Capability of mitigation options to adapt to climate change scenarios

The potential for the further establishment of these alternative supply options will depend on local conditions including the specificities of the water supply problems to be addressed, water resources at hand, the economic costs of the alternatives and capacity to pay for specified uses. In the Task 3 Report, the potential of alternative water supply options to solve real world water supply problems is evaluated.
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1.1 Objectives of the Report

In 2008 DG Environment of the European Commission launched a new project “Assessment of alternative water supply options” to assess four alternative water supply options in Europe, with the specific objectives to:

- **Task 1** - assess the risks and impacts of four alternative water supply options (desalination, wastewater re-use, gound water recharge, and rainwater harvesting);
- **Task 2** - assess the extent to which the possible negative effects from these water supply options in terms of environment and human health can be mitigated; and,
- **Task 3** - identify conditions for the sustainable development of alternative supply options.

This report meets the objective of Task 2 to identify the most appropriate mitigation measures that resolve the adverse impacts associated with the four alternative water supply options, and assess their technical and financial feasibility. This is done on the basis of 14 case studies across Europe.

1.2 Structure of the Report

The Report starts with an Introduction to outline the objectives of this part of the study, our approach and an overview of the identified case studies. The subsequent chapters deal with the mitigation measures for each alternative water supply option on the basis of case studies. For each case study we provide:

- An introduction to the water supply issues and the relevant mitigation measures;
- A detailed description of the most important mitigation measures and their technical and financial feasibility;
- A review of case study achievements and the need for future mitigation measures; and,
- A summary of the most important issues.

On the basis of this information we discuss the major differences between the mitigation measures presented and how this might influence decisions on whether to adopt alternative water supply options rather than conventional water transfer options. Finally we draw up the most important conclusions.

1.3 Approach to evaluating mitigation measures

There are three kinds of mitigation options that can be considered to tackle the adverse impacts of a particular water supply option:

1. Technical measures – to, for example, ensure good water quality by using an advanced water treatment technique;
2. Control or regulatory measures – to, for example, limit or restrict the scope of the alternative water supply source (regulation related to the water sources used and to the use of the end product, control,..); and,
3. Accompanying and compensation measures – to, for example, inspect installations and encourage the take up of a technology with subsidies or tax breaks.

The in-depth analysis of the technology alternatives and the associated mitigation measures are carried out on the basis of the case studies. The analysis includes technological (best available techniques), economic (affordability and financial capacity) and environmental impact analyses. Social impacts are addressed in terms of people’s attitude towards the use of alternative water supply for different uses and issues of equity or access to water (both for drinking and agriculture).

To this purpose, the study uses different types of information:
- In most cases, the choice of technologies and mitigation measures is by the characteristics (quality) of the water source and the type of envisaged water supply (e.g. for irrigation or human consumption). Especially for potential health impacts mitigation measures are discussed in the context of technology choice and legal requirements to meet the standards for different types of water uses.
- Mitigation measures to address more local environmental impacts are discussed in both technical studies and in environmental impact assessments.
- Consideration for the impact on energy use and GHG emissions are discussed as these have implications for affordability and for climate change.

1.4 Overview of case studies

We have selected 14 case studies in northern and southern Europe to evaluate the mitigation measures associated with desalination, wastewater re-use, gound water recharge, and rainwater harvesting (Table 1).

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<th>Case Study</th>
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*Table 1 Selected Case studies per alternative water supply technology to evaluate associated mitigation measures*
2.1 Mitigation measures associated with desalination: case study Lanarka area, Cyprus

2.1.1 Introduction

The focus of this brief presentation report is on identifying and assessing the most appropriate mitigation measures employed to address the most important adverse impacts caused directly or indirectly by Cyprus’ alternative water supply option of sea water desalination. Cyprus, having explored and practising sea water desalination for domestic purposes for more than 10 years, provides an excellent, tangible and appropriate case study of such and alternative water supply option, the desalination plant in the Lanaka area. An assessment of the measures practised to mitigate adverse environmental, economic and social impacts in terms of technical feasibility, costs and compatibility is provided.

Cyprus, an island with a semi-arid climate and with its water resources already intensely utilized, is suffering from structural and temporary water shortages. With a high level of utilization of its natural water resources, water demand increasing rapidly and water availability decreasing due to repeated droughts, the Government of Cyprus decided to construct a number of desalination plants. The capacity of these plants is currently at 90000 m³/d or 33 million m³/year with the objective to increase water availability and the level of reliability for domestic water supply systems (plans for a desalination capacity of up to 170,000 m³/year in the next 5 years). During the last fifteen years the available water from the Government projects and from other sources was very limited which led to supply cuts up to 30% of normal demand in the domestic sector and up to 70% of the normal demand in the agricultural sector. These had serious adverse effects on the social and economic activities and a negative impact on the environment. This summer (2008) Cyprus had for the first time to import by tankers 8 million cubic meters of water from Greece at a cost of about 5 €/m³ to meet deficits in the domestic supply of certain areas which could not have been met otherwise.

The first desalination plant was put into operation on April 1997, with a nominal daily output of 40,000 m³, whilst the second desalination plant with a nominal daily output of 51,667 m³ started operating in May 2001. The capacity of these plants is currently at 90000 m³/d or 33 million m³/year with the objective to increase water availability and the level of reliability for domestic water supply systems. Currently, there are plans that suggest an increase of Cyprus desalination capacity to 170,000 m³/year in the next 5 years.

Both existing plants use the reverse osmosis (RO) desalination technology with a product water recovery of 50% while they are powered with energy from the national electric power grid. Both use an open sea intake and the water is undergoing a pre-
treatment for reducing the Silt Density Index and the pH for the protection of the membranes. The desalinated water is post-treated for achieving an acceptable quality complying with the Cyprus and European drinking water quality standards. The Built, Own, Operate and Transfer principle (BOOT) was chosen as the method of project financing on a ten-year basis. Brine is discharged to the sea at a depth of at least 15 m and at a distance of at least one km from the shore. The marine environment around the brine disposal point is monitored, on a continuous basis.

2.1.1.1 Main adverse impacts of desalination identified in Task 1

The most important environmental impacts of desalination plants identified as per the report under Task 1 of this project in no particular order are: i) adverse effect on land use, ii) impact on the local aquifer, iii) impact on the marine environment due to the discharge of the brine to the sea and the installation of the feed and discharge pipes, iv) effect on local marine habitats due to the sea water intake construction and operation, v) noise impacts due to the use of high-pressure pumps and turbines, vi) intensive use of energy which indirectly affects the environment (global warming) through the increased release of greenhouse gas emissions (GHG), vii) other minor impacts due to water treatment and plant maintenance activities.

Other impacts may involve: a) health and safety issues from burn fuels from any on site power generators – especially with high sulphate content petrol, b) storage of fuel on site, c) traffic access for transporting of construction and operation materials and, d) future construction of pillars for power lines for provision of electric power.

Other issues with adverse impacts are: i) the high boron in desalinated water which imparts problems in the re-use of the treated wastewater for the irrigation of certain crops (such as citrus, apricot, cherry and apple trees), ii) increased cost of water supply to households, industry and tourism, although freeing them from the vagaries of weather, and iii) increased environmental cost that should be reflected in the final water price as specifically indicated by the Water Framework Directive.

Boron in water supply is normally less than 0.5 mg/l. Boron is known to cause reproductive and developmental toxicity in animals and irritation of the digestive tract. It also accumulates in plants, raising concern about high boron levels in water used for irrigation or landscaping. The World Health Organization (WHO) designates a provisional guideline value of 0.5 mg/litre for drinking water. The Food and Agricultural Organization (FAO) guidelines for boron concentration in water used for agricultural irrigation indicate that no problem will exist for plants at concentrations less than 0.75 mg/l. However increasing problems occur between 0.75 and 2.0 mg/l and severe problems result in concentrations above 2.0 mg/l.

The problem with boron in desalination is due to the fact that seawater has an average boron concentration of 4.5 mg/l. RO membranes can remove between 50% and 70% of this element but pass the rest, where it is then concentrated in the product water. Some membranes and processes are being developed to improve boron removal but additional energy is required for removing Boron to levels below 1 mg/l.

Concern has therefore been expressed that boron may be found in desalinated water at levels greater than the WHO provisional guideline of 0.5 mg/l. Additionally, and bearing in mind that wastewater from domestic supplies relying on desalination, receives an increased amount of boron from household detergents and that wastewater treatment plants are not effective in removing boron in their treatment processes unless some form of tertiary treatment such as chemical precipitation is carried out, the desalinated water needs to be low in boron accordingly, if it is to be reused for irrigation.

The main social risks and impacts are: i) the heavy investment required and price of water for households and tourism, ii) environmental concerns, global and site specific, regarding the location of new plants, and iii) palatability and effect of the desalinated water on the hydraulic systems.
The key issues that still need to be resolved are the high energy requirements to desalinate sea water and the accompanying increased CO\textsubscript{2} emissions, the inflexibility of the system to account for changes in demand and the risks of occasional, temporary, desalination plant failure.

2.1.1.2 Importance of case study

In Europe, several countries have turned to desalination technologies, especially in the southern more water scarce areas. The desalination capacities are concentrated around the Mediterranean Sea mainly on coastal regions or on islands where desalination is used to overcome water shortage in regions with limited water resources that suffer from intense water demand from tourism and agriculture. Furthermore, in Europe almost all recently installed desalination plants use the Reverse Osmosis (RO) technology. Most of the largest plants are in the range of 40,000 m\textsuperscript{3}/day with “Carboneras 1” being the largest at 120,000 m\textsuperscript{3}/day.

Cyprus, a Mediterranean island at the southernmost part of the EU, currently produces 93,000 m\textsuperscript{3}/d with two RO plants of the larger typical size operating for 7 and 11 years at the coast. The operation of these plants has helped in meeting the growing water demand due to tourism and to overcome water shortage due to an extended drought. This makes the Cyprus case study as very representative and should provide useful and interesting information to the EU.

2.1.1.3 Issues to be discussed in more detail

Issues and measures that are discussed refer to i) the suitability of the location of the Plant, ii) the protection of the marine environment due to the discharge of brine measures, iii) on the use of energy, and iv) on the quality of desalinated water.

2.1.1.4 Structure of the section and links to the report

This chapter introduces the case study providing information on its location, the water supply problems it is solving, describes in brief the impacts and the mitigation measures taken and then discusses in some further detail some of the most important mitigation measures drawing material from the Task 1 report on Desalination. Finally, in a summary form the specificities of the case study are outlined together with how the various problems and concerns were addressed or remaining to be addressed. The chapter ends with a summary of the lessons and implications for a further use of the technology throughout the EU.

2.1.2 Introduction to the Lanarka area case study

2.1.2.1 Information on the location, water supply problems and history

The prolonged drought in the 1990s in Cyprus resulted to reduced reserves of water in the dams built at the best sites of the island. This led to the construction of seawater desalination plants aiming at the freeing of the domestic water supply of the major urban centres and tourist establishments from the annual rainfall. Initially the Dhekelia Plant was put in operation in April 1997 at a 40000 cubic meter daily capacity meeting the demand of the “free” Famagusta area and part of the needs of Larnaka and Nicosia. This was followed by the Larnaka Desalination Plant, on May 2001, at an installed 54000 cubic meters daily capacity (total annual production of both plants being at the
minimum 30 to maximum 33 million cubic meters) aiming to the definitive resolution of the domestic demand (44 million cubic meters per year) of the Nicosia, Larnaka and Famagusta Districts. In fact some 75% of this domestic supply requirement is met by desalinated seawater.

The case study is built around the Larnaka Desalination Plant but experiences and problems gained from the Dhekelia Plant are also mentioned. Table 2 presents the contractual production capacities of the two plants.

The Larnaca Seawater Desalination Plant (a 10 year Built Operate Own Transfer (BOOT)) consists of: i) A seawater feed from a 1000m pipeline from the sea, ii) a fully automated desalination plant consisting of six units, 120 pressure vessels (PV) each, 8 membranes per PV, iii) an installed capacity of 54,000 m$^3$/d with product water conforming to WHO and EU drinking standards, iv) a recovery of 50%, (total energy consumption ≤ 4.52 kW h/m$^3$), v) product delivery to Tersefanou Treatment Plant facilities 12 km away at 90 m elevation, and vi) a distribution to households, offices, industry and hotels.

<table>
<thead>
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<td>Capacity (m$^3$/d)</td>
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<td>52 000</td>
</tr>
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<td>Minimum daily (m$^3$)</td>
<td>36 000</td>
<td>46 500</td>
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<tr>
<td>Minimum tri-monthly (m$^3$)</td>
<td>3 285 000</td>
<td>4 243 125</td>
</tr>
<tr>
<td>Minimum annual (m$^3$)</td>
<td>13 140 000</td>
<td>16 972 500</td>
</tr>
<tr>
<td>Unit price* of water €/m$^3$</td>
<td>0.92</td>
<td>0.68</td>
</tr>
</tbody>
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*The unit price of the renovated Dhekelia Plant after contract renegotiation on 20 May 2007 is 0.64 €/m$^3$

Table 2: Production capacities of the Cyprus Desalination Plants as per the contracts.

There are five main process stages of the plant as shown in Figure 1. A detailed schematic presentation with photographs of each process stage of the Larnaka Desalination Plant and a flowchart of them are presented as Annex I and II.

![Figure 1: Larnaca desalination process stages (E. Koutsakos et al. 2007)](image)

The Plant is at a distance of 800 m from the shoreline. In the case of the Larnaca Desalination Plant groundwater is saline with the area being part of a Salt Lake.
2.1.2.2 Context in terms of water supply issues in the EU

The built up and growing population along the coastal areas of the Mediterranean as well as the seasonal flux of tourists create a large demand for water supply. In deciding for new water supply options, more traditional supply technologies such as groundwater extraction, the intake and storage of fresh surface water and water transport over long distances may still be favoured. Today, water supply in the EU is mainly based on these traditional supply options, but in some regions, or sectors desalination as an alternative supply option has become an important source. Several countries in the EU including Spain, Italy, Malta and Cyprus have built desalination plants and more regions are considering it as a supply option.

The water scarcity has become a serious obstacle in the economic development of Cyprus which is experiencing drought conditions since 1990 with average rainfall having been reduced by as much as 15% and runoff to the surface reservoirs by as much as 40% compared to the long term average. Furthermore, all the attractive and economic sites for surface reservoirs have already been developed and groundwater is over-pumped with sea intrusion occurring in all coastal aquifers. Desalination of seawater by Reverse Osmosis through the Built Own Operate Transfer (BOOT) financial arrangement practiced in Cyprus for the last 11 years resolved to a very large extent the domestic water supply problem. The Larnaca Desalination Plant presented in this case study is currently within the 10 largest seawater RO plants in Europe.

2.1.2.3 Mitigation measures and problems addressed

A) Suitable location of the Plant:
- **Adverse effect on land use**: The Plant is located on State land where the International Airport is located and not far from the Larnaka Sewage Treatment Plant. The Plant is away from any tourist development and far from any other land development. Being State land no private development is foreseen for the area.
- **Impact on the aquifer**: The Plant is located on an area which is part of a Salt Lake. No groundwater exists in the immediate vicinity. Feed water is obtained directly from the sea.
- **Noise Impact**: The Plant is located far away from populated areas. Appropriate technologies for lowering noise intensities have been used but still there is some high noise level within the Plant.
- **Social concerns on environmental grounds and strong lobby of activists against desalination**: This resulted in difficulties in the location of plants and even abandoning some locations. On going water scarcity helped suppression of these.

B) Protection of the marine environment:
- **Impact on the marine environment due to discharge of brine**: The impacts are continuously being monitored by the Department of Fisheries and Marine Research. According to this Department the impact on the marine environment is of very limited extent. For the Dhekelia Plant the effect of the brine discharge on the marine biodiversity is noted in an area around the discharge point up to 100 m from the discharge point. For the Larnaka Plant the effect of the brine is even further confined due to improved dispersion of the brine and the more intensive wave action and currents in the area. Discharge point at 15 m depth of sea water at 1300 m from coast.

C) Measures on the use of energy:
- **Use of Energy**: An operational strategy for the Plant was implemented aiming to efficient plant operation, maximizing plant performance in the long term. This strategy included i) Optimization of process, ii) Review and standardize
operational procedures, iii) Operate a stable plant, maintaining plant efficiency and performance, and iv) Introduce innovations based on plant operational experience and new technology developments. The reported results show a steady drop of average annual energy consumption from 4.66 kWh/m$^3$ in 2002 to 4.48 in 2003 to 4.44 in 2005 and 4.42 kWh/m$^3$ in 2006 (5.1% drop). It should be noted that the contractual agreement for the 10 year period refers to 4.52 kWh.m$^3$ and if exceeded the Contractor bears the extra cost. This produced sustained plant performance which exceeded the minimum contractual criteria both in energy and water quantity while at the same time meeting all the water quality requirements. The good plant performance is supported by systems in place relating for example to membrane replacements, plant operation and maintenance planning which resulted in 97.7% plant availability operating in full capacity in 2006. The main optimized units of individual process stages are shown in Annex III.

D) Measures on the quality of desalinated water:
- **Boron:** The issue of the Boron is worldwide and is affected by sea water temperature and other process parameters. Both the Contractor and client maintain a well equipped Laboratory. Client is responsible for monitoring among other elements the Boron of the desalinated water. Analyses are done 4 times daily during winter to 12 times daily during summer. In summer warm sea water temperatures (>22 °C) have an effect on the quality of desalinated water produced. Problems existed with Boron at the initial commissioning of the Plant (summer period). The Contractor invested in the continuous monitoring of Boron (normally it requires at least 2 hours for analytical results) and through implementation of own Membrane System Management, adjustment on process parameters such as pH, process pressure, effective use of 2nd stage for boron removal has managed the solution of the problem. Boron ions rejection by RO membranes increases with increasing feed water pH. However, seawater desalination by the RO method is not practical at pH>9 due to the crystallization of CaCO$_3$ and Mg(OH)$_2$ salts on the RO membranes (fouling).
- **Corrosive water:** Corrosiveness of the desalinated water especially in areas where the distribution system consisted of metal/iron pipelines was resolved by increasing the pH range from 7.0 -8.0 (contract specification) to 6.5 -9.5 (EU recommendation). This was done by readjusting lime and carbon dioxide. By the increase of pH to values more than 8.5 the Langelier Index increased to 0.0–0.5 and the iron content in the water were decreased. For further increase of the hardness of the desalinated water, magnesium sulphate is added at the post-treatment stage in addition to the lime and carbon dioxide. Using corrosion inhibitors may protect distribution system.
- **Social concerns on palatability and its effect on household plumbing:** Quality control of desalinated water and production/use in early years helped for these concerns to subside.

E) Minor impacts:
- **Minor impacts: i) -Rupture of GRP pipes:** Occasional problems of rupturing of the Glass Reinforced Plastic (GRP) pipes leading to interruption until pipes were fixed, ii) - **Power interruptions:** Power generation failures in combination with the safety systems of the Plant led to interruption of production. Increased capacity has helped reduction of problem,

A listing of Risks and Impacts of sea water Desalination and Mitigation Measures/Options and the extent of resolving them in terms of "not-at-all, partial, complete" is shown in Annex IV.
2.1.2.4 Other important issues

The issue of desalination has through the years drawn heated discussions and strong opposition by environmental activists supported by communities not wanting the desalination plant “in their back-yard”. This had the result of changing the planned site of Plants or even abandoning completely some plans. The arguments against desalination plants have seriously subsided currently in view of the water scarcity facing the island this year and the fact that the Government had to resort to an immediate measure of transporting 8 million cubic meters of water from Greece by tankers at an approximate price of 5 €/m$^3$.

The environmental cost and the release of increased GHG due to the energy required remains a serious issue that has not been resolved as yet. Concern is also mounting due to the rising prices of fossil fuel that has to be imported to the island. It is estimated that the increase of power generation due to the desalination plants in the island varied from 1.02 to 3.77 %.

2.1.2.5 Data availability and approach

Information on the case study is available at the Water Development Department (WDD) which on behalf of the Government is the client for the desalination plants and which purchases the desalinated water and controls the contractual obligations of the Contractors. In turn, the WDD distributes in bulk the desalinated water mixed with water from other sources to the users (Water Boards, Municipalities and private users). Internet access is at www.moa.gov.cy/wdd.

The Larnaka Desalination Plant is run by the LARNACA WATER PARTNERS (a consortium of the IDE Technologies Ltd and OCEANA from Israel) under BOOT agreement until 2011.

The Dhekelia Plant was awarded to the consortium of CARAMONDANI BROS LTD and CARAMONDANI DESALINATION PLANTS LTD between 1997 and 2007 and re-awarded for 20 years to the same Contractor on the 20th of May 2007.

Other sources of information are provided under the paragraph “Literature and sources”.

2.1.3 Mitigation measure: Reducing adverse impact on land use

2.1.3.1 Summary

The Plant location is best if it is close to the seashore minimizing thus construction costs for pipelines for feed water and discharge of brine and seawater pumping costs. It should also preferably be close to an existing water distribution pipeline to minimize costs of works related to network connection. The brine pipe needs to extend to an adequate distance from the shore to reach sufficient depth of water to ensure adequate dispersion of the effluent to minimize impacts on the marine environment. Feed water should be obtained from below the surface of the sea (about 5 m) and above the seabed (about 2 m). Preferably, the Plant should be at some distance from populated areas to avoid problems with noise pollution which is usually associated with high pressure pumps required for RO. The location of the Plant should ensure the best overall performance, and should minimize the requirement for private land acquisition. The latter is directly related to the level of opposition to the Plant by the local communities and public. Finally, the seawater at the location should be suitable for desalination.
2.1.3.2 Problem and impacts

Selecting the best suitable site needs to be the subject of a Plant location study and a comprehensive Environmental Impact Assessment study.

2.1.3.3 Technical description of the mitigation measure

- The Plant is located on State land where the International Airport is located and not far from the Larnaka Sewage Treatment Plant. The Plant is away from any tourist development and far from any other land development. Being State land, no private development is foreseen for the area. The main Surface Water Treatment Plant from which the distribution of water to the three main population centres is carried out is only 12 km away. The Plant is located far away from populated areas thus the noise pollution impact is minimized. Appropriate technologies for lowering noise intensities have been used but still there is some high noise level within the Plant.

2.1.3.4 Evaluation of the mitigation measure

- The location of the Plant meets all the technical requirements.
- Also, from the economic point of view, it is the best location since the need to acquire prime private land is minimized, it is sufficiently close to the sea and not far from a major water distribution network (12km).
- The site is socially acceptable since it is in an area that does not offer itself for development in view that already the airport facilities are there as well as the Larnaka Sewage Treatment Plant.
- Environmental impact concerns on the Plant being located on an area which is part of a Salt Lake area have been voiced and still are being discussed. No groundwater exists in the immediate vicinity thus no concern on this issue exists.

2.1.3.5 Conclusions

The careful selection for the location of the Plant is of immense importance from the technical, the economic and the social acceptance point of view. The choice of the site for the Larnaka Desalination Plant met the least opposition from all concerned something that experience for the location of other Plants showed that could be of huge importance on deciding on the implementation of a project or abandoning it.

2.1.4 Mitigation measure: Reducing the adverse impact of brine discharge on the marine and coastal ecosystems

2.1.4.1 Summary

The discharge pipe extends to 1300 from the seashore releasing brine at a point where the sea water depth is 15 m. The Department of Fisheries and Marine Research monitors the marine environment in the area on a regular basis. It is reported that the effect of brine discharge is noted in an area around the discharge point and up to a distance of less than 100 m from it. At the discharge point the dispersion of the brine is adequate due to relative intensive wave action and currents in the area.
2.1.4.2 Problem and impacts

The high specific weight of the brine, the potential presence of additional chemicals introduced at the pre-treatment stage and the temperature difference may harm the marine population in the area of the discharge of the brine. Impacts in “Poseidonia oceanica” (which is on the base of the ecological sea chain) have been claimed as being one of the more significant risks of brine disposal. The installation of the feed and discharge pipes may in itself be also harmful.

2.1.4.3 Technical description of the mitigation measure

The brine discharge pipeline extends to 1300 m from the seashore to a point where the seawater has a depth of 15 m which is considered adequate for dispersion purposes.

2.1.4.4 Evaluation of the mitigation measure

- The reported result from the monitoring of the marine environment strongly suggests that the length of the discharge pipeline at the chosen depth of seawater has succeeded in minimizing any detrimental effects on the marine environment.
- Such length of pipeline could be seen as economically expensive but ensuring the marine environment is of main concern.

2.1.4.5 Conclusions

The careful design of the discharge pipeline to a length and point in the sea where modelling studies suggest sufficient dispersion and subsequent monitoring of the impact of brine discharge on the marine environment are very important in minimizing environmental impacts on the marine environment. The choices for the Larnaka Desalination Plant have proved to be satisfactory.

2.1.5 Mitigation measure: Increasing energy efficiency

2.1.5.1 Summary

Desalination is a high energy demanding process. In Cyprus desalination has led to a substantial demand for electric power. As a result, the Electricity Authority of Cyprus (EAC) has increased its production by 1.86% of the total Power consumption in the island to meet the requirements of the Larnaka Desalination Plant. This leads to a proportional increase in GHG since it is estimated that one cubic meter of desalinated water consuming 5.3 kWh of electricity emits nearly 5kg of CO₂.

Potential mitigation measures for reducing energy consumption (as applied in California² for example) refer to the use of renewable energy sources when feasible, and siting of plants near to power plants capable of cogeneration. Cogeneration refers to a process in which exhaust steam from electricity generating plants is used for another purpose. If a

desalination plant uses cogeneration to supply part of its energy needs, the plant could reduce both its demand for power and the associated environmental impacts of power generation.

Other options for saving energy refer to a) energy recovery by using heat in brine and fresh water leaving the distillation plant to preheat the feedwater and converting hydraulic pressure in the brine to electricity in RO plants, b) solar energy which could be used to heat the water for small distillation plant, and c) Ocean Thermal Energy Conversion (OTEC) which is an offshore technology for producing electricity where the difference in the temperatures of deep ocean water and warm surface water is used to vaporize liquid ammonia for turning a turbine.

Co-locating desalination and energy facilities offers a number of possible advantages, including making use of discarded thermal energy from the power plant (co-generation) lower-cost electricity due to off-peak use and avoided power grid transmission costs, and existing intake and outfall structures to obtain seawater and discharge brine. Co-location can produce substantial energy and economic advantages and, could reduce environmental impacts but it also has drawbacks that require careful review and consideration.

At various stages in the process ideas have been expressed in Cyprus both for co-generation and co-location of desalination to the energy facilities. These possibilities have not materialized as yet.

The possibility of running desalination plants with alternative energy systems, such as solar energy, as a way of reducing costs or dependence on fossil fuels, and more recently, as a way of reducing greenhouse gas emissions and local contributions to climate change has often been put forward. While this discussion continues, there is, as yet, no economic advantage to dedicating alternative energy systems to desalination because of the high costs relative to more-traditional energy systems.

Variations on the use of solar energy have been tested at various places in the world in an effort to increase efficiency, but they all share some major difficulties, including solar collection area requirements, high capital costs, and vulnerability to weather-related damage.

There are examples of desalting units that use more-advanced renewable systems to provide heat or electrical energy. Some modern desalination facilities are now run with electricity produced by wind turbines or photovoltaics. Most of these are demonstration facilities with capacities smaller than 50 m$^3$/d, though a 300 m$^3$/d plant using wind energy was recently built in Cape Verde. The largest renewable energy desalination plant listed by the end of 2005 was a 2,000 m$^3$/d plant in Libya, which was built to use wind energy systems for power.

Renewable energy systems can be expensive to construct and maintain. While the principal energy input is free, the capital cost of these systems is still high. Such systems may be more economical for remote areas where the cost of bringing in conventional energy sources is very high. If the price of fossil fuels increases or renewable energy costs drop, such systems will look more attractive. Ultimately, these energy systems must prove themselves on the market before any such coupling can become attractive.

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2.1.5.2 Problem and impacts

Minimizing the energy consumption for each cubic meter of desalinated seawater does not only reduce the overall cost but at the same time reduces the environmental impact from CO$_2$ emissions.

- The 10 year BOOT contract for the Larnaka Desalination Plant specifies a ceiling consumption of energy of 4.52 kWh/m$^3$ and if exceeded the Contractor bears the extra cost. This measure aims both to the overall cost of production but also to environmental concerns.
- The Contractor himself implemented an operational strategy for the Plant aiming to efficient plant operation and maximizing plant performance in the long term. This strategy included i) Optimization of process, ii) Review and standardization of operational procedures, iii) Operation of a stable plant, maintaining plant efficiency and performance, and iv) Introduction of innovations based on plant operational experience and new technology developments.

2.1.5.3 Evaluation of the mitigation measure

- The reported results by the Contractor show a steady drop of the average annual energy consumption from 4.66 kWh/m$^3$ in 2002 to 4.48 in 2003 to 4.44 in 2005 and 4.42 kWh/m$^3$ in 2006 (5.1% drop). This produced sustained plant performance which exceeded the minimum contractual criteria both in energy and water quantity while at the same time meeting all the water quality requirements. The good plant performance is supported by systems in place relating for example to membrane replacements, plant operation and maintenance planning which resulted in 97.7% plant availability, operating in full capacity in 2006.

2.1.5.4 Conclusions

The continuous upgrading and implementation of intelligent operational strategies for the Plant could result to a more efficient plant operation maximizing performance and reducing the energy consumption. This agrees with the IDAE (Spanish Institute for energy diversification and saving) estimations, that energy consumption in RO plants could be reduced to 3.2 kWh/m$^3$ or even less, as per Task 1 report on desalination.

2.1.6 Mitigation measures: Improving quality of desalinated water

2.1.6.1 Summary

Beyond the social concerns on the quality of the desalinated seawater referring to its palatability and its effect on the household plumbing, other problems that were faced especially at the early stages of the operation of the Larnaka Desalination were the issue of the Boron content in the desalinated water and the corrosiveness of the produced water to both the water distribution network and to that of the household plumbing.
2.1.6.2 Problem and impacts

The social concerns were reasonable especially when faced with a new source that involves chemicals in the process.

The issue of the Boron is worldwide and is affected by sea water temperature and other process parameters. Problems existed with Boron at the initial (summer period) commissioning of the Plant since in summer, warm sea water temperatures (>22 °C) have an effect on the quality of desalinated water produced. The corrosiveness of the desalinated water especially in areas where the distribution system consisted of metal/iron pipelines was due to the low pH of the desalinated water.

2.1.6.3 Description of the mitigation measure

- Quality control of desalinated water and production/use in early years helped for these concerns to subside. Both the Contractor and Client (WDD) maintain a well equipped Laboratory for controlling the quality of the produced desalinated water.
- The Client is responsible for monitoring among other elements the Boron of the desalinated water. Analyses are done 4 times daily during winter to 12 times daily during summer. The Contractor invested in the continuous monitoring of Boron (normally it requires at least 2 hours for analytical results) and through implementation of own Membrane System Management, adjustment on process parameters such as pH, process pressure, effective use of 2nd stage for boron removal, has managed the solution of the problem. Boron ions rejection by RO membranes increases with increasing feed water pH. However, seawater desalination by the RO method is not practical at pH>9 due to the crystallization of CaCO$_3$ and Mg(OH)$_2$ salts on the RO membranes (fouling).
- The corrosiveness of the desalinated water was resolved by increasing the pH range from 7.0 - 8.0 (contract specification) to 6.5 -9.5 (EU recommendation). This was done by readjusting lime and carbon dioxide. By the increase of pH to values to more than 8.5, the Langelier Index increased to 0.0–0.5 and the iron content in the water sampled from the distribution network at some distance from the Plant were decreased. For further increase of the hardness of the desalinated water, magnesium sulphate is added at the post-treatment stage in addition to the lime and carbon dioxide. Using corrosion inhibitors may protect distribution system.

2.1.6.4 Evaluation of the mitigation measure

- The measures on continuous quality monitoring of the produced water practically removed any public concerns on the palatability of desalinated water. Nonetheless, a large proportion of the population still prefers bottled water for drinking purposes.
- The boron content of the desalinated water is within the 1 ppm value specified by the contract. The measures taken by the Contractor were successful but these constitute a technique owned by the Contractor.
- The measures assumed for the control of the corrosiveness of the desalinated water as described above, were successful and no such problem exists any longer.
2.1.6.5 Conclusions

Continuous monitoring and control of the quality of the desalinated water is necessary both by the Client and the Contractor. This helps disperse any public concerns and ensures that the quality of the water is within the specifications of the contract.

Warm seas add to the Boron problem and early measures are needed to maintain the Boron content to less than 1 ppm since this affects certain crops sensitive to it. This has particular repercussions if the effluent is to be subsequently treated and re-used for irrigation.

The corrosiveness of the desalinated water can easily be controlled by increasing the pH of the produced water at its exit from the plant.

2.1.7 Other remaining issues not dealt with

Other remaining impacts not dealt earlier refer to:

- **Power interruptions:** Power generation failures in combination with the safety systems of the Plant lead to temporary interruption of production. Increased capacity of Electric Power Generation has helped to the effective reduction of the problem,

- **Machinery – instrumentation failures:** Availability of an arsenal of replacement tools and supplies, especially of those most sensitive and essential for the uninterrupted operation of the Plant is an absolute necessity. In June 2008 failure of electric circuits on pumps at the Dhekelia Desalination Plant left the Plant out of commission for 3-4 days until replacement was imported from abroad.

- **Rupture of GRP pipes:** Occasional problems of rupturing of the Glass Reinforced Plastic (GRP) pipes at the early stage of the operation of the plant led to the interruption of the Plant operation until pipes were fixed.

2.1.8 Review of case study achievements and the need for future mitigation measures

**Achievements:**

- Cyprus has explored and practised sea water desalination for domestic purposes for more than 10 years. Desalination has helped considerably in meeting the growing water demand due to increased population density along the coastal areas as well as due to the seasonal flux of tourists. Desalination has helped to overcome water shortages due to an extended drought.

- Large capital costs and specialised technology issues have been successfully resolved through the implementation of Built Operate Own Transfer (BOOT) contracts for desalination plant construction and operation.

- Through desalination, the serious obstacle in the economic development of Cyprus due to the water scarcity, experienced since 1990, has been tempered to a large degree. It should be noted that all the attractive and economic sites for surface reservoirs have already been developed and groundwaters are over-exploited.

- The careful selection the Desalination Plant location is of immense importance from the technical, the economic and the social acceptance points of view. The choice of the existing Desalination Plant sites always met the least opposition. The plants have been situated on state land, away from tourist centres, other developments and important aquifers.
- The impact on the marine environment due to the discharge of brine is being continuously monitored. The careful design of the discharge pipeline to a length and point in the sea where modelling studies suggest sufficient dispersion and subsequent monitoring of the impact of brine discharge on the marine environment is the best means of assessing sites for minimizing environmental impacts on the marine environment. The choices used for the existing Desalination Plants have proved to be satisfactory.

- The implementation of intelligent operational strategies and the continuous upgrading of the plants have achieved a more efficient plant operation maximizing performance and a reduction of the energy consumption.

- The Boron issue and corrosiveness of desalinated water have successfully been contained.

- The continued persistence of the general water scarcity in Cyprus has reduced the heated discussions and strong opposition by environmental activists to desalination.

- Continuous monitoring and control of the quality of the desalinated water both by the State and the Contractor has helped disperse any public concerns ensuring that the quality of the water is within the specifications of the contract.

Need for future mitigation measures:

The key issues that still need to be further tackled and resolved are:

- the high energy requirements to desalinate sea water and the accompanying increased CO2 emissions,
- the small flexibility of the BOOT system to account for changes in water demand,
- the risks of occasional, temporary, desalination plant failure,
- the need to incorporate the environmental cost of desalinated water (increased GHG) in the price of water
- the use of renewable sources of energy to counteract the rising price of fuel for energy production

2.1.9 Summary and Conclusions

2.1.9.1 Specificities of the case study

The Larnaka Desalination Plant operates under a Built Own Operate Transfer contractual agreement with the Government. The Contractor has to provide minimum quantities of desalinated water within specified time periods of specified quality and at a ceiling level of energy consumption per cubic meter.

The Plant is strategically well placed within 12 km from a major surface water treatment plant from which water is distributed in bulk to three districts. The Plant is located at State land away from populated areas.

2.1.9.2 How were the different problems or concerns addressed

- Problems/concerns solved: All the main concerns and problems have been solved and the Plant is now at its 7th year of uninterrupted operation. These problems and the mitigation measures applied for addressing them are listed in paragraph 2.1.2.3. These concern the location of the plant, the protection of the
marine environment, the use of energy through increased plant efficiency, and the quality of desalinated water.

- **Problems/concerns/issues remaining:** Problems that remain to be solved are the intensive use of energy and its repercussion on the environment through the increased emission of GHG.

  Efforts to employ renewable sources of energy are still at the research level.

  A major issue is the relative inflexibility of the BOOT Contract on wet years when the surface reservoirs are full and the need for the expensive desalinated water is reduced as it occurred in 2004.

  Another major issue is the rising price of fuel for energy production which will directly affect the cost of desalinated water production.

### 2.1.9.3 Lessons and implications for further use of technology in the EU

The problems faced by the implementation of desalination in Cyprus and the mitigation measures that have been applied, as described above, together with the method of financing such projects should be useful for further use of this technology throughout the EU.

Cyprus had to resort to desalination since although it made great strides in developing its water resources with the most feasible water development works implemented, the growing water demand coupled with an extraordinary dry sequence of years, practically since 1990, led Cyprus to ration water for domestic use. Improved water management, water demand management and conservation as well as change and even reduction of the cropping pattern are called for.

In view of the still high cost of desalination and the environmental impacts associated with it, careful consideration should be paid in developing traditional sources, if and when available, as well as improved water management, including demand management before embarking on desalination.

The desalination plants in Cyprus being under the Built Operate Own Transfer (BOOT) arrangement do not allow discussion on the investment costs for each of their components. What is clear though, as shown in Table 2, is that the unit price of desalinated water seems to be reducing due to the improvement of the technology. This was 0.92 €/m$^3$ in 1997, 0.68 in 2001 and 0.64 €/m$^3$ in 2007 not considering price adjustments made on the basis of the variation for energy production.

### 2.1.10 Literature and sources


WDD (1999) “Water Treatment and Desalination Plants“ WDD, MANRE, PIO

Chr. Michaelides (2007) “Presentation of the experience from the construction and operation of the Dhekelia and Larnaca Desalination Plants”, WDD, MANRE (greek)


2.2 Mitigation measures associated with desalination: case study Malta

The general introduction to Malta is provided in Annex A. Desalination at a larger scale is practised in Malta since the beginning of the 1980s with its share in the water supply being today at around 50%. Having already quite a long history of desalting water, Malta can be expected to have experienced most of the impacts related to it. The case study will be able to show which negative effects have been and are still today the most important ones in the Maltese context and which measures have been undertaken to address them.

2.2.1.1 Main adverse impacts of desalination identified in Task 1

As has been identified before, the main adverse impacts related to desalination processes include its high energy use, the impact on the marine environment through the process of water intake and brine discharge, the occupation of land, noise pollution and finally the possible impact on groundwater through leaking pipes.

A particularity of the Maltese case study might be that the use of desalination led to the situation that the Maltese population – although living in a country with high water scarcity – underestimates this problem. This is due to the fact that producing desalinated water gives the impression of abundant water availability, leading to unsustainable water consumption patterns.

2.2.1.2 Relevance of the case study

Malta has like other Mediterranean countries a long history of water scarcity. Being an island which is lacking in surface water sources, the emphasis in the past has been laid on desalination to solve the water supply problem. As Malta is at the same time a new EU Member State in the EU, it has to face additional challenges in terms of complying with EU legislation. Desalination contributes to a larger extent to the fact that Malta is probably failing to reach its objectives concerning greenhouse gas emissions. This makes further efforts necessary. Malta represents therefore the problems of the Mediterranean region as well as the situation of the new EU Member States.

2.2.1.3 Focus of the study

In Malta, mitigation measures concerning desalination processes have mainly concentrated on measures to reduce energy consumption of the desalination plants. The emphasis has been laid on augmenting energy efficiency of different technical components and on reducing leakages in order to decrease the required amount of


fresh water. Furthermore, the Maltese Water Service Corporation (WSC) which is responsible for the management of the plants decided to use sea wells near the shoreline instead of open sea water intakes resulting in reduced costs for pre-treatment and an assumed diminished impact on the marine environment.

In this case study report, the focus will be put on these particular mitigation measures: energy savings, leakage control and use of sea wells.

### 2.2.2 Introduction to the Malta case study

#### 2.2.2.1 Information on location, water supply problems and history

In the history of desalination in Malta, three distinct phases can be distinguished (Riolo 2001b). As early as 1886 a small distillation plant has been built in Tigne, consisting in a simple boiler with a condenser. In a second phase, the construction of a flash thermal distillation plant began in 1967 (until 1973) in conjunction with a power station being built at the same time. Needs to extend the desalination capacity and considerations on fuel consumption of the different technologies led finally to the first desalination plant using reverse osmosis (RO) technology, which was built in Malta in 1982 at Ghar Lapsi⁴. It has to be noted that in the three phases the technologies applied were in their infancy when introduced in Malta, showing the importance of this alternative water supply to the national development (Riolo 2001b).

![Location of the desalination plants in Malta](http://www.edsoc.com/Newsletter18.pdf)

**Figure 2: Location of the desalination plants in Malta⁵**

Today, three publicly owned RO desalination plants are working in Malta, namely in Pembroke, Cirkewwa and Lapsi (see Figure 2Together they produce around 17 Mio m³ of water per year (WSC 2007). Table 3 is showing the distribution of the produced amounts among the different plants, indicating the importance of the Pembroke RO

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Plant responsible for nearly 60% of the desalted water. In total, seawater desalination provides about half of the drinking water supply in Malta (Mangion & Sapiano 2005).
Table 3 Production of desalinated water by the three Maltese RO plants from August 2006 to July 2007 (WSC 2007)

The three main facilities are far from working on nominal full capacity of 100,000 m³/day as the high quality of the desalted water allows blending with today's low quality groundwater in order to achieve drinking water standards while reducing the need for the costly desalination process. Indeed, the input of electrical energy required for desalination is ranging between 3 to 6 times that to produce groundwater\(^6\) (Mangion and Sapiano, 2005).

2.2.2.2 Context in terms of water supply issues in the EU

As stressed previously, Malta is suffering from high structural water scarcity. Surface water is almost not present whereas groundwater recharge is not sufficient to meet with the population water demand and agriculture demand together. The situation is similar to that of several Mediterranean regions (e.g. Spanish Mediterranean coast) or islands (e.g. Cyprus).

2.2.2.3 Mitigation measures and problems addressed

Mitigation measures in place in Malta concern mainly the attempt to reduce energy consumption and related costs. WSC is mainly investing in the inclusion of energy recovery equipment in the RO plants and the enhancement of a leakage control programme (Sammut & Micallef 2004). Some of these measures help addressing several risks or impacts. The following table illustrates the crossing between the mitigation measures and the impacts addressed (Table 4). A short description of each measure is given below.

\(^6\) Specific Power Consumption: Groundwater – 0.75 kWh/m³; Seawater RO – 3.2 kWh/m³ < > 4.7 kWh/m³
Chapter 2 Mitigation measures associated with desalination

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Targeted impact</th>
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<tbody>
<tr>
<td></td>
<td>Energy use</td>
</tr>
<tr>
<td>Energy saving devices in RO plants</td>
<td>x</td>
</tr>
<tr>
<td>Leakage control measures</td>
<td>x</td>
</tr>
<tr>
<td>Use of sea wells</td>
<td></td>
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<tr>
<td>Blending of groundwater</td>
<td></td>
</tr>
<tr>
<td>Subsidizing energy prices</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Mitigation measures for desalination applied in Malta

Energy saving devices in RO plants. Upgrading of the Maltese RO plants has taken place in several steps. The main changes implemented include the introduction of Pelton wheels and pressure exchangers.

Leakage control measures. WSC is operating a leakage control program which already led to sizeable reductions of water losses.

Use of sea wells. Using sea wells near the coastline instead of open sea intakes provides the desalination plants with water of excellent quality. This measure reduces the impact on the marine environment and at the same time costs needed for pre-treatment.

Blending of groundwater. In order to reduce energy consumption and costs in the water supply service linked with desalination, the general policy of the Water Services Corporation is to extract as much groundwater as possible, without imposing negative impacts on the aquifer. The blending process allows furthermore guaranteeing the drinking water quality as the groundwater suffers from pollution in consequence of its over exploitation.

Subsidizing energy prices. In order to avoid a too high burden though water prices, electricity consumed by WSC is highly subsidized (2c/kWh compared to the real cost of generation of 6c/kWh, Cremona 2008)

2.2.2.4 Additional issues

Although water prices in Malta have been raised in the past due to rising/fluctuating energy costs (Ministry of Health 2006)\(^7\), the household water bills are still among the lowest in Europe. On average, the residential household bill is subsidised only by 5.8% (Delia 2004a) and although costly desalination makes up for about half of the supplied water, the share of the water bill in the household net monthly income is only about 0.3% (Anderson et al. 2008). At least two reasons are thought to explain this fact. First, most of the waste water in Malta has not been treated until recent times. This is important as the cost of water treatment in European countries complying with the Urban Waste Water Treatment Directive accounts for more than half of the water price in those countries. Secondly, as mentioned before, the energy price for WSC, which is one of the largest expenditure to produce desalted water, is subsidised. As for the difference between the real costs per cubic meter and the tariffs charged, Delia (2004) gives a production cost of € 1.28/m\(^3\) for public water supply (groundwater and

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\(^7\) A price hike in water tariffs took place in 1997 (Cardona 2006).
desalinated water), whereas households are charged € 0.38/m³ for the first 11 m³ consumed per person and € 2.56/m³ beyond it.

Compared with other European countries, the social consequences due to rising water bills could therefore be assumed to be affordable. Nevertheless, a high resistance can be expected as in general the current water prices are perceived to be high (Cardona 2006).

Water saving measures in general could be seen as a mitigation attempt in terms of avoiding the impacts linked to desalination through demand reduction. But as this is not a specific measure related to one water supply option, it is not going to be discussed further.

### 2.2.2.5 Available information and approach

Information about the mitigation measures is mainly taken from different reports available on the internet. Furthermore, contacts have been established with the Malta Resources Authority (MRA) to validate the information. Technical information about energy saving devices is furthermore compared with the state of the art described in scientific papers.

### 2.2.3 Mitigation measure: Increasing energy efficiency of RO plants

Being the largest electricity consumer in Malta, the plants consumed together about 86.7 Mio kWh of electricity from August 2006 to July 2007. WSC carries out monthly energy audits in order to assess the energy consumed by individual plant components (WSC 2007). Despite membrane deterioration, the specific energy consumption (SEC) shows a trend of constant decrease due to efficient plant management (Sammut & Micallef 2004).

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Lapsi</td>
<td>6.85</td>
<td>6.22</td>
<td>6.28</td>
<td>6.24</td>
<td>6.41</td>
<td>5.81</td>
</tr>
<tr>
<td>Cirkewwa</td>
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<td>7.22</td>
<td>7.25</td>
<td>7.20</td>
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<tr>
<td>Pembroke</td>
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<td>5.35</td>
<td>5.29</td>
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<td>5.30</td>
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<td>5.84</td>
<td>5.95</td>
<td>5.89</td>
<td>5.92</td>
<td>5.72</td>
</tr>
</tbody>
</table>

*Table 5 Specific energy consumption in RO plants (in kWh/m³) (Sammut & Micallef 2004, WSC 2007, adapted)*

### 2.2.3.1 Description of the mitigation measure

The introduction of the energy saving devices in Maltese desalination plants took place in different steps. Whereas the first RO plants in Malta were built with the then state-of-the-art integrated turbo pumps, the last plant construction phase in 1994 was based on a different concept. Energy recovery from separate reverse-running pumps was introduced for environmental purposes. The use of this technology led to the reduction of noise pollution and reached some small gains in efficiency and finally influenced the choice of the future energy recovery devices being retrofitted later (Riolo 2001b). Table 6 shows the different replacements and upgrading activities from 2001 to 2006.

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8 Specific energy consumption is generally defined as the total energy consumed to produce a unit volume of permeate (Manth et al. 2003).
including the introduction of Pelton wheels, pressure exchangers and spiral wound membranes.

<table>
<thead>
<tr>
<th>Year</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Two Pelton wheels at Pembroke RO plant</td>
</tr>
</tbody>
</table>
| 2002 | Four Pelton wheels at Pembroke RO plant  
One Pressure Exchanger at Lapsi RO plant |
| 2003 | One Pressure Exchanger at Lapsi RO plant  
One Pressure Exchanger at Cirkewwa RO plant |
| 2005 | Membrane replacement |
| 2006 | Four trains with spiral-wound membranes at Lapsi RO plant |
| >2007 | Replacement of seven trains throughout all three RO plants with new spiral-wound membranes  
Upgrading of six more trains to spiral-wound membranes instead of hollow-fibre units |

Table 6: Energy saving measures in Maltese RO plants (Sammut & Micallef 2004, WSC 2007, adapted)

**Pelton Wheel.** The Pelton Wheel uses the high-pressure energy, which remains in the brine, from the reverse osmosis process. The concentrate is led into the Pelton Wheel hydraulic impulse turbine, which then produces rotating power output. The so generated electricity is used to assist the main electric motor in driving the high-pressure pump (Farooque et al. 2004) (see also Box below).

**Pelton Wheel**
The Pelton impulse turbine (PIT) or Pelton wheel “typically consists of a rotor located between bearings in a housing vented to the atmosphere. A high velocity concentrate stream is directed against the buckets mounted on the periphery of the rotor to generate rotary motion on the shaft. Concentrate is discharged at atmospheric pressure. The PIT has an integral nozzle control valve that eliminates the need to bypass or throttle concentrate flow, thereby assuring that the entire hydraulic energy of the concentrate stream is available to the PIT.”
Source: Manth et al. 2003

**Pressure exchanger.** Pressure exchangers are devices which are using the principle of positive displacement. Energy saving is achieved by reducing the volumetric output required by the main high pressure pump. The device transfers pressure energy from a high pressure fluid stream to a low pressure fluid stream. The high-pressure pump operates at the full membrane pressure but supplies only the flow rate of the permeate. Figure 3 indicates its place within the structure of a RO plant

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9 Morris (2003) states 1999 as the year of introducing the Pelton Wheels in Pembroke.
Spiral wound membranes. Spiral wound membranes comprise a spiral wound membrane element including a separation membrane having high back pressure strength. They are used instead of the hollow fiber membrane elements which break more readily, letting raw water mix into permeate and therefore reducing separation performance. The spiral wound membrane element can provide a large membrane area per unit volume similarly to the hollow fiber membrane element and maintain separation performance, having a high reliability (Ando et al. 2001).

2.2.3.2 Evaluation of the mitigation measure

Technical evaluation
According to Manth et al. (2003) Pelton wheels are among the most efficient and thus most widely used centrifugal machines. Pressure exchangers are mentioned to hold as well an interesting potential but are a far less used technology. Investigations of Farooque et al. (2004) found pressure exchangers to be the most efficient (≈ 94%) energy recovery devices (ERD) which can result in lowest specific energy consumption (SEC). Those authors assign only a medium efficiency to Pelton Wheels, but mentioning as well that it is claimed that its efficiency stays relatively high over the full operation range.

Because of its high membrane surface area to volume ratio the spiral-wound membrane element is the most widely used membrane device. It can therefore be judged to be a good standard device in desalination plants (Bodalgo-Santoyo et al. 2004). In Malta, the use of the spiral wound membranes led to a higher water quality (WSC 2007).

Economic evaluation
Concerning the changing of membranes, WSC uses a simulation model – the RO membrane management database and model (ROMANS) – to ensure that the substitution only takes place if it seems cost-effective (Riolo 2001b). The introduction of the spiral wound membranes in 2006 together with the refurbishment of the high
pressure pumps resulted in overall operational savings of around € 58,000 per year and per train (WSC 2007). Being quite expensive, the large scale upgrade of the trains which is planned for the next years is co-funded by the EU within the “Drinking Water Quality Project” (WSC 2007). According to an assessment done by WSC, the installation of all forms of new energy recovery devices was judged to be very rewarding. Recovery of the expenditure was expected to be after 1 or 2 years through reduced running costs (Riolo 2001b).

Environmental impact
The four trains with spiral-wound membranes commissioned for the plant in Lapsi in 2006 obtained a substantial improvement in the specific power needed for operation after the refurbishment of the high pressure pumps. The new trains operate at an average of 3.8 kWh/m³ compared to 5.0 kWh/m³ hitherto required (WSC 2007). Pressure exchangers recover energy from the waste stream of seawater RO plants at up to 98% efficiency. The introduction of pressure exchangers in Lapsi together with the combination of two of the trains resulted in 26% less energy consumption (Morris 2003).

Finally, another point is worth mentioning. In earlier stages, noise pollution through desalination plants was generated by the then used high-speed turbo pump and gearbox, disturbing inhabited and prime tourist areas (Riolo 2001b). Changing pumps for energy saving purposes entailed also positive side effects in terms of noise reduction.

2.2.3.3 Conclusions
The energy saving measures applied in the Maltese RO plants have led to significant energy savings. Pelton Wheels, Pressure Exchangers and Spiral Wound Membranes are widely used technologies with a reputed efficiency. It can therefore be concluded that the Maltese RO plants are equipped with modern energy saving devices, although the upgrading of the plants happens only gradually and requires partly external financial aid.

2.2.4 Mitigation measure: Leakage control
Annually, a substantial volume of water leaks out of the distribution network (Delia 2004). In the year 1999 the WSC embarked an intensive leakage control programme. Losses were reduced by replacing old pipes or in situ re-lining (World Bank 2004).

In order to measure the effectiveness of this programme, an Infrastructure Leakage Index (ILI) was established (Rizzo 1999, in Sammut & Micallef 2004). The Index calculates the ratio between the Current Annual Real Losses and the Unavoidable Annual Real losses (which represent the lowest technically achievable level of real losses for a well managed infrastructure in good condition10) (Delia 2004). ILI is used to calculate leakages instantaneous (“snapshot ILI”) and on a zone-by-zone basis. In order to do so, Malta has been divided into 300 zones. Each area is having its own respective snapshot which is calculated on a weekly basis (WSC 2007). A visual tool used by WSC allows to quickly identifying zones which require most attention and therefore helping to identify priority areas (WSC 2007).

In 2001 the ILI level was equal to about 4, with a leakage rate of 1200 m³/h. The target is to reach unit ILI level by the end of 2010 which corresponds to a leakage level of 300 m³/h. The figures below are showing the ILI calculations from December 2003 to April 2007 as well as the assumed and projected leakage rates.

2.2.4.1 Evaluation of the mitigation measure

Repairing leakages costs the WSC approximately € 242,22011 annually. In 2004, 1.185 million m$^3$ of water could be saved through these measures (FAO 2006). Multiplying this with the average unit cost of water production in Malta of € 1.28/m$^3$ (Delia 2004a) the total saving made by the WSC amounts to € 1,517,926.

The available datasets do not allow a distinction between the effects of different energy saving measures in terms of saved greenhouse gas emissions. The impact reached through leakage control is included in the general energy savings given in the conclusions for this case study.

Though reducing leakages helps addressing some negative impacts of desalination, it has nonetheless non negligible impacts on groundwater recharge. If leakages are

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11 Cost figures have been converted from Maltese Lira (LM) to Euros using the following conversion rate: 1 LM = € 2,329.
reduced to a significant amount but with groundwater abstraction remaining at the same level, the balance of the latter will be even more negative than it is today.

2.2.4.2 Conclusions

Repairing leakages has been very successful in Malta and led to energy savings as well as to considerable economic benefits. The objective is to reduce the Current Annual Real Losses to the Unavoidable Annual Real Losses by the end of 2010 (ILI=1). As compared to 2001 leakage level (ILI =4), an avoided cost of 9 M€ would be realised by WSC each year.

Although this measure has considerable benefits on the economics of desalination, one might keep in mind that reducing leakages also reduces groundwater recharge.

2.2.5 Mitigation measure: Use of sea wells for feed water intake

2.2.5.1 Description of the mitigation measure

The porous limestone rock which composes the entire island allows Malta to draw seawater feed from wells instead near the shoreline of using open sea intakes. The porous rock acts as a natural filter, providing the plants with raw water of very good quality (World Bank 2004). The measure reduces the costs related to pre-treatment and hinders at the same time negative impacts on the marine environment which would be linked to open seawater intakes (Mangion, pers. comm.).

The wells consist of boreholes drilled in limestone rock adjacent to the desalination plants. Their depths varies from 30-60 meters with a diameter of 43 cm. Submerged pumps pump the seawater into a feed storage tank. Each well provides between 4000 and 6000 m$^3$/day$^{12}$ of feed-water (World Bank 2004).

2.2.5.2 Evaluation of the mitigation measure

Technical evaluation

The quality of the water in terms of silt content (SDI of 1-1.5) and biological quality are very good. At this depth the stable low temperature and absence of light ensure that there is no proliferation of microbiological or bacterial life that affects membrane performance (Riolo 2001b).

Economic evaluation

The lifetime of membranes is significantly affected by the feed water quality and the pre-treatment process. The excellent quality of the feed water contributed to an important extent to the fact that the membranes in the Maltese RO plants could be maintained for a relatively long period. 30% of the membranes bought in 1982 were still in operation 20 years later (Riolo 2001b, World Bank 2004). For comparison, the usual guarantee for membranes given from suppliers is limited to 3 years. Other authors (Avlonitis et al. 2003) indicate that membrane replacement usually takes place after 2 to 5 years. No specific information on membrane costs for the Maltese plants could be found. An example found for Greece indicates that average replacement costs for spiral-wound membranes are about € 1,500/element and € 6,000/element for hollow-fibre membranes.

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$^{12}$ Riolo (2001b) reports well yields between 6000 m$^3$/d and 8000 m$^3$/d.
Economic benefits arise not only from the longer lifetimes of the membranes, but are also related to the fact that no complex pre-treatment is needed (World Bank 2004). Occurring pollutants are transient in character and changing by-and-by (Riolo 2001b). Information on costs for pre-treatment is difficult to find, but Miller (2003, in Anderson et al. 2008) estimates that they can account for up to 30% of the operation and maintenance costs of RO plants.

Social evaluation
Although no direct social impact of this measure is assumed, effects in cost reduction can be supposed to be beneficial for water consumers.

Environmental impact
Concerning a potential impact on the environment, it can be assumed that the use of sea wells has less negative impacts on the marine environment than direct water intakes from the sea. This might in particular apply for marine fauna and flora which is free floating in the water body.

Furthermore, the pre-treatment process in desalination plants is usually linked to the use of chemicals, which afterwards are discharged into the sea (Semiat 2000). Avoiding pre-treatment reduces therefore the amount of chemical pollution of the sea.

2.2.5.3 Conclusions
The use of sea wells instead of open sea water intakes is linked to several benefits. It provides the desalination plants with good quality feed water – leading to less costs in the pre-treatment process and to longer lasting membranes. At the same time it reduces the risks related to direct seawater intakes on the marine flora and fauna.

2.2.6 Remaining issues not dealt with
The impact of brine discharge into the sea is linked to a potential harm of the marine environment. In Malta, no negative impact has been detected so far (Mangion, pers. comm.). A study carried out by a Maltese university examining brine discharges from desalination plants concluded that the brine mixed quickly and that few environmental impacts were to be expected (World Bank 2004). The brine discharges for the Maltese desalination plants are given in Table 7.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Quantity $m^3$</th>
<th>Conductivity $\mu S cm^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pembroke</td>
<td>12,997,959</td>
<td>96,837</td>
</tr>
<tr>
<td>Cirkewwa</td>
<td>5,467,197</td>
<td>89,364</td>
</tr>
<tr>
<td>Lapsi</td>
<td>5,787,438</td>
<td>81,689</td>
</tr>
<tr>
<td>Marsa(^{13})</td>
<td>16,180</td>
<td>52,663</td>
</tr>
<tr>
<td>Total</td>
<td>24,268,774</td>
<td></td>
</tr>
</tbody>
</table>

\(^{13}\) This plant has been closed in the meantime.

Table 7: Brine discharges from Maltese desalination plants, 2000/2001 (World Bank 2004)

Nevertheless, awareness exists that further research might be needed to assess this impact in more detail (Mangion, pers. comm.).
2.2.7 Review of case study achievements and the need for future mitigation measures

The main achievements of the mitigation measures applied in Malta are related to a decreasing consumption of energy: During the hydrological year 1999/2000, WSC consumed 131 GWh of electricity which is about 36% less than the energy consumed in 1995/1996. In the hydrological year 2006/2007, the WSC electricity consumption was 86.7 GWh, representing a further decrease of about 34% (WSC 2007). The available datasets do not allow differentiating the effects of the different measures. Figure 6 shows the expected decrease in CO2 emissions due to energy savings achieved or planned by WSC during the period of 2001-2010 (upgrade of plants and leakage control).

![CO2 emissions associated with production of potable water by RO between 2001 and 2010 (Sammut & Micallef 2004)](image)

Furthermore, the lifetime of the membranes and the related costs for the pretreatment of the sea water could be reduced by using sea wells instead of open sea water intakes.

As for the need of future mitigation measures, the necessity to look at the impact of discharging brine into the sea has already been mentioned. Another point would be to consider the possibility to use renewable energies for producing at least part of the required energy. With Malta being an island which is heavily populated, no large pieces of land are available for producing a significant amount of solar energy (World Bank 2004). As for the potential use of off-shore windpower or the use of sea-energy to desalt water, no reference could be found dealing with this issue in Malta. Efforts put into this direction are clearly worth considering.

2.2.8 Summary and Conclusions

The here presented case study has mainly looked at energy saving devices applied in Maltese RO plants. The technologies used led to a decreasing energy consumption: During the hydrological year 1999/2000, WSC consumed 131 GWh of electricity which is about 36% less than the energy consumed in 1995/1996. In the hydrological year 2006/2007, the WSC electricity consumption was 86.7 GWh, representing a further decrease of about 34% (WSC 2007). The available datasets do not allow differentiating
the effects of the different measures. Figure 6 shows the expected decrease in CO2 emissions due to energy savings achieved or planned by WSC during the period of 2001-2010 (upgrade of plants and leakage control).

2.2.8.1 Specificities of the case studies

With Malta being a country with heavy water scarcity problems and relying with around half of its drinking water demand on desalination, the RO plants play an important role for the Maltese society. Although investments in energy for the desalination process are seen as indispensable, efforts to reduce those costs have a high priority for the Maltese water managers.

2.2.8.2 How were the different problems or concerns addressed

Mitigation measures described in this case study were primarily technical and mainly addressing economic impacts (reducing the overall cost of the water) – being related to energy consumption and costs of pre-treatment of feed water.

Impacts on the marine environment through brine discharges are so far not directly approached (Mangion, pers. comm.), but might be considered in the future. As mentioned before, an impact on the groundwater balance can be expected due to leakage reduction.

2.2.8.3 Lessons and implications for a further use of the technology throughout the EU

The measures adopted in Malta correspond to good practices applied in desalination plants around the world. Although no innovative approaches could be found, the case study can be seen as an example of a conventional way to respond to the high energy consumption in the desalination process. Nevertheless, the optimal choice between the different energy saving devices will depend on the technical specifications of the desalination plant.

The use of sea wells instead of open seawater intakes has turned out to be very successful as the naturally filtered water reduces costs needed for pre-treatment. The application of this technology in other location will however depend on the geological conditions of the area.

2.2.9 Literature and sources


Personal communications
Mangion, J., Director for Water Resources, MRA, July 2nd 2008
2.3 Mitigation measures associated with desalination: case study AGUA Programme, Spain

2.3.1 Introduction

This case study deals with desalination measures under the Urgent Actions in Mediterranean Basins included in the AGUA Programme (Actuaciones para la Gestión y la Utilización del Agua – Water Management and Use Action Programme) run by the Spanish Ministry of the Environment and Rural and Marine Affairs (Ministerio de Medio Ambiente y Medio Rural y Marino).

The AGUA Programme includes two lines of intervention: reinforcement of actions to improve water management through water re-use and saving, and implementation of desalination projects to increase available water. The AGUA Programme promotes desalination in coastal towns as a general criterion for ensuring the water quality and availability required to supply the local population.

The programme covers the Spanish Mediterranean coastline and most of the proposed Actions focus on the south-eastern provinces, which for the last three decades have been suffering from a rising water deficit and a sharp growth in water demand, mostly for agricultural use and for the tourist sector.

2.3.1.1 A remainder of the main adverse impacts identified in Task 1

The main impacts arising from desalination are related to plants’ location, energy consumption, brine management mechanisms, and the economic cost of the water produced.

A. Impacts from intensive energy use: Possibly the main environmental impact arising from desalination stems from its energy consumption and its contribution to climate change, which can only be directly abated to some extent by using renewable energies and with technologies improvements\(^\text{14}\) to reduce energy consumption.

B. Impacts on marine and coastal ecosystems: The most important direct impacts from brine discharge\(^\text{15}\) can take place on marine flora. Seagrass meadows are especially sensitive. Construction of desalination infrastructure and its associated buildings along the coast may affect coastal dynamics by increasing erosion and sedimentation processes. The choice of plant siting is fundamental.

C. Impacts on land use and on nature and biodiversity: Mediterranean coastal areas are often fragile, with high conservation value, as is the case of coastal dunes, beaches or coastal wetlands. Desalination plants, on the other hand, are industrial facilities and, furthermore, are generally sited in coastal areas within 2 km of the sea or at river mouths, outside of urban areas. Desalination plants also require pipelines for seawater intake, for removing brine and for subsequently distributing the product, as well as pumping stations, storage tanks and infrastructure that occupies and fragments the territory if it is not properly planned.

D. Impacts on aquifers and river systems Salt-water desalination plants fed from aquifers may contribute to further salinating aquifers or seawater intrusion.

\(^{14}\) It is possible to consider the additional use of renewable energies external to desalination plants as compensatory measures for energy consumption in the plants themselves.

\(^{15}\) Generally speaking, for every litre of desalinated water, another litre of brine is produced with a saline concentration of 69 g/l, approximately double the salinity of sea water.
In other cases, however, brine is discharged directly into river systems, which are consequently polluted, causing alterations to natural ecological processes and species composition. Furthermore, desalination plants at some distance from the coast often resort to drilling bore holes to inject brine into deep aquifers, with the resulting risk of groundwater contamination. In other cases, however, brine is discharged directly into river systems, which are consequently polluted, causing alterations to natural ecological processes and species composition. Excess of Boron concentration levels in desalinated water could cause problems in agriculture crops or in animals feed.

**E. Economic effects:** The costs of large-scale desalination as proposed by the AGUA Programme are highly sensitive to variations in energy prices. An increase in water-production costs could severely affect the most sensitive economic activities, particularly traditional farming. Increases in the price of desalinated water for agriculture may require increases in productivity and intensification of farming activity that deteriorate water resource quality. Furthermore, possible fluctuations in demand for desalinated water (periods of greater availability from other sources or a drop in seasonal demand) may affect desalination plants’ economic viability.

### 2.3.1.2 Why this case study is representative and interesting for the EU

The Urgent Actions set out under the AGUA Programme offer a comprehensive alternative designed to meet the estimated combined additional water needs of Spain’s Mediterranean basins and are based to a large extent on desalination. Accordingly, what distinguishes this case study is the fact that the mitigation measures proposed among the desalination options do not refer to a specific project, but rather lie within a complex programme that implements a series of specific desalination projects together with other complementary water planning measures.

Spain currently has the EU’s greatest capacity for desalination, a capacity which is being strengthened by implementation of the measures set forth in the AGUA Programme. The series of mitigation measures laid down in the programme have been designed to allow for evaluation of their effectiveness within a broad framework of water supply and management measures at regional level. This aspect is relevant as a counterpoint to the evaluation and consideration of specific projects, especially when taking into account that certain supply solutions, such as desalination, can be applied locally on a modular basis as an alternative to regional supply systems, such as water transfers, and that, within this context, both the impacts and the mitigation measures and, in general, the suitability or benefits of one option or another should be assessed and compared in the broadest possible context of regional or national supply policy.

### 2.3.1.3 Generic information on location, water supply problems and history

The diagnosis of water resources in Spain, carried out prior to drawing up the AGUA Programme in 2004, highlighted as a key factor in national water policy the fact that available water resources were unequally distributed over Spain's territory and that the endogenous resources of some basins were insufficient to meet the needs arising from economic activity, especially during dry years, which are very common in the Mediterranean region.

In order to address the growing demand for water, successive water policies have given priority to implementing measures to increase water supply, employing active interbasin transfer policies to offset the water deficits in some basins with the surpluses
in others. In line with this policy, Act 10/2001, concerning the National Hydrological Plan, established future construction of major new interbasin transfer infrastructure, with capacity for 1,050 hm$^3$ per year and a length of 916 km, between the Ebro basin, considered to have a surplus, and the rest of the Mediterranean basins (the Catalonian, Jucar, Segura and South basins), considered to have deficits.

When Act 10/2001 was passed, it also had an effect on economic activity in the receiving basins, generally boosted by greater expectations of water availability, especially in the second-home construction and tourism sectors, and on intensive farming.

However, some studies and analyses identified serious social, economic, territorial and environmental risks associated with construction and operation of the new infrastructure, in response to which the Government passed Act 11/2005, whose measures included revoking plans for work on the transfer infrastructure and replacing it with a package of urgent and priority measures aimed at improving resource availability in the Mediterranean basins, and which were intended to spearhead the new national water policy represented by the AGUA Programme.

Figure 7 Desalination plants under the AGUA Programme. and Table 8 show the distribution of the Desalination according to the AGUA Programme forecast (August of 2006) of 713 Hm$^3$/year with an investment of €1,945 millions.

Source: AGUA Programme (August 2006)
### Table 8 Desalination AGUA Programme

<table>
<thead>
<tr>
<th>Provinces</th>
<th>Capacity (Hm³/year)</th>
<th>Provinces</th>
<th>Capacity (Hm³/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barcelona</td>
<td>60</td>
<td>Baleares</td>
<td>17</td>
</tr>
<tr>
<td>Girona</td>
<td>10</td>
<td>Canarias</td>
<td>19</td>
</tr>
<tr>
<td>Castellon</td>
<td>33</td>
<td>Almeria</td>
<td>117</td>
</tr>
<tr>
<td>Valencia</td>
<td>8</td>
<td>Malaga</td>
<td>100</td>
</tr>
<tr>
<td>Murcia-Alicante</td>
<td>314</td>
<td>Ceuta and Melilla</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>713</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: AGUA Programme*

#### 2.3.1.4 Context in terms of water supply issues in the EU

The AGUA Programme constitutes a reorientation of water policy and planning in Spain and represents a commitment to a new model based on managing demand and on exploiting alternative water sources. Plan promoters indicate that its aim is to try to defend the combined considerations of economic development, social cohesion, environmental protection and comprehensive water management in each basin as basic principles. It therefore takes into account resource limits, the need to incorporate cost calculations to guarantee the sustainability of resources and associated ecosystems and the efficient, rational use of water resources.

The AGUA Programme’s Urgent Actions, as an alternative to transferring water to the Mediterranean basins, rely on savings measures and on modernizing irrigation and supply infrastructure, as well as on increasing available resources through alternative measures, such as reusing treated water, new water abstraction and, in a significant proportion, desalination, which has to cover slightly over 50% of the 1000 hm³ per year planned under the Ebro transfer.

#### 2.3.1.5 Brief description of relevant mitigation measures and problems they address

Table 9 summarises the main mitigation measures to be applied in the desalination plants planned under the AGUA Programme and assesses their potential to reduce impacts. Mitigation measures and assessment of potential to reduce impacts have been included in section 2.3.2.

*Table 9 Summarising impacts and mitigation measures applied in desalination plants planned under the AGUA Programme*
## Chapter 2 Mitigation measures associated with desalination

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mitigation measures</th>
<th>Potential to reduce impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Intensified use of energy</strong></td>
<td>- Increase in R&amp;D to incorporate renewable energies associated with desalination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Research into direct use of mechanical energy produced by energy collection systems used in desalination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Incorporate pressure-recovery and co-generation systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Encourage alternative and more efficient systems</td>
<td>Complete</td>
</tr>
<tr>
<td><strong>2. Impacts on the marine environment</strong></td>
<td>- Avoid brine discharges in sensitive areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Avoid discharges in less hydrodynamic areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Select discharge points by analysing the saline plume’s behaviour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Collect brine for discharge in suitable marine areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Substitute discharge with evaporation in waterproof tanks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Advance research into brine impacts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Set up environmental monitoring programmes for seagrass meadows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Avoid interrupting the dynamics of sediments along the coast</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Avoid causing an increase in turbidity that could affect marine flora</td>
<td>Complete</td>
</tr>
<tr>
<td><strong>3. Impacts on land use, nature and biodiversity</strong></td>
<td>- Avoid siting plants in areas of high ecological value</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Take into consideration environmental restoration and conditioning of the surrounding area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Design water channelling and distribution infrastructure to avoid areas of high ecological value and avoid habitat fragmentation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Prevent brine being injected into aquifers or discharged into river courses</td>
<td>Complete</td>
</tr>
<tr>
<td></td>
<td>- Prevent direct discharge into river courses or dry river beds</td>
<td>Complete</td>
</tr>
</tbody>
</table>


### 2.3.1.6 Information available and our approach for this study

The information used in drawing up this chapter has been taken from a variety of sources among them, the Environmental Sustainability Report for the AGUA Programme’s Urgent Actions in Mediterranean Basins, a document that sets forth a series of environmental measures planned within the actions included in the AGUA Programme’s Urgent Actions. In addition, consultations were made with the Environment Department of the public company AcuaMed (http://www.AcuaMed.com/), a state-owned company reporting to the Spanish Ministry of the Environment and Rural and Marine Affairs and responsible for contracting, building, acquiring and operating hydraulic works in Spain.

It is worthwhile pointing out that the Spanish Ministry of the Environment and Rural and Marine Affairs and Acuamed have published a book exclusively dedicated to "Desalination in Spain" (2008).

### 2.3.2 Mitigation measure: Improving energy efficiency and using renewable energy sources

#### 2.3.2.1 Summary

The main environmental impact arising from desalination stems from its energy consumption and its contribution to climate change.

The mitigation measures being applied are the promotion of R&D to reduce energy consumption and the promotion of renewable energies; in particular, planning a programme of renewable energies for offsetting increases in energy consumption associated with the desalination. This programme’s success is the key factor in ensuring that the impact of greenhouse gas emissions is minimised.

#### 2.3.2.2 Problem and impacts

The main environmental impact arising from desalination stems from its energy consumption and its contribution to climate change, which can only be directly abated to some extent by using renewable energies and with technologies improvements.
Spain is highly dependent on overseas energy sources and besides, compliance with the Kyoto Protocol on greenhouse gas emissions have not been met. Desalination requires significant levels of energy consumption: energy consumption by reverse osmosis can be estimated at 5 kWh/m$^3$ and emissions can be estimated at 2.65 kg CO$_2$/m$^3$ supplied; Emissions resulting from construction of the desalination plants are calculated at 3.5 kg CO$_2$/m$^3$ supplied. This would mean that over 50 years, with production of 541 Hm$^3$/year: approximately 72.62 millions tonnes would be generated.

Spanish Drought Committee modifies these figures in the publication Drought in Spain, 2007 Report, considering that energy consumption are 4 kWh/m$^3$ and CO$_2$ emissions are 460g/kwh and 1.84 kg CO$_2$/m$^3$ and carbon emission rights could increase desalinated water cost in 0.04€/m$^3$.

### 2.3.2.3 Technical description of the mitigation measure

The AGUA Programme encourages research into ways to reduce energy consumption, promoting the efficient, alternative systems rather than conventional ones, but total consumption is important, anyway.

With problems and impacts in mind, the Renewable Energies Associated with Desalination Programme is being implemented by a Technical Committee reporting for the Spanish Ministry of the Environment, Rural and Marine, and working in collaboration with the CEDEX (Spanish Centre for Public Works Studies and Experimentation), the IDAE (Spanish Institute for Energy Saving and Diversification –), the Secretariat General for Energy and Acuamed. The Technical Committee is chaired by the Director General for Water. The renewable energies programme’s basic objective is to encourage desalination associated with energy efficiency and the use of renewable energies.

As the main mitigation measures to avoid intensive energy use and an increase in greenhouse gases, the AGUA Programme proposes the following measures:

- Increase R&D into use of renewable energies associated with desalination – solar power, tidal power, wind power and biomass energy.
- Research into direct use of mechanical energy produced by some energy collection systems used in desalination.
- Research and incorporate pressure-recovery systems into desalination.
- Promote the use of co-generation.

Simultaneously, measures to improve energy efficiency in reverse osmosis plants are to be fostered:

- Speed regulators: The pumps adjust their duty point between flow and pressure according to the resistance offered by the circuit. This means that if the resistance varies, the duty point moves to an equilibrium point that could be a long way from maximum performance. Speed regulators, by modifying the pump’s rotation speed and not its flow, improve performance and achieve greater energy savings.
- Pressure-recovery devices: Brine from the membranes is kept at high pressure, similar to intake pressure, and recovery devices are available that are able to take advantage of this energy (compact turbo-pumps, reverse-running pumps, Pelton turbines, integrated turbochargers and Pelton-wheel pumps) and recover between 30% and 40% of the energy from the osmosis process$^{16}$. The AGUA Programme’s Actions plan to make widespread use of these systems.

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$^{16}$ “Desalación de aguas salobres y de mar. Osmosis Inversa” José Antonio Medina San Juan
2.3.2.4 Evaluation of the mitigation measure

Technical and environmental evaluation

The measures included in the Renewable Energies Associated with Desalination Programme, see Table 10, are not all aimed at directly acting on desalination plants and, consequently, some of them should be considered more compensatory than mitigation measures. The nine measures being promoted are as follows:

<table>
<thead>
<tr>
<th>Renewable Energies Associated with Desalination Programme</th>
<th>Mitigation Measures</th>
<th>Compensatory Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase in available hydroelectric power</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2. Next-generation wind-power facilities at dams with hydroelectric power stations</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3. Wind-power facilities for desalination at existing plants</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4. Solar-power production combined with biomass</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>5. Use of solar panels to supply auxiliary services</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>6. Energy efficiency improvements at hydraulic facilities operated by Water Authorities</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>7. Energy efficiency improvements at existing desalination plants</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8. Promotion of renewable energies and improved efficiency in modernising irrigation</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>9. Encourage research, development and innovation in improving energy efficiency at desalination and reverse osmosis plants</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Source: In-house, based on the Ministry of the Environment Press Release dated 24-06-06

Table 10 Mitigation and compensatory measures to promote renewable energies and energy saving

Total installed power capacity expected from renewable sources, together with the energy savings expected from efficiency improvements, would amount to 1,120 MW, which would more than quadruple the 260 MW installed capacity of the desalination plants proposed. This power capacity is expected to produce and save around 2,875 GWh/year, approximately 1.5 times the consumption anticipated for desalination plants in full operation, which would be 1,950 GWh/year. Accordingly, the proposed measures would comply with the objective of wholly offsetting the increases in power and energy consumption associated with the desalination actions laid down by the AGUA Programme for the Mediterranean basins.

This programme's success is the key factor in ensuring that the Programme’s associated consumption is covered by renewable energies and, therefore, it could ensure that the impact of greenhouse gas emissions would be minimised.

As regards the use of renewable sources at desalination plants, it has been noted that their normally irregular production constitutes a drawback, as do the factors conditioning their physical siting. Direct transformation of wind energy into pressure used in the desalination process is also a viable option. And it is possible to store desalinated water in tanks, which would improve the options for discontinuous production adapted to energy production; however, this solution raises technical problems arising from degradation of membranes in discontinuous use and siting of desalination water tanks.
Chapter 2 Mitigation measures associated with desalination

At present IDAE (Spanish Institute for energy diversification and saving) and Ministry of Environment are developing projects, but there is not a report about the state of this programme.

R&D projects are being developed to produce wind power and desalinated water at an off-shore park in Gondo (Canary Islands). This project has five wind power turbines of 2 MW, and 32 units of 1000 m$^3$ desalinated water per day.

2.3.2.5 Economic and social evaluation

The estimated budget for measures in the Renewable Energies Associated with Desalination Programme in the five-year period 2006-2010 amounts to €1.500 millions$^{17}$.

It’s a very considerable cost if it’s compared with AGUA Programme that has a budget of €1,945 millions for desalination out of a total investment of €3,800 millions.

2.3.2.6 Conclusions

Desalination energy consumption could reduce their effects to the extent that greater technological efficiency would be achieved, through R&D, and to the extent that the Programme on Renewable Energies associated with desalination would be implemented. But the proposed large-scale desalination actions suppose considerable energy consumption, anyway.

It is necessary to point out that installed power capacity is not the same as energy production; therefore, a final balance between used and produced energy would be advisable.

Furthermore, the measures included in the Renewable Energies Associated with Desalination Programme, are not all aimed at directly acting on desalination plants and, consequently, some of them should be considered more compensatory than mitigation measures.

Besides, an ex-post assessment on energy consumption of desalination plants and use of renewable sources would be also advisable.

In summary, the reduction due to energy consumption would be considerable, but partial, it fully depends on the successful implementation of the Renewable Energies Programme, and it could be considered as uncertain, because the success of R&D activities is not assured.

2.3.3 Mitigation measure: reducing adverse impacts on marine and coastal ecosystems

2.3.3.1 Summary

The mitigation measures to reduce adverse impacts on marine and coastal ecosystems relate to the design of marine outfalls from desalination plants and the correct choice of discharge points, preventing brine discharge into sensitive areas and avoiding areas with low hydrodynamics.

$^{17}$ In-house, based on the Ministry of the Environment Press Release dated 24-06-06
In the event of not identifying appropriate discharge sites, the proposed mitigation measures involve collecting the brine for discharge in other marine areas and using evaporation systems based on waterproof tanks. Furthermore, and as a transversal measure, the need has been highlighted to advance research projects into the impact of brine and to establish environmental monitoring programmes in ecosystems, especially seagrass meadows, which are highly sensitive to saline discharges. An ex-post assessment on impacts on marine ecosystem related with desalination plants, mainly on *Posidonia oceanica*, would be advisable.

### 2.3.3.2 Problem and impacts

The most important direct impacts from brine discharge can take place on marine flora, with effects that are passed on throughout the ecological chain. Seagrass meadows are especially sensitive, as is the case of *Posidonia oceanica*, included in Annex 1 of Directive 92/43/EEC, and they are fundamental to the conservation of Mediterranean marine ecosystems. The analyses carried out on *Posidonia oceanica*’s tolerance to salinity established that the maximum tolerable salinity is 39 g per litre and an salinity increase of 1 kg were estimated in a CEDEX study (Torres, Miguel CEDEX). Besides, effluent from desalination usually contains traces of additives used in the desalination process, which may be toxic and alter the conditions of the receiving ecosystem (modification of the water's physical and chemical properties, changes in hardness and drop in pH and eutrophication).

The behaviour of the saline plume at the brine outfall is determined, to a large extent, by the siting, length and depth of the outfall or discharge, and by the hydrodynamics of the discharge area, upon which discharge dilution capacity depends. All these factors vary in influence and according to siting and, therefore, are variable in each desalination plant. Construction of desalination infrastructure and its associated buildings along the coast may affect coastal dynamics by increasing erosion and sedimentation processes.

### 2.3.3.3 Technical description of the mitigation measure

To minimise the possible impacts associated with the plants' siting, the AGUA Programme requires desalination plants to be located outside of fragile areas or areas of high ecological value. This considerably hampers the search for areas with suitable conditions for siting a desalination plant, and sometimes is not so easy in the Mediterranean coast, because the high level of land occupation (urban, agricultural or industrial).

To avoid damage to marine ecosystems, it is essential that brine discharge takes place away from sensitive areas. The AGUA Programme proposes the following measures:

- Avoiding direct discharge in marine ecosystems of high ecological value, especially over meadows of *Posidonia oceanica* (priority habitat included in Annex 1 of Directive 92/43/EEC).
- Avoiding discharge in areas with low hydrodynamics, especially enclosed zones such as bays and coves, where the discharge dilution capacity is low.
- Choosing brine discharge points, after analysing hydrodynamic parameters, which allow the saline plume’s behaviour to be interpreted, ensuring minimum impact on the marine environment in each specific case.
- Brine collection, transport and discharge in marine areas where the hydrodynamic conditions, chemical composition and other factors in the receiving environment ensure minimum possible impact.
• Substituting brine discharge with evaporation in properly waterproofed tanks. This measure requires evaluation of the effects of siting, foreseeable in a coastal area.

• Advancing research into brine impacts on the coast. Studies are required into the effects of the discharge’s separate elements and their possible interactions and synergies, establishing the tolerance limits for each different substance.

• Establishing a strict environmental monitoring programme for seagrass meadows, fishery resources and other marine environment resources.

As regards the construction of infrastructure on the coast, the choice of plant siting is fundamental, the impact on marine environments will be minimised by applying the following measures:

• Not interrupting the dynamics of coastal sedimentation, which could give rise to sediment accumulations and erosion along the coastline, altering the habitat of meadows of *Posidonia oceanica*.

• Not causing an increase in turbidity that blocks out light, reducing the photosynthetic capacity of macrophytes, algae and phytoplankton.

Furthermore, and as a transversal measure, the need has been highlighted to advance research projects into the impact of brine and to establish environmental monitoring programmes in ecosystems, especially seagrass meadows, which are highly sensitive to saline discharges.

### 2.3.3.4 Evaluation of the mitigation measure

The necessity of plant location outside of fragile areas or areas of high ecological value hampers considerably the search for areas for siting a desalination plant, and sometimes is not so easy in the Mediterranean coast, because the high level of land occupation.

At this moment, there isn’t a general impact assessment, because some plants are under construction and others has been opened lately. In Box 1 case of the desalination plant in Javea (Alicante-Spain) is revised, and mitigation measures are being a success there.

Any case, an ex-post assessment on impacts on marine ecosystem related with desalination plants, mainly on *Posidonia oceanica*, would be advisable.

### Box 1 Case of the desalination plant in Javea (Alicante-Spain)

The most important mitigation measures implemented in designing the desalination plant in Javea (Alicante-Spain) were:

1. Modifying the discharge point in the River Gorgos, due to the proximity of meadows of *Posidonia oceanica*, using the Canal de la Fontana, an artificial canal built for leisure use,

2. Brine was mixed with water from the River Gorgos to reduce its salinity.

3. Carrying out discharge via 16 sprinklers to increase dilution in the canal.

4. Carrying out several campaigns of sampling and environmental monitoring of the brine’s dispersion and dilution, and of the most sensitive communities, by the University of Alicante’s Marine Biology Unit.

The environmental monitoring programme for the desalination plant sampled areas near the discharge, and permanent beds of *Posidonia oceanica* close to the discharge were monitored. Salinity data were analysed using a variety of data-processing and spatial-imaging programmes to determine the differences between discharge areas and control areas.

The analyses pointed out that:\(^{18}\)

\(^{18}\) Data should be reviewed when the plant is enlarged and goes from its current two racks to six, which would increase the area affected
• Highest salinity occurred in the canal, without surpassing 44 units of salinity. Due to brine discharge and low water circulation, this canal does not have a significant benthic community, so it is ideal for discharge. The phosphorus, nitrite and nitrate levels detected in the discharge may be caused by other discharges in the canal. The discharge has avoided anoxia problems generated by the canal’s low water circulation.

• At the canal outlet, the area affected by the discharge is very small in summer and non-existent in winter (the plant reaches maximum output in summer, the hydrodynamic conditions are not as significant and there is less water in the canal). The salinity in the canal bed stretches about 300 metres from the canal mouth, and the saline plume’s shape and direction depends upon local bathymetry, where the discharge follows the direction of the greatest incline. Such insignificant effects may be explained by the brine’s dilution before discharge and by the area’s hydrodynamic factors.

• The population dynamics of *Posidonia oceanica* exhibit homogeneous behaviour and echinoderms, organisms highly sensitive to salinity, show no differences with respect to control stations. Marine seagrasses, such as *Posidonia oceanica*, are highly sensitive to marine actions along the coast and also to hypersaline discharges, so an effort should be made to prevent desalination waste from affecting them.

Monitoring has also allowed recommendations to be made regarding: diluting the brine with sea water prior to discharge, discharging in already-degraded areas, discharging in highly hydrodynamic areas and carrying out an environmental monitoring programme while the desalination plant is in operation\(^{19}\).

**Source:** In-house based on mitigation measures for the possible environmental impact of reverse osmosis desalination plants: the example of Jávea (Alicante)\(^{20}\).

### 2.3.3.5 Conclusion

The impacts on the marine environment depends on the desalination plants’ design, and taken measures could be enough to get a good level of impact reduction. This has been proven in a real case, see Javea case study in Box 1, although a extent analysis to the rest of desalination plants would be necessary to do a proper assessment. Monitoring and an ex-post assessment on impacts on marine ecosystems would be advisable.

Besides, an adequate plant location is not always easy in the Mediterranean coast, because the high level of land occupation.

In summary, the reduction of impacts on marine and coastal ecosystem would be considered partial, due to uncertainties to find adequate plant location and the great importance of Mediterranean ecosystems.

### 2.3.4 Mitigation measure: Reducing adverse impacts on land use

#### 2.3.4.1 Summary

The main mitigation measure for the effects on land use is the selecting of an optimum site for the desalination plants and their adjoining infrastructure, mainly aiming to

\(^{19}\) It should be noted that information on dispersion of hypersaline discharges from desalination plants in the saline ecosystem is very scarce.

\(^{20}\) Torquemada, et al. Marine Biology Unit, Environmental Science and Natural Resources Dept. and Chemical Engineering Dept. University of Alicante.
avoid siting them in areas of high ecological value. Locating the plants on sites away from urban zones and in non-sensitive areas on the Spanish Mediterranean coast is not always easy because of the high level of land occupation by human activities.

Once the location has been chosen and the works carried out, the projects must consider restoring the environment and conditioning the surrounding area. An ex-post assessment on impacts on coastal areas related with desalination plants, mainly on protected areas, would be advisable.

2.3.4.2 Problem and impacts

Mediterranean coastal areas are often fragile and many of them protected areas, with high conservation values, as is the case of coastal dunes, beaches or coastal wetlands. Desalination plants, on the other hand, are industrial facilities and, furthermore, are generally sited in coastal areas within 2 km of the sea or at river mouths, outside of urban areas.

Desalination plants also require pipelines for seawater intake, for removing brine and for subsequently distributing the product, as well as pumping stations, storage tanks and infrastructure that occupies and fragments the territory if it is not properly planned.

2.3.4.3 Technical description of the mitigation measure

To minimise the possible impacts associated with the plants' siting, the AGUA Programme requires desalination plants to be located outside of fragile areas or areas of high ecological value. This considerably hampers the search for areas with suitable conditions for siting a desalination plant, and sometimes is not so easy in the Mediterranean coast, because the high level of land occupation.

Desalination plants also require pipelines for seawater intake, for removing brine and for subsequently distributing the product, as well as pumping stations, storage tanks and infrastructure that occupies and fragments the territory if it is not properly planned.

The AGUA Programme plans to prevent the deterioration of high-ecological-value coastal areas, which could be affected by occupation of their territory and the impact on the landscape of building or enlarging desalination plants, by applying the following measures:

- Avoiding siting desalination plants in areas of high ecological value with regional, national or European protection status. Avoiding sitings that may affect fragile and valuable habitats, including those that are not protected areas, especially the areas included in Annex 1 of Directive 92/43/EEC – coastal lagoons and dune systems colonised by pines or juniper.

- In each case, considering an environmental restoration project and conditioning the use of the environment around the desalination plant to compensate for negative effects, which involves making the environmental and cultural resources associated with the coastline available for public and educational use.

2.3.4.4 Evaluation of the mitigation measure

Efforts are being made to minimize desalination risks associated to land occupation, success on minimising these risks depends on proper siting of desalination plants and involves the added difficulties arising from having to locate them in densely populated areas and with high level of land occupation.

Therefore, the solution of impact mitigation could be considered as partial due to difficulty and uncertainties to find adequate plant location in the Mediterranean coast.

An ex-post assessment on impacts on coastal areas related with desalination plants, mainly on protected areas, would be advisable.
2.3.5 Mitigation measures: Reducing adverse impacts on aquifers and rivers system

2.3.5.1 Summary

The mitigation measures to reduce impacts on aquifers will be applied when designing the desalination plants, avoiding the injection of brine into aquifers or brine discharges into rivers. In cases where it is necessary to inject brine in deep aquifers, their geology will be studied to avoid polluting and degrading other adjacent aquifers. An ex-post assessment on aquifers and river systems would be advisable.

2.3.5.2 Problem and impacts

Salt-water desalination plants are fed from aquifers degraded by abstraction of irrigation water, leaching of fertilisers and other agricultural agents, and seawater intrusion in the case of coastal aquifers. Salt-water abstraction for desalination may contribute to further salinating aquifers, either directly or through seawater intrusion. Furthermore, desalination plants at some distance from the coast often resort to drilling bore holes to inject brine into deep aquifers, with the resulting risk of groundwater contamination.

In other cases, however, brine is discharged directly into river systems, which are consequently polluted, causing alterations to natural ecological processes and species composition. Excessive Boron concentration levels in desalinated water can cause problems in agriculture crops or in animals feed.

2.3.5.3 Technical description of the mitigation measure

The AGUA Programme plans to diminish the burden on aquifers, reducing the risk of loss of water quality through over-abstraction, by applying the following measures:

- Avoiding project designs in which brine is injected into aquifers or discharged into river channels, with the resulting risk of losing the minimum quality necessary for agricultural and domestic uses. When this is impossible, geological studies will be carried out to identify deep aquifers with no risk of polluting adjacent aquifers.

The Programme of Urgent Actions proposes to ensure that no negative effects are caused in river systems and to guarantee minimum impact by water channelling and distribution infrastructure from desalination plants to end consumers, by means of:

- Designing the routing of channelling infrastructure to avoid areas of high ecological value with protected status and, as far as possible, taking advantage of existing infrastructure to avoid further habitat occupation and fragmentation.

- Improving the ecological permeability of infrastructure by incorporating specific solutions (underground sections, aqueducts, etc.) or by incorporating crossing points for fauna.

Boron concentration levels in desalinated water has been brought up in discussions about the desalinated water in Spain. Desalinated sea water could causes problems in agriculture crops or in animals feed if boron concentration is not sufficiently reduced. Also, Boron concentration levels need to adhere to the Spanish water quality standards:

- human consumption less than 0.5 mg/l (OMS21)

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21 The World Health Organization (WHO) designates a provisional guideline value of 0.5 mg/litre for drinking water.
Mitigation measures associated with desalination

- agricultural watering more than 0.5 ppm and less than 2-3 ppm, except for citrus fruits, when has to be less than 0.75 ppm

The management of boron concentration is a technological problem, which is being solved in the design phase of new desalinated plants.

2.3.5.4 Evaluation of the mitigation measure

Risks on aquifers and rivers systems have tried to be minimised, but depends on the availability of suitable places for brine discharge. Salt-water desalination plants fed from aquifers may contribute to further salinating aquifers or seawater intrusion, but great majority of desalination plants are feed by marine water. Therefore, the solution of impact could be considered as partial, with more uncertainties and risks in salt-water desalination plants. An ex-post assessment on impacts on river systems and ecological permeability related with desalination plants would be advisable, especially on salt-water desalination plants placed far from coast.

2.3.6 Mitigation measure: Reducing adverse economic impact of rising water prices

2.3.6.1 Summary

The costs of large-scale desalination as proposed by the AGUA Programme are highly sensitive to variations in energy prices. An increase in water-production costs could severely affect the most sensitive economic activities, particularly traditional farming. Furthermore, Increases in the price of desalinated water for agriculture may require increases in productivity and intensification of farming activity that deteriorate water resource quality.

Besides, possible fluctuations in demand for desalinated water (periods of greater availability from other sources or a drop in seasonal demand) may affect desalination plants’ economic viability. Nevertheless, the desalination alternative’s greater capacity to modulate and adapt to demand when compared with the transfer option improves the likelihood of effectively managing these risks.

The AGUA Programme is also trusted to progressively cutting production costs on the basis of technological improvement, mainly in plants’ energy efficiency and other significant costs, such as replacement of reverse osmosis membranes.

2.3.6.2 Problem and impacts

Desalinated water production costs can be accurately calculated, so they can therefore be easily passed on to final water prices. Passing on these costs will presumably involve an increase in comparison with current water prices and, consequently, may have an impact on the competitiveness of certain industries and particularly the agricultural sector.

Desalinated water may bring about an increase in costs with respect to the traditional costs of other supply sources, which could encourage farmers to produce more intensively, fomenting negative environmental dynamics, mainly through increases in the use of fertilisers and phytosanitary products. Furthermore, a greater volume of available water may give rise to an increase in the size of intensive farming operations.
2.3.6.3 Technical description of the mitigation measure

Concern about an increase in water prices is one of the factors behind social resistance to implementing a programme to recover desalination costs in full. To address these negative effects, the AGUA Programme proposes:

- Studying the structure of irrigation costs in the Mediterranean basins to assess the repercussions of potential water price increases on the activity’s viability.
- Establishing protection measures and/or compensation mechanisms to safeguard traditional irrigation systems with cultural and social values that are relevant to the land-use model.
- Establishing a realistic co-ordination and programming framework for cost integration measures to adapt the economically weakest sectors to production conditions.

Furthermore, in order to reduce the price increase’s impact on agriculture, the former Spanish Ministry of Agriculture proposed a subsidy for desalinated water that cut its price to €0,30/m\(^2\), a reduction justified by agriculture’s lower capacity to absorb the real cost of water. According to this intervention measure, agreements have been signed between irrigation associations in Almería and Murcia. Full real cost of desalination is applied to urban and industrial users.

The AGUA Programme is also committed to progressively cutting production costs on the basis of technological improvement, mainly in plants’ energy efficiency and other significant costs, such as replacement of reverse osmosis membranes.

The AGUA Programme plans to diminish the economic risks and avoid agriculture intensification, therefore lays down measures to:

- Implement minimum environmental quality thresholds on farming operations, which will affect the beneficiaries of the new resources, and proposes an monitoring programme to detect and control processes that deteriorate resource quality.

Additionally, the application of policies to reallocate water rights has effects on production activities in the Mediterranean basins, on the population and on territorial balance. Market mechanisms to reallocate water resources may lead to a strengthening of the sectors with greatest economic power, especially tourism and housing, to the detriment of traditional farming, and their effects would be felt most along the coast, which has the most fragile and vulnerable systems. In the agricultural sector, an increase in water prices may also boost technology-based intensive farming in comparison with traditional irrigation farming, which is more common in the basins’ inland areas.

As intervention measures, the AGUA Programme proposes:

- Establishing mechanisms to control water rights trading so that the reallocation of resources takes into account the possible social and territorial effects.

2.3.6.4 Evaluation of the mitigation measure

The impacts on economic sectors’ competitiveness are tried to be minimised to the extent that the cost-integration programmes, adapted to the least competitive economic sectors, are successful. But an increase in the water price could be difficult to avoid if cost recovery system would have to be developed. Least competitive farmers would be the most affected.

\[22\] Water and Progress Foundation supports that desalination price is closed to 1 €/m\(^3\), far from 0.3-0.4 €/m\(^3\) suggested by the Environmental Ministry to farmers.
Besides, technological improvement in desalination technology could be more difficulty, due to there's less room for improvement than years before had. Finally, Impacts caused by intensification of farming practices are tried to be minimised to the extent of the environmental quality control programmes' success in farming operations. But the programmes' success is also uncertainty, since intensification could be difficult to reduce if water price would be increased. Therefore, the solution of impact could be considered as partial, with more uncertainties to the least competitive farmers.

### 2.3.7 Review of case study achievement and the need for future mitigation measures

Below we review the case study achievements and the need for future mitigation measures

#### 2.3.7.1 Mitigation measure: Improving energy efficiency and using renewable energy sources

The main environmental impact arising from desalination stems from its energy consumption and its contribution to climate change. The mitigation measures are the promotion of R&D to reduce energy consumption and the promotion of renewable energies: planning the Renewable Energies Associated with Desalination Programme for offsetting increases in energy consumption associated with the desalination.

Total installed power capacity expected from renewable sources is expected to produce and save around 2,875 GWh/year, approximately 1.5 times the consumption anticipated for desalination plants in full operation, which would be 1,950 GWh/year. This programme's success would be the key factor in ensuring that the impact of greenhouse gas emissions is minimised. But some of the measures should be considered more compensatory than mitigation measures.

It is necessary point out that a final balance between used and produced energy would be advisable. Besides, an ex-post assessment on energy consumption of desalination plants and use of renewable sources would be also advisable.

The reduction in energy consumption depends on the successful implementation of Renewable Energies Programme in the region. In the future the progress of R&D activities to improve the performance of renewable energy resources is uncertain.

#### 2.3.7.2 Mitigation measure: Reducing adverse impacts on marine and coastal ecosystems

These mitigation measures relate to the design of marine outfalls from desalination plants and the correct choice of discharge points, preventing brine discharge into sensitive areas and avoiding areas with low hydrodynamics. In the event of not identifying appropriate discharge sites, the proposed mitigation measures involve collecting the brine for discharge in other marine areas and using evaporation systems based on waterproof tanks and diluting the brine with sea water prior to discharge, discharging in already-degraded areas.

As a transversal measure, the need to advance research projects into the impact of brine and to establish environmental monitoring programmes in ecosystems, especially seagrass meadows.
Chapter 2 Mitigation measures associated with desalination

The impacts on the marine environment depend on the desalination plants’ design, and taken measures could be enough to get a good level of impact reduction, but monitoring and an ex-post assessment on impacts on marine ecosystems would be advisable.

An adequate plant location is not always easy in the Mediterranean coast, because the high level of land occupation.

In summary, the reduction of impacts on marine and coastal ecosystem would be considered partial, due to uncertainties to find adequate plant location and the great importance of Mediterranean ecosystems.

2.3.7.3 Mitigation measure: reducing adverse impacts on land use

The mitigation measures are based on selecting an optimum site for the desalination plants and their adjoining infrastructure, mainly aiming to avoid siting them in areas of high ecological value. Once the location has been chosen and the works carried out, the projects must consider restoring the environment and conditioning the surrounding area. An ex-post assessment on impacts on coastal areas related with desalination plants, mainly on protected areas, would be advisable.

Efforts are being made to minimize desalination risks associated to land occupation, therefore, the solution of impact mitigation could be considered as partial due to difficulty and uncertainties to find adequate plant location along the Mediterranean coast.

2.3.7.4 Mitigation measures: Reducing adverse impacts on aquifers and rivers system

The mitigation measures to avoid the leakage/infiltration of brine into aquifers and river systems are applied when designing the desalination plants. In cases where it is necessary to inject brine in deep aquifers, their geology are studied to avoid polluting and degrading other adjacent aquifers. Salt-water desalination plants fed from aquifers may contribute to further salinating aquifers or seawater intrusion, but great majority of desalination plants are feed by marine water.

In order to ensure that minimize negative effects are caused in river systems and to guarantee minimum impact by water channelling and distribution infrastructure from desalination plants to end consumers, by means of: firstly, designing the routing of channelling infrastructure to avoid areas of high ecological value with protected status and, as far as possible, and secondly, taking advantage of existing infrastructure to avoid further habitat occupation and fragmentation and improving the ecological permeability of infrastructure by incorporating specific solutions or by incorporating crossing points for fauna.

Therefore, the solution of impact could be considered as partial, with more uncertainties and risks in salt-water desalination plants. An ex-post assessment on impacts on river systems and ecological permeability related with desalination plants would be advisable, especially on salt-water desalination plants placed far from the coast.
2.3.7.5 Mitigation measure: Reducing adverse economic impact of rising water prices

The costs of large-scale desalination as proposed by the AGUA Programme are highly sensitive to variations in energy prices. An increase in water-production costs could severely affect the most sensitive economic activities.

A general economic mitigation measure is related to technological improvement in order to progressively cut production costs. Other mitigation measures are related with studying the repercussions of potential water price increases on an activity’s viability, establishing protection measures to safeguard traditional irrigation systems with cultural and social values that are relevant to the land-use model and, finally establishing a realistic co-ordination and programming framework for cost integration measures to adapt the economically weakest sectors to production conditions.

On the other hand, increases in the price of desalinated water for agriculture may require increases in productivity and intensification of farming activity that deteriorate water resource quality. Mitigation measures are related with implementing minimum environmental quality thresholds on farming operations, which will affect the beneficiaries of the new resources, and proposes an exhaustive monitoring programme to detect and control processes that deteriorate resource quality. In addition, other means involve establishing mechanisms to control water rights trading so that the reallocation of resources takes into account possible social and territorial effects.

Finally, possible fluctuations in demand for desalinated water (periods of greater availability from other sources or a drop in seasonal demand) may affect desalination plants’ economic viability.

The impacts on economic sectors' competitiveness need to be minimised to the extent that the cost-integration programmes, adapted to the least competitive economic sectors, are successful. But an increase in the water price could be difficult to avoid if a cost recovery system is required. Least competitive farmers would be the most affected.

In addition there is limited technological improvements in desalination technology expected in the future. So general costs are unlikely to reduce significantly.

2.3.8 Summary and Conclusions

The main risks considered by the Urgent Actions in Mediterranean Basins under the AGUA Programme as regards desalination, are: impacts from intensive energy use and problems associated with greenhouse gas emissions; impacts on marine and coastal ecosystems, especially the risk of effects upon marine flora; impacts on land and on nature and biodiversity, especially relevant in the Mediterranean area considering the high level of land occupation by human activities; impacts on aquifers, which are at risk of deteriorating below their initial situation; impacts on river systems, due to brine discharge in river courses or dry river beds; and economic effects, mainly through the expected increase in the cost of water.

2.3.8.1 How were the different problems or concerns addressed

For each of the risks identified, the Urgent Actions plan to introduce mitigation measures to reduce the risks identified in implementing desalination projects. With respect to impacts from intensive energy use for desalination, the mitigation measures being applied are the promotion of R&D to reduce energy consumption and the promotion of renewable energies; in particular, planning a programme of renewable energies for offsetting increases in energy consumption associated with the desalination, with a budget of €1,500 million for the period 2006-2010, and which is expected to reach 1,120 MW installed power in renewable sources or energy saving...
actions. This programme's success is the key factor in ensuring that the Programme's associated consumption is covered by renewable energies and, therefore, ensuring that the impact of greenhouse gas emissions is minimised. An ex-post assessment on energy consumption of desalination plants and use of renewable sources would be advisable. But some measures included in the Renewable Energies Associated with Desalination Programme are not all aimed at directly acting on desalination plants and, consequently, some of them should be considered more compensatory than mitigation measures.

Secondly, the mitigation measures to reduce impacts on marine and coastal ecosystems relate to the design of marine outfalls from desalination plants and the correct choice of discharge points, preventing brine discharge into sensitive areas and avoiding areas with low hydrodynamics. In the event of not identifying appropriate discharge sites, the proposed mitigation measures involve collecting the brine for discharge in other marine areas and using evaporation systems based on waterproof tanks. Furthermore, and as a transversal measure, the need has been highlighted to advance research projects into the impact of brine and to establish environmental monitoring programmes in ecosystems, especially seagrass meadows, which are highly sensitive to saline discharges. An ex-post assessment on impacts on marine ecosystem related with desalination plants, mainly on Posidonia oceanica would be advisable.

Thirdly, mitigation measures for the effects on land use will be based on selecting an optimum site for the desalination plants and their adjoining infrastructure, mainly aiming to avoid siting them in areas of high ecological value. Locating the plants on sites away from urban zones and in non-sensitive areas on the Spanish Mediterranean coast is difficult because of the high level of human occupation produced during the late 20th century and over the last decade. Once the location has been chosen and the works carried out, the projects must consider restoring the environment and conditioning the surrounding area. An ex-post assessment on impacts on coastal areas related with desalination plants, mainly on protected areas would be advisable.

Fourthly, mitigation measures to reduce impacts on aquifers will be applied when designing the desalination plants, avoiding the injection of brine into aquifers or brine discharges into rivers. In cases where it is necessary to inject brine in deep aquifers, their geology will be studied to avoid polluting and degrading other adjacent aquifers. An ex-post assessment on aquifers and river systems would be advisable.

And mitigation measures to reduce impacts on nature and biodiversity will aim to guarantee optimum route design for water channelling and distribution infrastructure which avoids passing through areas of high ecological value and resulting habitat fragmentation. They will take advantage of already-existing infrastructure to avoid further land cover or fragmentation and solutions will be included in the design to safeguard the territory's permeability, such as crossing points for fauna, underground sections, aqueducts, etc. An ex-post assessment on impacts on river systems and ecological permeability related with desalination plants would be advisable.

Lastly, expected increases in the price of desalinated water for agriculture may require increases in productivity and, consequently, a greater intensification of farming activity. To address this risk, the mitigation measures will be based on implementing minimum environmental quality thresholds for beneficiary farmers and on developing an exhaustive monitoring programme to detect and control processes that deteriorate resource quality.

Cost increases may affect economic sectors' competitiveness, particularly traditional agriculture, so a study is planned into the cost structure of irrigation in the Mediterranean basins and, specifically, to establish compensation measures and mechanisms for traditional irrigation that forms part of traditional Mediterranean landscapes. The final aim is to establish a cost recovery system adapted to the needs of the weakest economic sectors and establishing mechanisms to control water rights.
trading so that the reallocation of resources takes into account possible social and territorial effects.

2.4 Mitigation measures associated with desalination: case study Aquasol Project, Spain

2.4.1 Introduction

Desalination plays an important role in fighting fresh water shortages in places where sea water is abundant. The latest world inventory of desalination facilities established that around 26 Mm$^3$ of fresh water is produced every day. Two technologies are implemented at commercial scale: thermal process (MSF, MED) and membrane process (RO). RO technology has undergone important improvements regarding energy consumption whereas thermal processes have stagnated. As a consequence, market tendencies show a much more important development of RO as compared to distillation plants. It is in that context, aiming at improving the Multi Effect Distillation process' features, that a research project called AQUASOL was carried out between 2002 and 2006 in Southern Spain.

2.4.1.1 Main adverse impacts of desalination

Risks and negative impacts linked to seawater desalination were identified in Task 1. They were classified into 4 categories:

- **environmental risks.** The most important adverse impacts on the environment are (i) aquifer contaminations (in the case that a desalination plant is constructed inland and seawater has to be transported through pipes that can have leakages) and (ii) marine ecosystem damage due to brine discharge to the sea. Other negative impacts include the impact of noise and the mobilisation of a piece of land on the shore line that could be used for recreation or tourism activities.

- **economical risks.** The production of freshwater with by a desalination technology is costly; having being by a high investment costs as well as but also high recurrent costs, mainly linked to energy requirements. Therefore, the cost to produce 1 m$^3$ of desalted water is often much more expensive than the direct abstraction of fresh water, ranging from around 0.70 €/m$^3$ (reverse osmosis) to more than 1€/m$^3$ (thermal processes).

- **social risks.** In most of the countries, there is no differentiation of price between desalted water and “conventional” water. The cost of desalted water, is usually higher and has a global impact on the water price. Although there were some concerns linked to its the use of the desalted water in the early years (repercussion of households hydraulic systems), desalination desalted water is now in generally fully accepted by the consumers.

- **relevance to global warming issues.** Desalination is probably the option that has the highest green-house gazes emissions amounts per m$^3$ of water produced. This is linked to the important amounts of energy needed to desalt water (between 3.5 and 24 kWh/m$^3$ according to the technology), especially with thermal processes.
2.4.1.2 Relevance of the case study

The AQUASOL project was launched in 2002 and consisted in improving an existing solar energy desalination plant located in Almeria, Andalusia, Spain. The research project focussed on the technological development of three main technological aspects that are expected to improve significantly the present efficiency of the Multi Effect Distillation plant (Blanco et al., 2002).

The case study is unique in the world. The objective of the project was to demonstrate that desalination coupled with solar energy and a zero brine discharge to the sea could be an option to produce freshwater with reduced negative impacts in the countries where seawater is abundant and solar radiation is high.

2.4.1.3 Focus of the case study

The case study illustrates how the most important risks and impacts linked to desalination can be significantly reduced. In particular, the issues that will be discussed are:

- Efficient use of solar energy to reduce fossil energy demand
- Recuperating the salt from the brine to avoid injuries to ecosystems linked to traditional brine discharge and to enhance the process economic figures of the process (selling of the salt)
- Reduction of greenhouse gases emissions

2.4.1.4 Structure and links to the report

After introducing the context of the case study, the mitigation measures and the problems they address are studied in more details. In the case described, For that case study, the mitigation measures correspond to technological improvements. Whenever possible, quantified figures are provided, based on collected data or estimations.

2.4.2 Introduction to the Aquasol case study

2.4.2.1 General information

Seawater desalination using solar energy is seen as an appropriate alternative source of fresh water in countries suffering from important water shortage and having abundant seawater resources and a high level of solar radiation. However, although demonstrated to be as technically feasible for a long time, this technology could so far not compete with conventional thermal or membrane technologies, on a produced water cost basis, compete with conventional thermal or membrane technologies so far.

It is in that context, having with a research objective but also the aim to make the technology economically more competitive, that the original PSA (Plataforma Solar de Almeria) project was initiated in the early 1990s.
The desalination system is based on a Multi-Effect Distillation technology (see illustration box) using a solar system coupled with a heat pump. The nominal distillate production of the plant is 3 m$^3$/h (72 m$^3$/day). The results were globally satisfying but further developments were expected to significantly improve the efficiency.

**Illustration box: Multi-Effect Distillation process**

MED is a desalination technology making part of the Distillation category (such as Multi Stage Flash (MSF)) as opposed to the Membrane category (such as Reverse Osmosis for instance). In MED, vapor from each stage is condensed in the next successive stage thereby giving up the heat to drive more evaporation. To increase the performance, each stage is run at a successively lower pressure. (Miller, 2003).

MED is not widely used. However, it has gained attention due to better thermal performance than MSF. The following figure gives a schematic view of the MED process.

The AQUASOL project ("Enhanced Zero Discharge Seawater Desalination using Hybrid Solar Technology") was then initiated in 2002, after the approval of for partial financing by the European Commission. Three main technology
improvements were targeted: (i) improvement of the heat pump efficiency, (ii) improvement of the solar system efficiency and (iii) reduction to zero of any discharge from the process.

2.4.2.2 Representativness at EU level

The AQUASOL project was developed in a southern region of Spain, particularly suffering from water shortages. However, being a research project, the aim of the plant was to investigate the potential of new technologies rather than producing water in significant amounts to supply local water demand. Indeed, daily production was only 60\(^2\) m\(^3\).

As said in the introduction, the experiment was innovative. As far as it is known, it has not been repeated the same experiment was not carried out since. Although some studies making part of the project have investigated the possibility to build desalination plants using AQUASOL technology at a commercial level, apparently no such plant has would have been built so far.

2.4.2.3 Mitigation measures and problems addressed

The desalination process relies on high quantities of energy to produce 1 m\(^3\) of water and therefore produces high levels of Greenhouse gGazes emissions. According to the technology used, CO\(_2\) emissions are between 1.8 to 23 kg per cubic meter of fresh water produced (see Task 1 - Desalination). In the current global context of significant oil price significant raise and environmental requirements derived from compliance with the Kyoto Protocol, the sustainable development of this alternative water supply option has to pass through energy efficiency improvements as well as the use of renewable energy.

Three main mitigation measures were developed and investigated during the AQUASOL project:

- Improved heat pump
- Improved solar system
- Solar dryer to produce salt from the brine

These technologies allowed addressing or reducing three types of problems:

- **Economic risks:** the improvement of a heat pump as well as the coupling of solar energy with fossil energy aims at reducing the overall cost linked to water desalination. Moreover, the profits generated by the sales of the salt should also help reducing the production cost per cubic meter of water.

- **Environmental risks:** the brine discharge to the sea of conventional desalination plants can cause severe damages to the coastal ecosystems. The development of a solar dryer to produce salt from the totality of the brine was part of the project.

- **Global warming issues:** the desalination process is highly energy consumptive, leading to high levels of gGreenh-House gGazes emissions. The use of solar energy and the improvement of the heat pump efficiency allowed reducing the amounts of energy needed to desalt 1 m\(^3\) of water.

The following table illustrates the crossing between the mitigation measures and the risks they address. Three levels of are considered: totally (++), partially (+) and not at all (–).
all (-). One can state that some technologies allow addressing several problems and some problems are addressed by more than one mitigation measure.

<table>
<thead>
<tr>
<th>Mitigation measure/ Technology</th>
<th>Economical risk</th>
<th>Environmental risk (coastal ecosystems)</th>
<th>Global warming issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump improvement</td>
<td>++</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Solar field</td>
<td>+</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Solar dyer to produce salt</td>
<td>+</td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>

### 2.4.2.4 Available information

Most of the information used found comes from articles written by the scientists involved in the project. These articles can be found on the AQUASOL project website: [http://www.psa.es/webeng/aquasol/index.html](http://www.psa.es/webeng/aquasol/index.html)

A phone interview with one of the project’s coordinators, Mr Julian BLANCO, helped to collect more information and to get a better understanding of some issues.

However, quantified information could not be gathered for all topics. Mostly economic analyses were made during the project. Moreover, as the project was of small size in terms of desalted water production, the figures would not be representative of a commercial use. For example, the total cost to produce 1 m$^3$ of desalted water with the capacity of the project (60 m$^3$/day) was more than 8€/m$^3$ whereas SSensitivity analyses have shown that the cost would be reduced to 0.90€/m$^3$ for a 12,000 m$^3$/day plant.

This important variation is mainly coming from the fixed costs, as shown by the following table, which is giving that give the details of the amortization costs for four different plant sizes.

<table>
<thead>
<tr>
<th>Interest rate (%)</th>
<th>4.5</th>
<th>4.5</th>
<th>4.5</th>
<th>4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant economic life (y)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Reference unit size (m$^3$/day)</td>
<td>60</td>
<td>1000</td>
<td>6000</td>
<td>12000</td>
</tr>
<tr>
<td>Availability (%)</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CPC collector</th>
<th>141,240.00</th>
<th>1,059,300.00</th>
<th>3,177,900</th>
<th>4,755,850</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas system</td>
<td>35,025.56</td>
<td>350,255.60</td>
<td>1,050,705</td>
<td>1,570,152</td>
</tr>
<tr>
<td>Thermal storage tanks</td>
<td>14,255.32</td>
<td>142,553.20</td>
<td>425,000</td>
<td>642,743</td>
</tr>
<tr>
<td>MED Plant</td>
<td>1,000,000.00</td>
<td>2,500,000.00</td>
<td>7,000,000</td>
<td>11,000,000</td>
</tr>
<tr>
<td>DEAHM</td>
<td>560,000.00</td>
<td>600,000.00</td>
<td>1,100,000</td>
<td>1,600,000</td>
</tr>
<tr>
<td>Others</td>
<td>99,999.93</td>
<td>986,999.93</td>
<td>2,888,888</td>
<td>3,000,007</td>
</tr>
<tr>
<td><strong>Total Capital Investment (€)</strong></td>
<td><strong>1,839,442.74</strong></td>
<td><strong>5,541,327.40</strong></td>
<td><strong>15,423,982</strong></td>
<td><strong>23,885,973</strong></td>
</tr>
<tr>
<td>Annual Production (m$^3$/y)</td>
<td>19,710</td>
<td>325,500</td>
<td>1,971,000</td>
<td>3,942,000</td>
</tr>
<tr>
<td>Annual Amortization rate (%)</td>
<td>7.0670</td>
<td>7.0670</td>
<td>7.0670</td>
<td>7.0670</td>
</tr>
<tr>
<td><strong>Amortization (€/m$^3$)</strong></td>
<td><strong>7.17</strong></td>
<td><strong>1.30</strong></td>
<td><strong>0.60</strong></td>
<td><strong>0.47</strong></td>
</tr>
</tbody>
</table>


The evolution of the annuals costs with plant size is less important but however significant. The analysis performed by CAJAMAR has shown an evolution from 0.95€/m$^3$ for a 60 m$^3$/day plant to 0.46 €/m$^3$ for a 12 000 m$^3$/day plant.
Whenever the information was available, figures for both “installed AQUASOL plant” and “larger AQUASOL plants” are given. Otherwise, for the purpose of the present study, estimations were made.

### 2.4.3 Mitigation measure A: The double-effect absorption heat pump

#### 2.4.3.1 Description of the mitigation measure

A first-world prototype of a double effect absorption heat pump (DEAHP) was built and installed within the AQUASOL project. This pump allowed to increase the performance ratio from 10 to 20 (Blanco and Alarcon, 2005). Basically, the DEAHP increases the energy efficiency of the distillation process by making use of the 35°C saturated steam produced in the last plant effect, as per the following figure.

![Double Effect LiBr-H₂O absorption heat pump](source.png)

Source: Blanco and Alarcon (2005)

#### 2.4.3.2 Evaluation of the mitigation measure

The DEAHP improves the efficiency and therefore reduces the fossil energy demand by a factor of 2.

**Economic evaluation**

Producing 1 m³ using MED technology at commercial scale cost between 0.96 and 1.01 € before 2006 (Martinez Beltran et al, 2006). At that time, the cost linked to fossil energy was around 50% of the total production cost, or around 0.5 €/m³. In June 2008, oil price level has more than doubled as compared to 2006 price, reaching an oil barrel price of 150€. Therefore, the increased efficiency of that technology would address the oil price increase but not reduce the reference cost of 2006: the energy costs remains around 0.5 €/m³.

The DEAHP has also an investment cost. This cost is very high for the installed AQUASOL plant with a capacity of 60 m³/day (2.18 €/m³) but was estimated to be almost negligible for larger AQUASOL plants (0.04€/m³ for plants larger than 6000 m³/day).

**Relevance to GHG emissions issues**

\[24\text{ kg of distillate per 2,326 kJ heat input}\]
Chapter 2 Mitigation measures associated with desalination

Half less the fossil energy is used thanks to the DEAHP. The conventional MED plant CO\textsubscript{2} emission is around 18.05 kg CO\textsubscript{2}/m\textsuperscript{3} (Miller, 2003). For a 12,000 m\textsuperscript{3}/day plant working at full capacity, CO\textsubscript{2} emissions would then drop from 79 tonnes/CO\textsubscript{2}/year to 40 tonnes/CO\textsubscript{2}/year.

2.4.3.3 Conclusions

The DEAHP improves the efficiency of the system regarding oil demand by a factor of 2. This technology acts as a mitigation measure by reducing the energy cost of desalination and CO\textsubscript{2} emissions by half. The energy cost estimations found were made before 2006. At that time, for a MED process, the energy costs amounted to 0.5€/m\textsuperscript{3} (50% of total cost). From 2006 price level to June 2008, the oil barrel price has doubled. The net economic benefit induced by the improved efficiency is then entirely hidden by the oil price raise, leaving the energy cost at 0.5€/m\textsuperscript{3}. As per fixed costs, investment cost of large plants are expected to be around 0.04€/m\textsuperscript{3}.

Regarding CO\textsubscript{2} emissions, a net reduction of 50\% can be considered. For a 12,000 m\textsuperscript{3}/day plant, emissions would drop from 79 to 40 tonnes of CO\textsubscript{2}/year.

2.4.4 Mitigation measure B: The solar field

2.4.4.1 Technical description of the mitigation measure

The solar field is made of 252 stationary solar collectors with a total surface area of approximatively 500 m\textsuperscript{2}.

Source: Blanco and Alarcon (2005)

The nominal capacity of the field is 250 kW\textsubscript{th}. Enough energy is produced during day time\textsuperscript{25} to supply the MED plant (nominal energy needed: 150 kW\textsubscript{th}). Extra-energy (100 kW\textsubscript{th}) is used to supply the solar dryer.

\textsuperscript{25} Day time is around 6 or 7 hours during winter and 12 to 14 hours during summer
Chapter 2 Mitigation measures associated with desalination

In average, the solar field can supply 50% of the plant's energy requirements (=day time energy needs).

### 2.4.4.2 Evaluation of the mitigation measure

As for the DEAHP, the use of solar energy has a positive impact on desalination cost and GHG emissions.

**Economic evaluation**

CAJAMAR has estimated that the solar field amortization cost for the installed AQUASOL capacity is about 0.55 €/m³. For a 12 000 m³/day plant, this cost would not be higher than 0.09 €/m³. The cost is rather low, which demonstrates how competitive the technology can be as compared to use of fossil energy.

A reference found in literature confirmed that assumption. El-Nashar (2001) calculated that for a fossil fuel cost of 11 €/GJ, a small MED plant fed only with solar energy from static solar collectors can obtain fresh water at a cost near to that of a conventional plant when the cost of the solar collector is 227 €/m² (Blanco et al, 2002). Today, fossil fuel cost is about 25€/GJ and solar collectors are sold between 100 and 200€/m².

**Relevance to GHG emissions issues**

Solar fields do not produce GHG emissions when producing energy. Therefore, assuming that the plant can work 50% of the time with solar energy, half of the GHG emissions would be reduced. Implemented on a conventional MED plant, CO₂ emissions would drop from 79 to 40 tonnes of CO₂/year.

### 2.4.4.3 Conclusions

The use of solar energy allows reducing the cost to produce fresh water. It was calculated that for a fuel cost of 11€/GJ, a small MED plant fed only with solar energy could produce water at the same ranges than of a conventional plant using fossil energy. In June 2008, fossil fuel costs reached 25€/GJ and the investment cost of solar field has decreased. It is assumed that, within this context, solar energy for desalination is profitable.

### 2.4.5 Mitigation measure C : Solar dryer

#### 2.4.5.1 Description of the mitigation measure

The solar dryer increases the concentration of the brine until it reaches the saturation point of calcium carbonate. The final prototype developed during the AQUASOL project consists of three parallel 4 meter*17 meter interconnected evaporation channels.

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27 Oil price level: 150€/oil barrel. 1 oil barrel contains 160 litres. 1 GJ = 0.04 litres of oil.
The purpose of this dryer is to transform the totality of the brine into salt. This salt can be sold on the market, decreasing reducing the overall desalination cost. Furthermore, it avoids any discharge of brine and related which causes damages to the coastal ecosystems.

### 2.4.5.2 Evaluation of the mitigation measure

**Economic evaluation**

No economic evaluation was carried out during the project. Investment costs and productivity figures were not calculated by the experts. According to the project coordinator Mr Julian Blanco, this step of the project was not completely finalised so that no precise calculations could be made.

**Environmental evaluation**

This mitigation measure has clearly a positive impact on the ecosystems. Indeed, the high specific weight of the brine, the potential presence of chemicals and the temperature difference can cause serious damages when disposed close to the coast. Using the presented technology, these risks are avoided.

### 2.4.5.3 Conclusions

The mitigation measure consisting in the transformation of the brine into salt addresses two important risks. Firstly, the benefits coming from salt sales allow reducing the overall cost of desalination. Secondly, the damages caused by brine disposal with conventional desalination plants are avoided.

### 2.4.6 Other remaining issues not dealt with

The noise issues and the mobilisation of a piece of land on the shore line that could be used for recreation or tourism activities are important risks that were identified in task 1. These issues are not dealt with in this case study.

### 2.4.7 Summary and Conclusions

The case study “AQUASOL” is based on a specific research project. Carried out between 2002 and 2006, it has developed several mitigation measures to address some of the

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28 kg of salt produced per unit of energy
most important desalination risks and impacts. An improved heat pump and the use of solar energy allowed reducing the fossil energy demand thus therefore reducing desalination cost and GHG emissions. A solar dryer allowed getting zero brine discharge and is therefore addressing the risks of harming the coastal ecosystems.

**Overall economic evaluation of the mitigation measures**

The latest reference costs of desalination found in literature are from 2006. At that time, average energy costs for MED plants were around 0.5€/m$^3$. From 2006 to June 2008, the oil price level has doubled, reaching 150€/oil barrel. Today energy costs for a conventional MED plant would be around 1€/m$^3$.

The double effect absorption heat pump (DEAHP) allows doubling the efficiency as compared to a conventional heat pump. Applying this technology would reduce the energy cost to 0.5€/m$^3$ with today’s oil price.

The amortization of the improved pump is very low for a 12 000 m$^3$/day MED plant: 0.04 €/m$^3$.

Calculations have shown that, for a fossil energy price above 11€/GJ, solar energy is profitable. The oil price is currently at 25€/GJ. With an average commercial size MED plant (12,000 m$^3$/day capacity) already equipped with a DEAHP, 0.25€/m$^3$ of fossil energy is saved. The investment cost of a solar field which is fully capable to supply the plant during day time is only about 0.09€/m$^3$.

Finally, coupling a DEAHP with solar energy boils down to a cost of 0.43€/m$^3$, which is 67% less than today’s reference energy cost for a conventional MED plant. The gain provided by solar energy can seem limited. Nevertheless, this gain would be even more important as the fuel price level increases.

The benefits coming from salt sales have also to be added. That part of the project was not finalised; no estimations were made.

**Overall relevance to GHG emissions issues of the mitigation measures**

An evaluation of the benefits in terms of GHG emissions can also be made. AQUASOL technology proposes a 50-50 coupling of an improved heat pump and solar energy. The improved heat pump has an efficiency twice as higher as than an average heat pump. With this configuration, a desalination plant can reduce its GHG emissions by 75%. This represents a drop from 79 to 20 kg of CO$_2$/year for a 12,000 m$^3$/day plant.

**Overall environmental evaluation of the mitigation measures**

Brine discharge can cause serious damages to the coastal ecosystems. A zero brine system avoids these negative impacts.

The AQUASOL project was a success in many ways. Major technological improvements were developed at affordable costs for commercial use. Until today, no commercial plant is using the developed technology developed. It is though, however, given the actual global context (energy price increase, global warming concerns, etc.), it can be expected that sooner or later the technology will start to be used for commercial production.

**2.4.8 Literature and sources**

**Literature**


Blanco J. and Alarcon D., Improving the efficiency of high capacity solar thermal seawater desalination systems: the AQUASOL project, 2005


Miller J.E., Review of water resources and desalination technologies, 2006

**Interviews**
Phone interview with Julian Blanco (June 2008)
3.1 Mitigation measures associated with wastewater re-use: case study agricultural sector in Cyprus

3.1.1 Introduction

The focus of this brief report is on the identification and assessment of the most appropriate measures of mitigation to address adverse impacts of the alternative water supply option of the re-use of treated wastewater for agriculture. Cyprus, having explored and practising the re-use of treated wastewater for agriculture provides an excellent, tangible and a very relevant case study of such re-use in the Limassol area. An assessment of the measures taken to mitigate adverse impacts on the environment is provided.

The re-use of tertiary treated effluents for irrigation purposes releases/frees good quality water for domestic supply purposes. This has been practiced for quite some time for the irrigation of agricultural areas and amenity areas of hotels. A small amount of treated effluent is also used for the irrigation of sports grounds and for groundwater recharge.

For the establishment of water re-use projects, the Government undertakes all the costs concerning the construction and operation of the tertiary treatment facilities (at the Wastewater Treatment Plants) and the conveyance of the treated effluent to farms and/or recharge facilities. Re-use depends upon the readiness of the farmers to accept it. Campaigns and demonstration experiments helped convince farmers to accept treated sewage effluent. Use of this extra resource is gathering momentum.

The wastewater re-use system for agriculture in the Limassol area, the second largest urban area of Cyprus, with about 200,000 inhabitants, is in operation since 1995. The high quality effluent of about 6.7 million m³ annually (18000 cubic meters daily), is fully recycled and used for many purposes such as groundwater recharge, restricted irrigation excluding vegetables and similar crops, public amenity areas, golf courses, etc.. Wastewater re-use has the main advantage of environmental protection from discharge of untreated effluent, whilst at the same time it offers an alternative water resource, with a marginal cost much lower than the cost of desalinated water. The marginal cost for tertiary treatment is also much less than the cost paid for dam water. As a result, recycled water provides the potential for the utilization of the national water resources in the most economical and efficient way, providing to the national economy great savings in real terms. The Limassol reclaimed water re-use scheme has demonstrated in practice that domestic wastewater is a valuable resource which can and should be used in order not only to combat the water shortage in Cyprus in an economical way, but also to upgrade and maintain the environment which is constantly under tremendous pressure.
3.1.1.1 Main adverse impacts of wastewater re-use identified in Task 1

The identified most important potential environmental risks and impacts of wastewater re-use are: i) to human health via the indirect consumption of or exposure to pathogens, heavy metals and harmful organic chemicals contained within it, ii) to groundwater due to heavy metals, increased loads of nitrate and organic matter contained in it in areas where re-use for irrigation is practiced, iii) to the soil due to heavy metals and salt accumulation and acidification, iv) to crops due to the presence of certain substances in the wastewater in such concentration that are toxic, v) to the environment due to high concentration of toxic substances and vi) need to store treated wastewater during the season when irrigation is not practiced.

The main issues in the social dimension of water re-use is the farmers’ acceptance in using wastewater for irrigation, the training in such use and control, and the public acceptance of such practice.

There are at the same time major environmental benefits identified from the wastewater re-use such as: i) conservation of freshwater sources, ii) recharge of aquifers through infiltration water (natural treatment), iii) use of the nutrients of the wastewater (e.g. nitrogen and phosphate) resulting to the reduction of the use of synthetic fertilizer and, to the improvement of soil properties (soil fertility; higher yields), iv) reduction of treatment costs: through the Soil Aquifer Treatment (SAT) of the pre-treated wastewater via irrigation, and v) reduction of environmental impacts (e.g. eutrophication and minimum effluent discharge requirements) from direct discharge.

The result of the above is: i) reduced diversion and withdrawal from natural systems which in turn promotes environmental enhancement, ii) restoration of natural wetlands, iii) reduced withdrawals from overexploited aquifers helping them to restore their qualitative status, and iv) reduced discharge of pollution into water bodies.

The key issues in this case study are the possible contamination of groundwater that is used for drinking purposes, the clogging up of sprinklers and drippers, and the choice of crops to irrigate (i.e. not for vegetables). The acceptance of farmers is varied and depends on the availability of traditional water supplies. On the other hand, groundwater replenishment and some control of the seawater intrusion caused by over pumping in the area are achieved.

3.1.1.2 Importance of the case study

In Europe, wastewater re-use faces obstacles that include insufficient public acceptance, technical, economic and hygienic risks and further uncertainties caused by a lack of awareness, accepted standards, guidelines and uniform European legislation. So far, there are no European regulations on water re-use and further development is slowed by lack of standards in water quality, treatment and distribution systems (except the UWWD Directive in article 12 where reference is made to the treatment of wastewater: “Treated waste water shall be re-used whenever appropriate. Disposal routes shall minimize the adverse effects on the environment.”).

Cyprus, a Mediterranean island at the southernmost part of the EU, currently produces some 21 million cubic meters of recycled water, 17.5 of which is being used for irrigation. Cyprus has adopted effluent standards for irrigation and through the enactment of a Code of Good Agricultural Practice (CGAP) regulates among others the recycled water re-use. This Code is in accord also with the policy of integrating recycled water in the stressed water balance of the island.
The case study of the Limassol wastewater re-use of 6.7 million cubic meters per year for agriculture is in operation since 1995. The re-use of wastewater has helped in meeting the growing water demand, reducing the over-pumping of the local aquifer and to overcome the water shortage due to the extended drought. Considerable experience has been gathered from the operation of this scheme succeeding in securing public acceptance and implementing a Code of Good Agricultural Practice. These make the Cyprus case study as very representative in terms of evaluating the alternative water resource and should provide useful and interesting information to the EU.

3.1.1.3 Issues to be discussed in more detail

Issues and measures that are discussed refer to i) Health, soil, crop and water resources protection from the re-use of wastewater in agriculture, and ii) the promotion of farmers and public acceptance in the re-use of wastewater.

3.1.1.4 Structure and links with the report

This chapter introduces the case study providing information on its location, the water supply problems it is solving, while it describes in brief the impacts and the mitigation measures taken and then it discusses in some further detail some of the most important mitigation measures, drawing material from the Task 1 report on wastewater re-use in agriculture. Finally, in a summary form the specificities of the case study are outlined together with how the various problems and concerns were addressed or remain to be addressed. The chapter ends with a summary of the lessons learnt and implications for a further use of this alternative water supply throughout the EU.

3.1.2 Introduction to the case study

A major strategic target for water resources in the Island’s Strategic Plan for Sustainable Development is the treatment of liquid waste effluents for improvement of the environment and the water resources and their utilization for irrigation aiming in supporting the water balance. Among the actions foreseen are: i) the promotion of the re-use of recycled water and of the sewage sludge, ii) information campaigns for the public and users for the vanishing of any prejudice in the use of water and sludge, iii) extension of central wastewater collection and treatment schemes, and iv) implementation of actions in nitrogen vulnerable areas including the use of the Code of Good Agricultural Practice and monitoring of the water in relation to nitrogen pollution caused from agricultural activities and evaluation of the efficiency of the measures.

One of the areas where wastewater is used for irrigation is the area of Limassol the second largest urban centre in the island.

3.1.2.1 Information on location, water supply problems and history

The prolonged drought since the 1990s together with the increasing water demand create water shortages which together with the cost associated with freshwater have made water re-use and recycling of major importance especially since most of the fresh water resources of the island have already been developed. Wastewater re-use though costly is quite cost effective in the long term. Wastewater treatment required to provide suitable water that can be re-used is governed by the need for protection of the public health and the environment. The quantities of tertiary treated recycled water produced island-wide in 2007 from the seven major treatment plants at the urban centres and from other 22 smaller plants of small communities and other sites are shown in Table
11. From these some 42% was produced in Limassol where the quantity used for irrigation represents 46% of the total used in the island.

Cyprus promotes the construction of new sewerage networks and WWTP, as well as extensions at the already working systems, in compliance to the EU UWW Directive 91/271/EC, according to which every area with over 2000 equivalent population must have a suitable wastewater treatment scheme. It is estimated that the production of recycled water will be 59 million cubic meters by 2012, 65 by 2015 and 85 by 2025.

<table>
<thead>
<tr>
<th>Treatment Plant</th>
<th>Quantity produced</th>
<th>Disposal To the Sea</th>
<th>For Irrigation</th>
<th>Groundwater recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limassol</td>
<td>6.4</td>
<td>1.0</td>
<td>5.4</td>
<td>-</td>
</tr>
<tr>
<td>Paphos</td>
<td>2.5</td>
<td>-</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>Agia Napa</td>
<td>0.9</td>
<td>0</td>
<td>0.9</td>
<td>0</td>
</tr>
<tr>
<td>Paralimni</td>
<td>1.4</td>
<td>0</td>
<td>1.4</td>
<td>0</td>
</tr>
<tr>
<td>Larnaca</td>
<td>2.1</td>
<td>0</td>
<td>2.1</td>
<td>-</td>
</tr>
<tr>
<td>Anthoupoli</td>
<td>0.3</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>Vathia Gonia</td>
<td>0.3</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>22 Minor Plants</td>
<td>1.4</td>
<td>1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total quantity used</strong></td>
<td><strong>15.3</strong></td>
<td><strong>1.0</strong></td>
<td><strong>11.8</strong></td>
<td><strong>2.5</strong></td>
</tr>
</tbody>
</table>

*Table 11: Annual quantities of recycled water in Cyprus for 2007*

This case study focuses on the wastewater re-use practice for irrigation in the area of Limassol exploiting the tertiary treated effluent produced by the city’s wastewater treatment plant and presents the experience gained from such practice. Table 12 shows the growing use of recycled water for irrigation in this area.

<table>
<thead>
<tr>
<th>Production Use/year and Use/year</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>6.1</td>
<td>6.4</td>
<td>6.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Disposal To the sea</td>
<td>2.3</td>
<td>2.3</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Irrigation</td>
<td>3.8</td>
<td>4.1</td>
<td>4.7</td>
<td>5.4</td>
</tr>
</tbody>
</table>

*Table 12: Production and growing re-use of recycled water in the study case of Limassol (all in million cubic meters)*

The Limassol WWTP started in 1995 and was extended in 2003 to serve about 100,000 population equivalents (PE). It consists of:
- A sewage network of about 210 km
- Six large pumping stations
- A tunnel of about 800 m long
- A sea outfall for emergency situations
- A secondary treatment plant
- A tertiary treatment plant

The wastewater enters a primary treatment unit (bar racks, grid chamber, skimmer tanks), after passing through primary sedimentation tank. From here it enters the secondary treatment unit, consisting of aeration tanks and the secondary Settlement
Tanks. Finally, the biologically treated wastewater enters the Tertiary Treatment unit (consisting of sand filter and chlorination unit). The Flow Diagram of the Limassol WWTP is presented in Annex I and views of the WWTP are shown in Annex II.

The Distribution of the Tertiary Treated Effluent Scheme of Limassol consists of:
- A Tertiary treatment Unit and a storage reservoir of 14600 m$^3$ capacity
- Pumping stations for the pumping of water from the tertiary treatment into two balancing reservoirs for servicing the Eastern (491 ha) and Western Area (850 ha) of Limassol
- Two balancing reservoirs of 14600 and 8200 m$^3$ capacity
- Irrigation Works at the area east of Limassol
- Irrigation works west of Limassol (conveyor from tertiary treatment until the recharge ponds at Kouris riverbed, conveyance of recycled water to the Polemidia dam, conveyors for hotel irrigation and, modification and extension of irrigation networks for recycled water)

Annex III shows a simple schematic presentation of the distribution/conveyance of the recycled water. The annual disposal-use of the treated effluent for the period 1999 to 2007 is shown in Annex IV. Part of the recycled water is stored in Polemidhia dam especially during low irrigation demand periods for later use.

Besides the “green areas”, the irrigated crops in the case study area include citrus, fruit trees, vines, olives, fodders and, vegetables.

The recycled water is tertiary treated at the WWTP which operates in accordance with the effluent disposal permit issued as per the Water and Soils Pollution Control Law (106(I)/2002). The quality of recycled water is assured through monitoring at the inlet and outlet of the Plant after the tertiary treatment. Analysis of samples at intermediate steps of the treatment involve: biological load, total nitrogen, nitrogen, ammonium, suspended solids and other parameters required for the assurance of steady good quality and suitability of recycled water for irrigation.

The irrigation is practiced according to the Code of Good Agricultural Practice (CGAP) (Annex V) which is a Regulation issued under the Law for the prevention of pollution of water. The methods and system of irrigation according to the type of crop and use of the amenity areas as prescribed in the CGAP).

As an incentive to the farmers for the use of recycled water the selling price is 6.83 € cents per m$^3$ with a surcharge of 3.42 € cents per m$^3$ for over-consumption. For organized Irrigation Divisions the price is reduced by 1 € cents per m$^3$. Fresh water for irrigation from reservoirs costs 18.8 € cents per m$^3$ and over-consumption is charged at 56.4 € cents per m$^3$.

### 3.1.2.2 Context in terms of water supply issues in the EU

In the wastewater re-use case study in Cyprus for Limassol, which currently operates successfully for more than 10 years, the technical problems have been addressed successfully while health risks have been considerably controlled through the enactment and implementation of the Code of Good Agricultural Practice (CGAP) which contains quality standards and specifications on the practice of recycled water re-use. Incentives for the use recycled water necessitated the subdued price of this water use of which frees fresh water for domestic supply which would have to be developed through more expensive options such as seawater desalination. The original reluctance of farmers and acceptance by the public for the re-use of recycled water has been gradually reversed through campaigns involving pamphlets (Annex VII), demonstration fields, and lectures and increasing experience of farmers utilizing this water. The
scarcity of water in the recent years due to prolonged drought conditions has helped in this direction. The experience in solving the technical matters and the regulations and standards on treatment, distribution and irrigation methods and crops under which the re-use of recycled water is practiced in Cyprus should be a very good example for application in the EU elsewhere under similar conditions.

3.1.2.3 Brief description of the relevant mitigation measures and which problems they address

The most important mitigation measure is the enactment and implementation of the Code of Good Agricultural Practice (Annex VI) and the strict standards of tertiary treatment of urban wastewater for use in irrigation (Annex VIII).

The Decree 263/2007 on the Code of Good Agricultural Practice on the basis of article 7(2)(e) of the Law on Control of Water Pollution of 2002 to 2006 guides the farmers to avoid or minimize pollution of the environment and overload it with unnecessary quantities of fertilizer and animal waste and defines environmentally acceptable conditions for the use for agricultural purposes of recycled water as well as of sludge that is produced from the treatment of urban wastewater.

The Decree specifies that the quality of the recycled water from UWWT Plants must be verified that it corresponds to the specifications defined on the discharge permit that has been issued. It specifies that the water conveyance and distribution network of the recycled water should carry a distinct labeling (red color) and should not cross pipes carrying drinking water. If unavoidable, the recycled water pipes should be placed at least half a meter lower. The methods and conditions for irrigation with recycled water differ according to the type of crop. Irrigation of green or amenity areas differs depending on access of public. It states that irrigation systems should always be in a good operating condition.

These mitigation measures address the problems of:
- Human health (hygiene, public health and quality control both for workers and consumers)
- Soil, plant and water contamination
- Farmer’s and public acceptance (marketability of crops)
- Excessive growth of algae in canals carrying wastewater (eutrophication), and
- Good operation of irrigation systems
- Non-regulated use of recycled water in agriculture

Table 13 presents a listing of the mitigation options and which impacts are resolved (in terms of not-at-all, partial, complete)

<table>
<thead>
<tr>
<th>Risk and impact</th>
<th>Mitigation measure</th>
<th>Not at all</th>
<th>partial</th>
<th>complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human health</td>
<td>Continuous monitoring - Effluent standards - application of CGAP</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Soil, plant and water contamination</td>
<td>Continuous monitoring - Effluent standards - application of CGAP</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Farmer’s and public acceptance (marketability of crops)</td>
<td>Pamphlets, Media, demonstration fields</td>
<td></td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>
3.1.2.4 Other important issues

A major problem is that of storing recycled water produced in the winter season when the demand for irrigation is less. Plans and efforts to recharge the treated effluent through ponds in the aquifer area of the case study and re-pump it during the irrigation season through an arsenal of wells has not been materialized as yet due to objections by local communities in the area expressing their concern on the eventual deterioration of their water supply from a well in the area. Environmental studies carried out indicated otherwise but the matter is used as a pressure and lever for other demands. This matter is still to be resolved. Temporarily, a surface dam, Polemidhia, of 3.1 million cubic meters capacity, is being used but still occasionally, tertiary treated effluent has to be disposed to the sea mainly during the winter months.

3.1.2.5 Data availability and approach

Information on the case study is available by the Water Development Department (WDD) which on behalf of the Government is responsible for the tertiary treatment and which distributes the recycled water to the farmers and to other users (Internet access is at www.moa.gov.cy/wdd).

The Sewerage Board of Limassol – Amathus (76, Franklin Roosvelt, Block A, P.O. Box 50622, 3608 Limassol, Cyprus, Tel. +357 5 881888; Fax +357 5 881777; e-mail: sbla@cytanet.com.cy) operates the WWTP and can provide information on the quantities produced and the quality of the recycled water.

Other sources of information are provided under the paragraph “Literature and sources”.

3.1.3 Mitigation measure: Legal standards including monitoring

3.1.3.1 Summary

One of the most critical steps in any re-use program is the protection of public health, with emphasis on workers' and consumers'. Consequently, neutralisation or elimination of any infectious agents or pathogenic organisms that may be present in the wastewater is of high importance. At the same time protection of the soil, plants and water resources receiving recycled water are also of great importance.
3.1.3.2 Problem and impacts

Some of the potential negative impacts of wastewater irrigation are:
- health risks for irrigators and communities with prolonged contact with recycled water and consumers of vegetables and other crops irrigated with wastewater
- contamination of groundwater (nitrates)
- build-up of chemical pollutants in the soil (heavy metals)
- creation of habitats for disease vectors
- excessive growth of algae and vegetation in irrigation systems carrying wastewater

3.1.3.3 Technical description of the mitigation measure

- Implementation of the requirements as specified in the Code of Good Agricultural Practice in terms of network labelling, irrigation systems according to type of crop, irrigation practice according to access of public in the irrigated areas etc.
- The enacted Regulation on the CGAP, and the strict treated effluent quality standards adopted by the Government and enforced in the disposal permits of the WWTP.
- Monitoring of the quality of treated effluent at the exit of the WWTP

3.1.3.4 Evaluation of the mitigation measure

**Technical evaluation:** The CGAP specifies all the technical requirements needed to protect public health and safeguard against accidental misuse of the recycled water. It employs strict standards and best available techniques.

**Economic evaluation:** The costs for a proper water distribution network for the use of recycled water do not exceed seriously those that would normally be needed for other water resources. The added costs though of demanding tertiary treatment should be considered. The latter has to be considered against with the option of discharging secondary treated water to the environment and the replacement of this source by a traditional source of water which in the case of Cyprus, suffering by water scarcity, is a very difficult matter.

**Social evaluation:** The CGAP has been accepted by the general public, since it usually provides water at a steady supply in areas where otherwise irrigation water would have been absent. Problems could arise on the occasion of the existence of domestic water well within the area to be irrigated which has to be replaced from another source.

**Environmental impact:** The local and more global economic impact has already been mentioned in terms of the benefits to the environment from the use of an additional source of water and the avoidance of disposing not fully treated water to the sea, river or elsewhere.

3.1.3.5 Lessons learned from other countries.

Experience and standards applied in other countries has helped in developing the treated effluent standards and the Code of Good Agricultural Practice.

3.1.3.6 Conclusions

The very strict standards that have been set helped in the observation of no health and other environmental impacts caused by the re-use of wastewater in the area.
3.1.4 Mitigation measure: Public and user awareness and acceptance

3.1.4.1 Summary
The social acceptance by farmers, retailers and consumers of the re-use of recycled water is one of the most sensitive areas of this topic. Farmers are not going to re-use water, if their product cannot be sold. Consumers will not buy products where re-use water was used unless it is proven to be safe. Such social issues play a significant role in water re-use initiatives and need to be adequately addressed. This to be successful requires adequate political will accompanied by awareness programmes to overcome cultural and social objections.

3.1.4.2 Problem and impacts
The main problem that can create significant obstacles in the safe re-use of the treated wastewater in agriculture is the lack of information of all the involved actors, namely:
- Governmental authorities: lack of legislation and guidelines on the re-use of treated wastewater
- Local authorities and authorities responsible in wastewater treatment: (i) lack of information on innovative cost effective technologies for wastewater treatment, (ii) difficulties in the development of technical specifications for the construction and operation of appropriate wastewater treatment systems (in terms of technology, size, quality of the outflow), (iii) difficulties in the development of specifications for the proper use of the final outflow, (iv) difficulties in finding the appropriate funds for the improvement of the wastewater treatment system
- Operators: lack of knowledge for the efficient operation, control and monitoring of the wastewater treatment system
- Farmers: lack of information on the health risks related to the use of treated wastewater and the appropriate management procedures

3.1.4.3 Technical description of the mitigation measure
Pamphlets, workshops, media presentations, field demonstration of the re-use of recycled water on different crops and various methods of irrigation, lectures and demonstrations by agricultural officers in the field and adequate explanation of the Code of Good Agricultural Practice.

3.1.4.4 Evaluation of the mitigation measure
Developing awareness and acceptance for the re-use of wastewater in agriculture is a difficult subject and can only be done gradually and after being accompanied by sufficient demonstrations and gaining experience. Water scarcity though, can sometimes help in removing last reservations.

3.1.4.5 Lessons learned from other countries
Techniques developed elsewhere in public participation, and ways and methods to approach the public on the matter of reusing recycled water are useful. Local conditions and cultural particularities should always be taken into consideration.
3.1.4.6 Conclusions

Developing farmer’s and public acceptance to the use of recycled water is a necessary and demanding task. Continued control in the implementation of the CGAP is an absolute necessity since long efforts could fall apart on the occasion of the smallest unfavourable incident. Diligent and persevering monitoring and control for the observance of the CGAP is an absolute necessity.

3.1.5 Review of case study achievements and the need for future mitigation measures

Achievements:
- Cyprus been reusing treated effluents for the irrigation of agricultural areas and the amenity areas of hotels for over 10 years. A small quantity has also been used for the irrigation of sport grounds and aquifer recharge.
- All the costs concerning the construction and operation of the tertiary treatment facilities and conveyance of this water to the location of use are undertaken by Government. This approach secures the quality of the treated effluent and helps promote its re-use.
- Campaigns, involving pamphlets, lectures and demonstration experiments by the Agricultural Extension offices, the Agricultural Research Institute and other departments, have helped convince farmers to accept treated sewage effluent. Farmer’s acceptance in using wastewater and the public acceptance of such practice has been one of the most important achievements. Nonetheless, the acceptance of farmers is varied and depends on the availability of traditional water supplies.
- The drafting and implementation of the Code of Good Agricultural Practice (a Regulation issued under the Law for the prevention of pollution of water) in the re-use of wastewater for irrigation has been instrumental in the successful use of this alternative water resource. This has been aided by actions in nitrogen vulnerable areas, monitoring of the water in relation to nitrogen pollution caused from agricultural activities and evaluation of the efficiency of the measures.
- The re-use of wastewater is gathering momentum.
- The practice of wastewater re-use in the case study of Limassol has demonstrated that this is an economical way to combat water shortages and helps also to upgrade and maintain the environment which is constantly under tremendous pressure.
- The increase in wastewater re-use in the case study alone has been 42% between 2004 and 2007.
- Experience has been gathered in solving technical matters, improving regulations and standards on treatment, improving distribution and irrigation methods.

Need for future mitigation measures:

The key issues that still need to be further tackled and resolved are:
- Continuous monitoring of effluent standards, diligence in the monitoring and control of the Code of Good Agricultural Practices to safeguard human health, and prevent soil, plant and water contamination. This is an absolute necessity since any mishap or accident will in an instant effect all the achievements made so far in the re-use of wastewater.
- Resolving the issue of storing recycled water produced in the winter season when the demand for irrigation is less. Groundwater recharge schemes need to be identified and or storage in surface reservoirs.
- Continued campaigns and demonstrations for developing and maintaining awareness and acceptance for the re-use of wastewater in agriculture.

3.1.6 Summary and Conclusions

3.1.6.1 Specificities of the case study

A new water resource has been developed through the implementation of the urban wastewater collection and the construction of a Wastewater Treatment Plant. The tertiary treatment of the effluent constitutes a steady water resource since it originates from domestic supply which normally is provided at a very high reliability, normally greater than 90%. The area irrigated in the case study had been a traditional agricultural area depending mainly on the local aquifer. This aquifer has been deprived of most of its natural recharge due to a major dam built upstream (Kouris at 115 million cubic meter capacity). In addition to this, the area has been experiencing a prolonged drought since the 1990s. As a result over-pumping has caused sea intrusion to occur and restrictive measures had to be taken on pumping. Under these conditions the re-use of recycled water has been very useful and welcome by the farmers since it allowed the continuation of their activities.

3.1.6.2 How were the different problems or concerns addressed

Problems/concerns solved: The health and protection of soil, crop and water resources of the area have been protected through the adoption and implementation of a Code of Good Agricultural Practice which although quite demanding on certain aspects safeguards the proper re-use of recycled water. Farmer and public acceptance has been gained through awareness campaigns and field demonstrations.

Problems/concerns/issues remaining: The issue that needs attention is the storage of recycled water during winter when irrigation needs are reduced. Recharge of the local aquifer is a sound solution but in this case it met the objection of the local community on the grounds of a domestic well in the vicinity. Storage at the surface in a reservoir is an option that needs to be techno-economically evaluated.

3.1.6.3 Lessons and implications for use of the technology throughout the EU

The problems faced by the implementation of the tertiary treated wastewater re-use in Cyprus and the mitigation measures that have been applied, as described above, should be useful for further use of this alternative water supply throughout the EU.

The successful implementation of the CGAP, the strict requirements of the quality of tertiary treated effluent and the sound monitoring of the effluent quality has helped in the implementation of the use of wastewater in agriculture without any serious problems.

Cyprus had to resort to the wastewater re-use since although it made great strides in developing its water resources with the most feasible water development works implemented as well as non conventional water resources such as desalination, the growing water demand coupled with an extraordinary dry sequence of years, practically since 1990, led Cyprus to ration water for irrigated agriculture seriously and even for domestic use. Improved water management, water demand management and conservation as well as change and even reduction of the cropping pattern are called for. The inclusion of treated wastewater in the water balance of the island will help
meet some of the water problems it faces. Recycled water is becoming a major source of water with the implementation of urban wastewater collection and treatment schemes.

### 3.1.7 Literature and sources


A. Larkou Yiannakou (2008): “Use of recycled water in Cyprus”, WDD

N. Kathijotes (2007) “Wastewater Re-use for Irrigation : an Acceptable Soil Conditioner?” Higher Technical Institute, Nicosia, Cyprus, (nkathijotes@hti.ac.cy)

Dr. M. Zachariou Dodou (2000) “Strategies to minimize health risk in Cyprus Standards for reclaimed waters used for irrigation”, WDD, Nicosia, Cyprus


3.2 Mitigation measures associated with wastewater re-use: case study agricultural sector in the region of Wolfsburg, Lower Saxony, Germany

3.2.1 Introduction

The focus of this case study is on the identification and assessment of the most appropriate precautionary and mitigation measures to address risks and impacts of treated waste water re-use in agriculture. The case study reflects the situation on a waste water re-use site in Germany, in specific the region of Wolfsburg in the State of Lower Saxony.

Figure 8: Location of the Case study (source http://www.deutsche-postleitzahlen.de)

In Germany, agricultural irrigation and industrial use are the main issues of interest in terms of waste water re-use. Concerning the regulation of waste water re-use in agriculture and/or ground water recharge, the Federal Water Act and the corresponding federal State water acts lay the foundation. Principally, waste water has to be disposed of in such a manner, that the general welfare is not endangered. In addition, the German sewage sludge regulation regulates the application of sludge onto agricultural land, with a special focus on heavy metals, persistent organic pollutants and pH-values in order to reduce the risks to human health.

The scheme of agricultural waste water re-use in the Wolfsburg region is a prominent example within Germany. Wolfsburg is situated in Germany's less fertile soil regions in the east of the federal State of Lower Saxony. The low soil fertility is compensated with waste water re-use schemes on agricultural fields since the 1940s. In Wolfsburg, ca. 7 million m³ of wastewater are re-used annually (6 million m³/year for irrigation purposes on 1,500 ha and 1 million m³/year for groundwater recharge).
3.2.1.1 Main adverse impacts identified in Task 1

The main environmental concern in waste water re-use for agricultural purposes is the presence of threats to the environment via contamination by nutrients, heavy metals, pathogens and salts. In order to minimise this risks it is important to ensure appropriate treatment. Health problems, such as water-borne diseases and skin irritations, may occur if people come into direct contact with re-used waste water. Furthermore, if waste water re-use is implemented on a large scale, revenues to water supply and waste water utilities may fall as the demand for potable water for non-potable uses and the discharge of waste waters is reduced. In some cases, re-use of waste water is not economically feasible because of the requirement for an additional distribution system. Finally, the application of untreated waste water as irrigation water or as injected recharge water may result in groundwater contamination.

On the other hand, several advantages of waste water re-use can be pointed out. Waste water re-use reduces the demands for freshwater, but also can reduce nutrient pollution of rivers and groundwater. The technology can be used for a wide set of water uses in the agriculture, industry, recreation and domestic sector. It can be applied almost everywhere across Europe and does not require a specific location. Centralised and decentralised approaches are both possible. Also, capital costs are low to medium for most systems and are recoverable in a very short time. Operation and maintenance are relatively simple but require strict quality controls in order to minimise the risk of environmental contamination and human health problems. Provision of nutrient-rich waste waters can increase agricultural production in a cost-effective way as less artificial fertiliser is needed.

3.2.1.2 Importance of case study in the context of the EU action on water scarcity and droughts

The Wolfsburg model of wastewater re-use in agriculture is representative of natural conditions in which low fertile sandy soils and irregular precipitation patterns require good irrigation and fertilisation practises to enable economically viable agricultural production. Especially when considering the future trend of climate change with a high risk of decreasing precipitation patterns in several parts of Central Europe, a rising driving force for waste water re-use becomes clear.

The German Wolfsburg case study of waste water re-use in agriculture is of further EU interest, because it shows high compliance with legal environmental standards and high acceptance by public and water users. In general, Germany is characterised by high environmental and health consciousness as well as legal environmental requirements. The case is an example of how waste water re-use may be practised sustainably within a strict legal framework. Last but not least, waste water in Wolfsburg is partly used to grow bioenergy crops whose energy potential is transformed to electricity in a close-by biogas plant. Thus, Wolfsburg can provide a possible case for the future development of sustainable water and energy cycles in other parts of Europe and beyond.

3.2.1.3 Issues to be discussed in more detail

Issues and mitigation measures that are discussed refer firstly to legal measures and standards that aim at minimising possible environmental and health risks from the re-use of waste water in agriculture. Legal standards are discussed in combination with the monitoring carried out in the case of waste water re-use in Wolfsburg. Secondly, issues discussed refer to measures that aim at raising public and farmer awareness and acceptance of the scheme.
3.2.2 Introduction to the case study

3.2.2.1 Information on location, water supply problems and history

Historically, waste water re-use in Wolfsburg was developed in the 1940s as a strategy of waste water disposal via agricultural irrigation. In the early stages of the scheme, emphasis was given on a cost-effective waste water disposal means (avoiding thus costly waste water treatment) as well as on water and nutrient application on cultivated fields. In the area of Wolfsburg, irrigation with waste water takes place on agricultural land of low soil quality index values which requires additional fertilisation in order to be able to support economically viable agricultural production (WEB, pers.comm, 2008).

Since the construction of a central municipal waste water treatment plant (Wolfsburg Stahlberg) in the end of the 1980s, the waste water of Wolfsburg is biologically treated with state-of-the-art technology. The construction of the plant was a result of increasing waste water quantities, rising environmental awareness and elevated living standards of the population. In fact, major first driver for the construction of the waste water treatment plant were complaints of the population due to malodours from waste water irrigation. The aim was thus to reduce the odour nuisance (WEB pers.comm. 2008b).

The quality of the treated waste water allows in theory its discharge into the environment (the River Aller). In Wolfsburg, however, it was decided to maintain the existing scheme of sustainable re-use of waste water in agriculture. The treatment plant was constructed amid the area irrigated with waste water, thus clearly indicating the intention to continue the successful irrigation practice with re-used waste water (Peters, 2008). Right from the start, state-of-the-art technology was used to fulfil the objective of waste water re-use also in the future (WEB pers.comm. 2008b).

In Wolfsburg, treated waste water is used in two different ways:

- In summer time, the waste water is used for agricultural irrigation. Partial biological treatment removes odorous organic carbon (Peters, 2008). Nitrogen and phosphate remain in the waste water to serve as fertiliser supplement during the vegetation period (WEB, pers.comm, 2008). The agricultural area irrigated with treated waste water amounts to 1,500 ha. During this partial purification period in the summer, the entire waste water is applied on to the designated fields, since a disposal into the River Aller would not be permissible due to elevated nutrient concentration levels (Peters, 2008).
- In winter time, the treated waste water is used for groundwater recharge within regional woodlands, after its full biological treatment including nitrate and phosphate elimination (WEB, pers.comm, 2008). As a result of the treatment, total phosphorous has a concentration of < 1 mg/l and inorganic nitrogen of < 12 mg/l. In the case of high water tables, when infiltration is not or only marginally possible, the purified waste water is discharged into the River Aller (Peters, 2008). This way, nutrient-free clear water is stored in groundwater, to be followed by withdrawal for irrigation when needed during vegetation periods without impacting the natural groundwater system.

Annexes I-V illustrate different aspects of the waste water treatment and re-use scheme of Wolfsburg.

The year-round inflow of approximately 7 million m³ of waste water per year is provided by the waste water treatment plant of Wolfsburg which collects the waste water of the city of Wolfsburg and some surrounding rural districts of Gifhorn. 6 million m³ of treated waste water per year are used for irrigation purposes and 1 million m³ per year is used for groundwater recharge (WEB, pers.comm, 2008).
This system of two distinctive ways of re-using waste water created the basis for the so-called “Wolfsburg Model of Water Recycling” (Peters, 2008) (see schematic presentation in Annex II).

At present, the Wolfsburg treatment plant has a capacity of 170,000 population equivalent (WEB, n.d./a). The first step in the treatment process is mechanical treatment. In a second step, biological and chemical treatment of the waste water takes place. Biomass is separated from treated water and returns to an activated sludge tank for additional treatment, while the treated water flows into storage reservoirs. The third step in the process involves the treatment of sludge (Abwasserverband Wolfsburg, n.d./a). The plant was solely enlarged in 1990-1992 with extra biological treatment basins in order to increase its capacity from 130,000 to 170,000 population equivalent.

Apart for the treatment technology itself, the following key technical conditions are needed for the purpose of waste water re-use in Wolfsburg (Peters, 2008):

1. 9 irrigation pumps
2. 100 km underground pressure pipes to pump treated water to the fields
3. 30 ha of plantations for wind and spray protection
4. 100 spray irrigation machines
5. 15 workers

The waste water treatment and re-use scheme of Wolfsburg is organised under public law. It was initially financed as a measure of waste water disposal via the system of waste water charges. In the meantime, there is pro rata financing via waste water charges and via payments from the agricultural beneficiaries (WEB, pers.comm, 2008). The investment costs for the construction of the waste water treatment plant itself in the period 1988-1998 were approximately 38.5 million €, funded by the Town of Wolfsburg, the federal State of Lower-Saxony and a research programme of the Federal Republic of Germany (Abwasserverband Wolfsburg, 1999).

The costs of treatment amount to 0.63 €/m³ of waste water, out of which 0.18 €/m³ are costs for the re-use of waste water in irrigation (including all costs such as electricity costs, labour costs, capital costs and machine costs) (Peters, 2008).

### 3.2.2.2 Data availability and approach

The waste water treatment plant Wolfsburg Stahlberg has been operated since 1988 by the Wolfsburg Waste Water Association (Abwasserverband Wolfsburg). Since 2007, the task of waste water re-use has been taken up by the WEB - Water Drainage of Wolfsburg on behalf of the Waste Water Association.

Information on the case study of Wolfsburg has been generously provided in written form and via phone communications by the WEB - Water Drainage of Wolfsburg (http://www.wolfsburg.de/verwaltung/web/). The WEB has been contacted by the authors by means of structured questionnaires in German language, according to the specifications developed for the Task 2 reports of this study. The WEB has provided a wide range of materials, including general information on the waste water re-use scheme, the volumes of waste water re-used, the legal framework and monitoring programme applied, the current state of risk from pollutants monitored, description of awareness raising measures, figures and photos of the area, information flyers and others.
3.2.2.3 Brief description of relevant mitigation measures and problems they address

In the case of Wolfsburg as outlined in Table 14 the following risk have been identified related to the re-use of waste water.

<table>
<thead>
<tr>
<th>Risk and impact</th>
<th>Mitigation measure</th>
<th>Solution of impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Not at all</td>
</tr>
<tr>
<td>Human health</td>
<td>● Legal measures requiring technical measures</td>
<td></td>
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<tr>
<td></td>
<td>● Monitoring</td>
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<tr>
<td>Soil and water quality</td>
<td>● Legal measures requiring technical measures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>● Monitoring</td>
<td></td>
</tr>
<tr>
<td>Public acceptance and farmer acceptance</td>
<td>● Public awareness activities, international fora, e.g. EXPO contribution, sign-posting, spray protection hedges, discontinuation of sludge use on farmed fields/ transformation into fuel</td>
<td></td>
</tr>
</tbody>
</table>

Table 14: Risks and impacts of waste water use for irrigation in Wolfsburg and relevant mitigation measures

As shown above mitigation measures have to address the problems of:
1. Risk to soil and water quality
2. Risks to human health
3. Farmer’s and public acceptance of waste water re-use

The main mitigation measure addressing the risks to human health and the environment are legal requirements setting minimum standards for the level of treatment. In other words the legal standards set in the water permit of the Wolfsburg treatment plant are considered as a key mitigation measure to minimise possible environmental impacts and health risks due to the re-use of waste water in irrigation. This water permit sets the framework for the irrigation, the groundwater recharge and the discharge of waste water from the Wolfsburg plant. As none of the pollutants exceed threshold values defined in the present legal framework it has not been necessary to add extra levels of treatment to the Wolfsburg treatment plant in order to minimise the presence of specific pollutants. The treatment plant was planned and constructed from the start with state-of-art technology in order to meet the needs of the waste water re-use scheme in agriculture. Furthermore, the main share of pollutants ends up into the sludge, which is not used for agricultural fertilisation anymore but for combustion purposes (WEB pers.comm. 2008b).

To ensure that safety standards are met on a continuous basis in terms of water and soil quality, an elaborate monitoring programme of high-effort has been set up.
An additional mitigation measure is related to activities of public as well as user awareness and acceptance of the re-use scheme. Users in this case are the farmers whose fields are treated with waste water and, in the past, with sludge.

Further details on the mitigation measures are discussed in the following sections.

3.2.3 Mitigation measure: Legal standards including monitoring

3.2.3.1 Summary

The strict legal standards set in the water permit of the Wolfsburg treatment plant address the issue of possible risks to soil and water quality as well as to human health. As described in the following, the water permit sets in detail the framework for the irrigation, the groundwater recharge and the discharge of waste water from the Wolfsburg plant. Additionally, an elaborate monitoring programme of high-effort is being run by the WEB – Water Drainage of Wolfsburg.

3.2.3.2 Description of the mitigation measure

In Germany, a variety of regulations, laws and technical requirements have to be met when waste water is intended for re-use in agricultural irrigation, such as the Federal Water Act (WHG 1957) and the relevant federal State water acts, the law on application of fertiliser (DMG 1977), the fertiliser regulation (DüV 2006) and the DIN 19650 on hygienic aspects of irrigation water.

Using (treated) waste water in agricultural irrigation has to comply with several parameters and standards so that soil, plant and groundwater protection as well as hygiene aspects meet sustainability objectives. In German law, re-used waste water is considered as a secondary fertiliser resource (according to the DMG 1977).

In the case of sludge re-use in agriculture, the waste water sludge regulation (AbfKlärV 1992) has to be respected. The aim of the waste water sludge regulation is to control the nutrient, organic and inorganic pollutant loads in terms of eco-toxicological and horticultural considerations. Certain threshold values have to be met and a stringent monitoring has to be implemented. Waste water sludge originating from municipal waste water treatment plants, i.e. with no industrial origin, may in principle be used for fertilisation. The application of waste water sludge is prohibited on vegetable and fruit plantations, permanent greenland, forestry, and water protection zones. The sludge itself and the land where sludge is applied have to fulfil stringent heavy metal, polychlorated and halogenic organic hydrocarbon as well as pH threshold values.

The Wolfsburg waste water treatment plant operates on the basis of its current water permit, which sets the legal standards for the irrigation, the groundwater recharge and the discharge of waste water into the environment from the plant. The water permit is granted by the local water authority according to the federal water act (WHG), the water act of the State of Lower-Saxony and the sewage sludge regulation. The fertiliser regulation and the law on fertilisers are also taken into consideration. Furthermore, the maximum value of 50mg/l nitrate in groundwater, as stated in the drinking water regulation, is used as a guiding value. The WEB - Water Drainage of Wolfsburg ensures compliance with this value to avoid negative publicity that could lead to a questioning of the waste water irrigation practices in the area (WEB, pers.comm. 2008b).

The water permit defines in detail the parameters that have to be monitored in specific water compartments related to irrigation with wastewater, groundwater recharge with
wastewater as well as discharge of wastewater into the environment (River Aller). The permit sets different specifications for different times of the year and it also defines the frequency and sampling points of monitoring.

Next to environmental standards set for irrigation, recharge and discharge of wastewater, the water permit also sets rules with respect to crop types and irrigation practices. In specific, waste water irrigation of vegetables intended for direct human consumption is not permitted. Potatoes and sugar beets, which are produced for industrial use, can be subject to irrigation up to two weeks before harvest. Wheat can be irrigated only up to the stage of milk ripeness of the grain.

The permit defines specific threshold values for different parameters that should not be exceeded during the operation of the scheme. These values are used to guide the monitoring programme of the WEB – Water Drainage of Wolfsburg, as summarized in Annex VI.

Annex VI gives an overview of the parameters that are being monitored in the different compartments. For instance:

- In the case of irrigated waste water, COD, phosphate and inorganic nitrogen should be monitored.
- In the case of groundwater and drainage discharge, potassium, nitrate, BOD$_5$, TOC (total organic carbon) and phosphate should be monitored.

In addition, farmers need to follow good agricultural practice, which is used as a further measure to inhibit nitrate accumulation in the groundwater. It is possible for farmers to calculate the extra mineral fertiliser that they need on the basis of the nutrient loads of the irrigated waste water communicated to them by the WEB – Water Drainage of Wolfsburg. In fact, some of the waste water irrigation areas overlap with water protections zones. In these areas, the correct advice of farmers is of utter importance to ensure the avoidance of nitrate accumulation in the groundwater.

Except for environmental standards in different water compartments, the water permit also sets a number of additional legal requirements, e.g. distance of waste water re-use installations from houses as well as maximum waste water quantity that can be irrigated per season.

The monitoring of soils is not defined in the water permit but takes place rather as a result of an agreement between the WEB – Water Drainage of Wolfsburg and the regulatory authorities. This agreement was developed in order to ensure that sufficient precautionary measures are taken to avoid the accumulation of contaminants in the soil from the re-use of waste water. Soils and harvests are sampled at 26 points within and outside the waste water re-use area. Exclusively wheat fields are monitored in order to guarantee comparability. Soils are monitored for all heavy metals (lead, cadmium, nickel, chromium, copper, mercury and zinc). Wheat is monitored for cadmium, nickel and zinc. To date, the values recorded have been much lower than the maximum values set in the sewage sludge regulation.

Further measures to minimise environmental risk from the re-use of waste water include the following as far as the industrial sector is concerned (WEB, pers.comm. 2008b):

- The close-by automobile Volkswagen industry is not connected to the municipal waste water collection system of Wolfsburg. This reduces the risk of too high pollutant loads ending up into the treatment plant, in case of malfunctions in the industrial operation.
- Other commercial dischargers in the region are strictly monitored aiming at minimising pollutants such as heavy metals at source. This is done by on-site inspections to check whether the appropriate pollution mitigation technologies in the respective discharges are in place and functional (e.g. petrol traps at petrol stations, grease traps in restaurants). Point source sampling of the
waste water discharge is carried out, in case increased concentrations are detected in the waste water treatment plant monitoring system.

### 3.2.3.3 Evaluation of the mitigation measure

#### Technical evaluation

**State-of-the-art technology** has been used in the construction of the waste water treatment plant not only to meet legal standards of that time but also to enable waste water re-use in the long-term.

To date, standards for water quality and environmental quality in general have been consistently met. The following gives an overview of the risk situation for key groups of pollutants related to waste water re-use in irrigation (WEB, pers.comm. 2008b):

- **Nitrate in groundwater**: At present, nitrate poses no risk to groundwater. The German drinking water regulation permits an upper limiting value of 50 mg/l nitrate, which is complied with. During irrigation with waste water, nitrogen is applied onto the fields mainly in the form of ammonium and only in quantities below 22 mg/l of nitrate. The nutrient load of the irrigated waste water is communicated in advance to the farmers, so that these can calculate the required additional amount of fertiliser. The nutrients applied via waste water during the vegetation period are almost completely taken up by the plants.

- **Heavy metals in groundwater and soil**: Heavy metals are mainly found in the solid parts of waste water (and thus in sludge). In the Wolfsburg model, waste water sludge is no longer used for fertilisation purposes, therefore, there is no high risk of heavy metal contamination of soil and groundwater. Some weak traces of heavy metals have been detected in the soil, however, far below the maximum allowed values set in the sewage sludge regulation of Germany. The monitoring results of soil on control locations outside the area irrigated with waste water similarly show concentrations far below the maximum allowed values set in the sewage sludge regulation. These concentrations are in fact not significantly lower than those measured in the areas irrigated with waste water.

- **Organic contaminants in groundwater**: Organic pollutants are monitored via the parameter of TOC (total organic carbon). The TOC values recorded in the area of waste water re-use in Wolfsburg are low enough, to conclude that there is no environmental risk due to persistent organic substances.

- **Endocrine disruptive and pharmaceutical substances in groundwater and soil**: Currently, no conclusive statement can be made on the environmental risk due to the presence of endocrine disruptive substances in the re-used waste water. Environmental risk due to endocrine disruptive and pharmaceutical substances is a relatively new ongoing field of research, which is closely followed by the WEB – Water Drainage of Wolfsburg. The aspiration is to possibly eliminate hormones and pharmaceuticals from treated waste water in the future with the help of the appropriate waste water treatment plant technology.

- **Pathogens and related health risks**: Research and monitoring findings have confirmed that no significant health risks are posed by the re-use of waste water for irrigation in the region of Wolfsburg.

#### Economic and social evaluation

The entire re-use model of Wolfsburg including the precautionary and risk mitigation measures taken is evaluated as affordable. Otherwise, the public acceptance of the scheme would not be as high. The costs for monitoring environmental parameters to ensure that legal standards are being met are related to own monitoring (of the WEB – Water Drainage of Wolfsburg) and to monitoring outsourced to external laboratories. It
is estimated that approximately 16,000€/year are being spent on monitoring investigations (of waste water and sludge) by external accredited laboratories. The laboratory costs of the WEB run up to approximately 20,000€/year including material but not labour costs (WEB, pers.comm. 2008b).

**Environmental impact**

The positive environmental impact of the measure of legal standards and monitoring is obvious by the fact that no risk is currently posed by the main groups of pollutants related to waste water re-use in agriculture. The positive environmental benefits of the waste water re-use scheme overall have been summarised.

### 3.2.3.4 Conclusions

The mitigation measure of legal standards and monitoring can be considered as very effective, since it ensures the avoidance of environmental and health risks related to the use of the waste water treatment and re-use technology in Wolfsburg.

### 3.2.4 Mitigation measure: Public & user awareness and acceptance

#### 3.2.4.1 Summary

Except for respecting legal standards and continuously monitoring environmental status, it is important to ensure that the waste water re-use scheme of Wolfsburg has the support of the local population as well as key water users (i.e. farmers). Therefore, an additional measure taken involves publicity and public relation activities to raise public awareness and acceptance. This measure also involves close communication of the WEB – Water Drainage of Wolfsburg with the farmer community and responding to their needs in order to ensure the marketability of their crops.

#### 3.2.4.2 Description of the mitigation measure

The measures being taken to maintain and increase awareness and acceptance of the scheme target, on the one hand, the general public and, on the other hand, the direct users of the scheme, i.e. the farmers affected (WEB, pers.comm. 2008b).

In terms of the general public, the WEB – Water Drainage of Wolfsburg is carrying out several public relations activities to keep the public informed about the details and benefits of the scheme. This is done, for instance, by holding an Open Door Day, specific activities on the Day of the Environment, treatment plant sightseeing tours, publication and distribution of information brochures and by making teaching contributions at schools.

There is also an effort to inform the international community about the merits of the scheme. For instance, the Wolfsburg model of sustainable water and energy cycles is presented at the EXPO World Exhibition 2008 in Zaragoza “Water for Life“.

Additional public awareness and acceptance measures include:

- Sign-posting on waste water irrigation: In the waste water re-use and groundwater infiltration areas, sign-postings indicate and explain the facts about the scheme of irrigation and groundwater recharge using treated waste water. As foot and bicycle paths as well as farmer roads run across the re-use areas, the signposts contribute to strengthening the acceptance among the population.

- Wind and splash guard plantations: These plantations were built around the irrigated fields in order to reduce odour emissions and to inhibit disgust
sensations of neighbours. The splash guard plantations also help in strengthening the acceptance by the population.

The water permit of the treatment plant defines the presence of sign-posting and wind guard plantations as obligatory requirements.

Regarding farmers, their overall attitude towards the waste water re-use scheme is positive. In general, they value the fact that the use of waste water makes intensive agriculture in that region possible (in view of low soil quality). An issue of acceptance, however, has occurred with regard to the re-use of the sludge produced in the treatment plant. Although, in principle, sludge may be used in agricultural production in Lower Saxony (when threshold values for heavy metals, dioxins etc. are met), this is not practised anymore in the case of the Wolfsburg fields. There has been pressure from commercial purchasers of the sugar beet and wheat industry to stop buying crops fertilised with sewage sludge. This, in its turn, exercised pressure on the Wolfsburg farmers to discontinue sludge use in order to safeguard the marketability of their crops (the re-use of treated waste water has not been contested) (WEB, pers.comm. 2008b).

The alternative created for sludge in Wolfsburg is its transformation into fuel. The waste heat produced in the nearby biogas plant\textsuperscript{29} is used for the additional processing and drying of the sludge produced during waste water treatment. The sludge can be used as a recycling material only in a dried condition. The energy for the drying process of sludge is provided to 100\% by the biogas plant so that no fossil fuels are required (WEB, n.d./c). The dried sludge, which is equivalent to domestic brown coal in terms of its energy potential, is used as fuel in the close-by power plant of the automobile Volkswagen industry (WEB, n.d./b).

3.2.4.3 Evaluation of the mitigation measure

Technical evaluation
To date, standards for water quality and environmental quality in general have been consistently met (see relevant summary under mitigation measure A).

Economic and social evaluation
The measures taken to support public acceptance of the re-use scheme are considered affordable. Annual costs of the WEB – Water Drainage of Wolfsburg for publicity and public relations lie in the range of ca 30,000\€. This includes costs for the entire WEB public relations programme, e.g. including information on flood protection next to information on the waste water re-use model (WEB, pers.comm. 2008b).
Overall, the acceptance of the scheme by the local population as well as farmers is positive.

In the case of the discontinuation of sludge re-use to ensure the marketability of the Wolfsburg farmers’ crops, a further evaluation of the economic impacts may be worthwhile. This is especially relevant in view of the rising prices of mineral fertilisers, which could be an incentive to farmers for the use of sewage sludge.

Environmental impact
The positive environmental benefits of the waste water re-use scheme overall have been summarised.

\textsuperscript{29} The biogas plant (of 5 MW nominal output) is used to transform the bioenergy crops grown in the region of Wolfsburg into electricity.
3.2.4.4 Conclusions

It can be concluded that the measure of awareness and acceptance has so far been effective, since the waste water re-use scheme of Wolfsburg has the support of both the local population and the farmer community. Ever since the solution of the malodour problem of waste water re-use via the construction of the treatment plant in the 1980s, the local population has accepted the re-use scheme. As far as farmers are concerned, they have a positive attitude towards the re-use because the waste water provides valuable fertilizers for their fields as well as continuous water supply to make the cultivation of several crops possible in their region.

3.2.5 Other important issues in the context of the case study

A further issue of importance that is not taken up explicitly in other parts of this case study report is the issue of benefits from the operation of the Wolfsburg waste water re-use scheme. Key benefits can be summarised as follows (WEB, pers.comm, 2008):

- Waste water accumulates all year-round in the urban areas of Wolfsburg and has to be disposed of. Through the re-use of waste water on agricultural land, it is avoided to discharge treated waste water directly into the natural water environment of the area.
- During groundwater recharge, the natural subsurface is used as storage media for the infiltration of waste water in winter time. The stored water can be used in the summer months (under hot weather conditions) as supplement for irrigation, without having to use up natural water reserves. The only additional construction needed is a piping system.
- Artificial fertilisers do not have to be used in great quantities, since nutrients are applied on fields also via the irrigation water.
- Irrigation with waste water in this region of porous sandy soils with poor sorption capacity makes agricultural production possible. Nutrient-poor and partially dry soils have a limited suitability for tillage and crop production. Only the increase of soil fertility via fertilisers and irrigation ensures the production of demanding plants such as sugar beet. Thanks to the waste water re-use scheme, it is possible at present to cultivate several species of plants in the district of the Wolfsburg Waste water Association, such as potatoes, wheat, maize for biomass, sugar beets etc (see also Annex VII) (Abwasserverband Wolfsburg, n.d./b).
- No negative impacts exist on energy consumption. On the contrary, the energy consumption of the waste water treatment plant in part-time purification operation tends to drop. Additionally, the biogas gained from the cultivated bioenergy crops is transformed into electricity and can be used for the treatment of waste water.
- In economic terms, the costs of irrigation with waste water almost correspond to the costs that would incur if groundwater were to be used for irrigation instead. Costs of waste water irrigation even tend to be lower than for groundwater irrigation, because the pumping effort needed is lower.

3.2.6 Review of case study achievements and the need for future mitigation measures

Considering the current knowledge about how the various substances that occur in water water are influencing human health and the environment the mitigation measures taken so far should ensure a minimum risk mitigation. This is also reflected in the high acceptance of the Wolfsburg model by the general local public.
However as stated earlier the risk of endocrine disruptive and pharmaceutical substances in groundwater and soil is not fully explored. This is not only a particular problem of Wolfsburg, it is an issue for the overall waste water treatment sector. Until now, more than 90 pharmaceuticals and their metabolites, out of 3000 registered in EU have been found in environmental waters and sediments across. Except from some clear examples of negative impacts of endocrine disruptive and pharmaceutical substances on non-target living organisms, the knowledge on the nature and extent of the environmental impact is still limited. Even if negative impacts are not fully proven, there is a raising concern and awareness (Kampa, under preperation)\(^{30}\).

As data indicates that the classic treatments of water treatment plants lead to an incomplete elimination of these substances (Stumpf, et al 1996; Hirsch, et al (1996), Webb et al, (2003)\(^{31}\)). In the future when there is a better understanding of the impacts of endocrine disruptive and pharmaceutical substances additional mitigation measures might be needed. Different mitigation option are currently discussed and assessed under the Framework programme 6 funded project KNAPPE\(^{32}\).

3.2.7 Summary and Conclusions

3.2.7.1 Specificities of the case studies

This case study has reported on a waste water re-use scheme in Wolfsburg of Germany for the purpose of irrigation. The scheme was initiated in the 1940s and was further developed via the construction of the Wolfsburg wastewater treatment plant in the 1980s. Treated waste water is used in two different ways in the context of the so-called “Wolfsburg model of water recycling”. Firstly, in the summer, waste water is used for agricultural irrigation. Partial biological treatment removes organic carbon, but nitrogen and phosphate remain in the waste water to serve as fertiliser supplement. Secondly, in winter, treated waste water is used for groundwater recharge after its full biological treatment including nitrate and phosphate elimination. Thus, nutrient-free clear water is stored in groundwater, to be followed by withdrawal for irrigation when needed during vegetation periods without impacting the natural groundwater system.

In the case of Wolfsburg, irrigation with waste water takes place in a region of low soil quality index values requiring additional fertilisation to be able to support agricultural production. Under these conditions, farmers benefiting from the scheme highly value the fact that the use of waste water makes intensive agriculture in their region possible.

3.2.7.2 Different problems addressed and solved

Main issues that needed to be resolved to ensure good practice operation of the Wolfsburg model of waste water re-use include concerns about risks to soil and water

\(^{30}\) Kampa, E.; Vidaure, R. (under preperation): Identification of options for future instruments to limit water pollution from Pharmaceutical Propoducts.


\(^{32}\) For further details please see www.knappe-eu.org.
quality, concerns about risks to human health as well as farmers’ and public acceptance of the waste water re-use.

Environmental and health risks were addressed in a precautionary way, since the planning and construction phase of the treatment plant in the 1980s. State-of-the-art technology was used in the plant construction not only to meet legal standards of that time but also to enable waste water re-use in the long-term. Furthermore, strict legal standards are set and complied with in the water permit of the Wolfsburg treatment plant, which sets the framework for the irrigation, the groundwater recharge and the discharge of waste water from the Wolfsburg plant. To ensure that safety standards are met on a continuous basis in terms of water and soil quality, an elaborate monitoring programme of high-effort has been set up.

The mitigation measure of legal standards and monitoring can be considered as very effective. Thanks to consistent compliance with the standards set, environmental and health risks related to the use of the waste water treatment and re-use technology are avoided.

Public acceptance of the scheme has been successfully achieved, since the solution of the malodour problem of waste water re-use via the construction of the treatment plant. To maintain a positive image of the scheme in the local population, publicity and public relations activities are carried out on a continuous basis. As far as farmers are concerned, they have a positive attitude towards the re-use because the waste water provides valuable fertilizers for their fields as well as continuous water supply to make the cultivation of several crops possible in their region. The operators of the scheme also remain in close consultation with the farmer community to respond to their needs in order to ensure the marketability of their crops. In this context, sludge re-use on agricultural fields has been discontinued due to external market pressure and an alternative way of using sludge (as fuel) has been developed.

### 3.2.7.3 Problems/concerns/issues remaining

An open issue at this stage, not only in Wolfsburg but presumably in most waste water re-use schemes around in Europe, is the fate and possible environmental risks due to hormones and pharmaceuticals substances in treated wastewater and sludge. This remains an ongoing field of research on European level.

Furthermore, there are indications that the issue of sludge re-use may be put again on the agenda in the future in view of rising prices of mineral fertilisers.

### 3.2.7.4 Lessons and implications for a further use of the technology throughout the EU

The Wolfsburg model of waste water re-use in agriculture is a case, where appropriate measures have been successfully taken to avoid and mitigate possible environmental and health risks as well as to avoid rejection by the public and farmers. In this context, interesting lessons can be learned for other regions of Europe considering the alternative water supply option of re-use in agriculture. The Wolfsburg model of waste water re-use is put forward as an example of sustainable cycles of both water and energy that can be used in other parts of Europe and beyond. The following summarises the five main processes of the model related to both the water and the energy cycles (WEB, n.d./a):

- Classic agricultural use of treated wastewater to use nutrients recovered from the water as a fertiliser supplement during the vegetation period.
Chapter 3 Mitigation measures associated with wastewater re-use

- Storage of nutrient-free clear water during the winter months in groundwater, followed by withdrawal for irrigation when needed during vegetation periods without impacting the natural groundwater system.
- Growing renewable raw materials in the irrigated zone (bioenergy maize) and generating electrical and thermal energy from the raw materials in a biogas plant and a combined heat and power plant, in order to achieve energy-autarchic waste water treatment as well as electrical power feed-in to the electricity grid.
- Use of thermal energy for drying sewage sludge, in order to produce a substitute fuel having thermal value similar to that of lignite.
- Secondary use of biogas as substitute fuel in motor vehicles (planned project under design).

3.2.8 Acknowledgements

The authors gratefully acknowledge the support of the WEB – Water Drainage of Wolfsburg, especially Mrs. Gudrun Peters and Dr. Gerhard Meier, who provided a lot of key information and their expert knowledge on the Wolfsburg model of waste water re-use.

3.2.9 References


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Chapter 3 Mitigation measures associated with wastewater re-use

3.3 Mitigation measures associated with wastewater re-use: case study agricultural sector in Campo Dalías (Almería-Spain)

3.3.1 Introduction

One relevant alternative for water provision for agriculture explored in Spain in the last decade is the use of treated wastewater for irrigation purposes: water re-use for agriculture.

The water re-use for agriculture can not be considered a unique solution for the water demand from agriculture, at least in a dry country such as Spain. According to the Agricultural Ministry only a small percentage of land is irrigated by treated waste water. However, in some areas of Spain, in particular in the Mediterranean South East this can be a very efficient and relevant alternative for the agricultural water supply.

A Royal Decree 1620/2007, was recently passed to set up a legal framework for the use of treated wastewater in agriculture. In addition, the National Irrigation Plan includes a special subprogram on this specific topic to provide incentives for the use of treated waste water in agriculture in particular in the Canarias, Murcia and Baleares regions (addition of 170 H m³/year of treated wastewater for agriculture). The AGUA Programme has also estimated an increment of almost 137 H m³/year in water resources. These initiatives will encourage this alternative option in the near future.

In 2006 only 496 cubic hectometres of treated wastewater of a total of 5.015 cubic hectometres was re-used (National Statistic Institute, Water supply and wastewater treatment Spain 2006). 80% of this amount was used in the agricultural sector. There still remains opportunities to increase the use of this water supply alternative in Spain.

The case study analyses the use of treated wastewater in the “Campo Dalías” in the Almería Province. Campo Dalias is one of the oldest and biggest irrigation areas in south east Spain. It is located in Almería Province and receives the lowest rainfall in Spain. Campo Dalias is characterised by a well developed intensive agriculture, mainly greenhouses (30.000 ha), which have partially exhausted the groundwater, resulting in the salinisation of the aquifers.

Given this water supply deficit and the necessity to improve water quality, the local authorities drew up plans for wastewater treatment plants in Campo Dalias with the capacity to supply 320,000 population equivalents. Works were planned to regenerate 11.4 H m³/year, for aquifer recharge and for agricultural irrigation. However, farmers requested that regenerated water should be used principally for irrigation and the aquifer re-charge project to be just an experiment. However, the lack of appropriate infrastructures to distribute regenerated water from the WWTPs meant that the treated water could not be used on farms, and was discharged into the sea via a marine outfall.

In order to solve distribution problems and to be able to re-use waste water in Campo Dalias, the AGUA Programme initiated new works to:

Personal communications
WEB pers.comm (2008): Written personal communication on the content of this case study, 10 June 2008.

WEB pers.comm. (2008b): Phone personal communication on the content of this case study, 3 July 2008.
• Adapt effluent quality to the various uses and guarantee the quality of re-used water
• Distribute the flows and increase regulation capacity to manage the resource more efficiently.

### 3.3.2 A reminder of the main adverse impacts indentified in Task 1

The main environmental risks of wastewater re-use for irrigation are related to:

• Effect of water quality, particularly salts, nutrients, heavy metals, salts, pathogenic (bacteria, viruses, and parasites) microorganism, and harmful organic chemicals on public health, soil and crops.
• Local impacts of construction and operation as effects on the landscape or odour pollution.

The main socioeconomic risks of wastewater re-use for irrigation are related to:

• Farmers acceptance of wastewater re-use
• Marketability of crops

**Environmental and socio-economic benefits**, mainly relate to water management issues in the long term:

• Reduction of the demand for freshwater
• Reduction of the need of new water infrastructures for water supply
• Reduction of nutrient disposal that occurs in the rivers and groundwater from urban wastewater
• Make possible agricultural economic activity with high added value in dry areas of the country

Water quality depends heavily of the quality of the entrance flow of wastewater and of the type and performance of the treatment plan.

### 3.3.3 Why this case study is representative and interesting for the EU

Campo Dalías is a typical example of a southern Europe region with a huge water demand, but at the same time scarce renewable water resources. Wastewater re-use is an opportunity to reduce groundwater overexploitation and improve sustainability of water management.

Mitigation measures for wastewater re-use are related to improvement of technological treatment, environmental assessment to minimize possible risks on the environment of developed infrastructures and water quality criteria and monitoring.

### 3.3.4 Issues that will be discussed in more detail

Mitigations measures that will be discussed in detail are: treatment improvements, (osmosis and microfiltration), local impacts and continuous monitoring and water quality criteria.
3.3.5 Introduction

3.3.5.1 Generic information on location, water supply problems and history of the case study

This case study deals with the measures for Wastewater Re-use for Agriculture in Campo Dalías (Almería).

Figure 9 Location of the Campo Dalías case study in Spain

1. Economic and environmental situation

Campo Dalías is the area with the biggest economic growth in the province of Almería (Spain). This area produces a fifth of the agricultural wealth in Andalusia, with just 3% of the irrigated area and representing less than 1% of the cultivated area.

With the support of local authorities, farmers have established an irrigation area of 30,000 ha under plastic greenhouses, which constitutes the 70% of the total national greenhouse area and 25% of the Mediterranean greenhouse area. In this cultivated area, between 3 and 5 harvests are grown between September and June, with an agricultural production that reaches 2,650,000 Tm-year, netting €1,320 million per year and employing almost 60,000 people.

This growth has been possible due to intensive uses of energy to pump up water from the aquifers, but the use of advanced farming techniques e.g. computerized fertigation, hydroponic farming, seed selection, product standardization. This has given the local agriculture system a strong industrial profile, requiring complex service systems.

Those results have been achieved in spite of natural resource scarcities (water, land with low organic content etc..). As a result wells are bored increasingly deeper and
more numerous; however, such intensification has overexploited aquifers, endangering the sustainability of current irrigation practices.

2. The need of Wastewater Re-use

Available water resources in Campo Dalías were estimated for the year 2010 to be 94 hm³/year, estimated demand stands at 143.9 hm³/year. This represents a deficit of 50 hm³/year, see Table 15.

<table>
<thead>
<tr>
<th>Water Supply (Hm³)</th>
<th>Water demand(Hm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir</td>
<td>15</td>
</tr>
<tr>
<td>Drinking water</td>
<td>31.9</td>
</tr>
<tr>
<td>Aquifer</td>
<td>79</td>
</tr>
<tr>
<td>Irrigation</td>
<td>110.5</td>
</tr>
<tr>
<td>Golf</td>
<td>1.46</td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
</tr>
<tr>
<td>Total</td>
<td>144</td>
</tr>
<tr>
<td>Deficit</td>
<td>50</td>
</tr>
</tbody>
</table>

Source: South Basin Hydrologic Plan (Plan Hidrológico de la Cuenca Sur)

Table 15 Campo Dalías’ Hydrological Balance

Wastewater treatment plants and wastewater re-use

Given the deficit and also the necessity of water quality improvements, projects were initiated in the year 2000, when the former Ministry of Public Works, Transport and the Environment (Ministerio de Obras Públicas, Transportes y Medio Ambiente), together with the Regional Government of Andalusia (Junta de Andalucía), drew up the plans for 9 wastewater treatment plants in Campo Dalías with the capacity to supply 320,000 population-equivalents.

In 2001, works valued at €31.7 millions were planned to treat 19.3 hm³/year and regenerate 11.4 hm³/year. The intended uses were to be aquifer recharge and agricultural irrigation. Of the 9 WWTPs, the 3 largest plants situated close to large expanses of farmland were chosen for wastewater re-use. These were Adra (6,960 m³/day), El Ejido (12,460 m³/day) and Roquetas de Mar (38,900 m³/day). Other WWTPs at Félix, Énix and Castala (8,149 m³/day) were not yet considered suitable for wastewater re-use. But these WWTPs are expected to be included in a new project. WWTPs are being run by a local management board (Consortio para la Gestión de Aguas del Poniente Almeriense).

At the WWTPs employing tertiary treatment, a process had been planned to treat activated sludge, at half load, using nitrification, denitrification and anaerobic digestion. Water from the secondary settling tanks intended for aquifer recharge would therefore undergo physicochemical treatment and coagulation, decarbonisation, flocculation, sedimentation and filtration through a bed of sand, followed by desalination using reverse osmosis. The designated salinity of the treated water at the outlet from the secondary settling tanks was set at 1,500 mg/l and, from the membrane at the reverse osmosis outlet, at less than 500 mg/l.

Meanwhile, water from the secondary settling tanks intended for agricultural irrigation would be pressure-filtered then filtered through a bed of sand, after which it is disinfected with ozone.

The initial project had planned to use most of the water regenerated, 24,000 m³/day, from tertiary treatment to recharge aquifers and only planned to allocate a small part to agricultural irrigation, 4,500 m³/day. However, farmers requested that regenerated water, with a salinity of less than 800 ppm, should be used principally for irrigation. So, when finally designing the plants, it was assumed that all the regenerated water would be used for agricultural irrigation, golf clubs and green-areas, with only one re-injection to the aquifer being carried out as an experiment.
The needs to be met are as follows:

- **Irrigation associations**: Irrigators' requirements are currently supplied by surface water and groundwater from the area’s aquifers, which are suffering from problems of overexploitation and seawater intrusion, thereby resulting in concerning drops in level and deteriorating quality.

- **Golf clubs**: Golf clubs' requirements are currently supplied, in equal measure, by regenerated water from local WWTPs and groundwater.

- **Local councils** (green-area maintenance).

The volumes to be treated by the developed facilities and uses are as follows:

<table>
<thead>
<tr>
<th>WWTP</th>
<th>Capacity (hm³/year)</th>
<th>Type of treatment</th>
<th>Complementary treatment of Reverse Osmosis (hm³/year)</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adra</td>
<td>1.7</td>
<td>• Continuous sand filter&lt;br&gt;• Flocculation&lt;br&gt;• Disinfection&lt;br&gt;• Microfiltration</td>
<td>1.1</td>
<td>Agricultural (irrigation association)</td>
</tr>
<tr>
<td>El Ejido</td>
<td>3.4</td>
<td>• Continuous sand filter&lt;br&gt;• Flocculation&lt;br&gt;• Disinfection&lt;br&gt;• Microfiltration</td>
<td>1.1</td>
<td>Agricultural (irrigation association)&lt;br&gt;Municipal (green areas)</td>
</tr>
<tr>
<td>Roquetas de Mar</td>
<td>5</td>
<td>• Continuous sand filter&lt;br&gt;• Flocculation&lt;br&gt;• Disinfection&lt;br&gt;• Microfiltration</td>
<td>2.2</td>
<td>Agricultural (irrigation association)&lt;br&gt;Leisure (golf)&lt;br&gt;Municipal (parks)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>10.1</strong></td>
<td></td>
<td><strong>4.4</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: AcuaMed

**AGUA’s Programme in the waste-water re-use process**

The lack of appropriate infrastructures to distribute regenerated water from the WWTPs meant that the treated waste water was not used by farms, but discharged instead to the sea via a marine outfall (at an average annual volume of 10 hm³, equivalent to 26,000 m³/day). As the water is not re-used, the tertiary treatment has not been operative.

The irrigation system in Campo de Dalias is very complex, it has been built during decades and its distribution was designed to supply the fields mainly with ground waters, and the new infrastructures had to adapt to this, in order that the new supply could be used.

In order to solve this problem and to be able to re-use waste water, the AGUA Programme of included works in the Act 11/2005 (*Ley 11/2005*), the so-called
“Complementary Wastewater Re-use Actions in Campo Dalías”, were assigned by the Ministry to ACUAMED. After, they were adjudicated in June 2006 for €9.8 million. These actions objectives were as follows:

- Adapt effluent quality to the various uses for which it is intended: irrigation, green-area maintenance and leisure activities.
- Distribute the above flows to such areas and increase regulation capacity to manage the resource more efficiently.

Conveyance and force mains works planned under Annex II to Act 7/1994, of 18 May, concerning Environmental Protection (Official Gazette of the Andalusian Regional Government. No. 79, of 31/05/1994) (Ley 7/1994, de 18 de mayo, de Protección Ambiental – BOJA nº 79, de 31/05/1994), require an Environmental Report. As a result, a report was drawn up on the project’s environmental integration.

### 3.3.5.2 Brief description of the relevant mitigation measures and which problem they address

The case study analyses the mitigation measures planned within measures for Wastewater Re-use for Agriculture in Campo Dalías (Almería). The proposed measures focus essentially on minimising the main impacts associated with the use of wastewater re-use, which are related to effect of water quality, local impacts of construction and operation and socioeconomic risks of wastewater re-use for irrigation, which are related to farmers acceptance of crops and marketability of crops.

Table 16 summarises the main mitigation measures to be applied in the waste water re-use in Campo Dalías.

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mitigation measures</th>
<th>Potential to reduce impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Not at all</td>
</tr>
<tr>
<td>1. Effect on water quality</td>
<td>Treatment improvements: osmosis and microfiltration</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>Water quality criteria and monitoring</td>
<td></td>
</tr>
<tr>
<td>2. Local Impacts</td>
<td>Corrective measures included in Environment Report</td>
<td></td>
</tr>
<tr>
<td>3. Marketability and public acceptance of crops grown with treated waste water</td>
<td>Treatment improvements: osmosis and microfiltration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water quality criteria and monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agreements between ACUAMED and other public and private entities</td>
<td></td>
</tr>
</tbody>
</table>

*Table 16 Summarising impacts and mitigation measures applied in desalination plants planned under the AGUA Programme*

### 3.3.5.3 Data availability and approach

The information used in drawing up this chapter has been taken from a variety of sources among them, Memory: “Wastewater treatment Complementary Actions Campo Dalías” and its viability report. Additional information was obtained through
consultations with the Environment Department of the public company AcuaMed (http://www.AcuaMed.com/), a state-owned company reporting to the Spanish Ministry of the Environment and Rural and Marine Affairs and responsible for contracting, building, acquiring and operating hydraulic works in Spain.

### 3.3.6 Mitigation measures: Treatment Improvements: Osmosis and microfiltration

#### 3.3.6.1 Summary

**Problems and impacts**

Problems in the wastewater treatment could affect water quality and produce environmental and economic risks. In order to prevent these risks, different treatments have to be used.

**Technical description of the mitigation measures**

The principle treatment techniques are:

- Physicochemical treatment to obtain bacteria-free water and to reduce suspended solids and nutrient concentration and to preserve reverse osmosis membranes.
- Because wastewater sewer are not properly maintained, waste water is being affected by sea intrusion, therefore, it’s necessary to use reverse osmosis technology to desalinate part of the water.
- Desalinated water is mixed with microfiltrated water before the Sodium Absorption Ratio (SAR) correction and Clorohamines treatment in order to adapt the salinity index to irrigation requeriments.

Although the irrigation system in Campo Dalías is complex and the new infrastructures have to be adapted to supply water to farmers it was planned to implement or adapt the pumping facilities with 9 pipelines to transport the water to consumption and storage sites. This would avoid that discharging the re-used water into the sea.

**Evaluation of the mitigation measure**

The new infrastructures and complementary treatment facilities were evaluated and the feasibility report determined that:

- Treatment did not raise any relevant environmental issues, as the works would be performed within the boundaries of the WWTPs’ sites.
- It would be enough for the effluent leaving the secondary treatment facilities to be physicochemically treated, leaving ultrafiltration and reverse osmosis, which are costlier treatments, for exceptional situations. But inadequate maintenance of wastewater sewers and sea intrusion could demand reverse osmosis.
- Reverse osmosis guaranteed that the salinity index of re-used water was suitable to irrigate crops but water costs subsequently increased.
- Re-use option is considered optimal in comparison with desalination, given the former's lower economic cost. But this extra desalination treatment meant that the water price of re-use option to increased €0.30/m³, making it less attractive to irrigation associations who would prefer straight desalinated water.
- Microfiltration treatment offers the environmental and health advantages, since water is disinfected, water is free of suspended material and colloidal particles.
The main expected environmental benefits for the Campo Dalías aquifer are substitution of water abstracted from the Campo Dalías aquifer, improve the ecological status of the coastal water body and reduce seawater intrusion and deterioration of other resources' quality.

According to the economic and financial analysis carried out in the feasibility report, the cost-recovery percentage is very high, 91.24%. In order to ensure cost recovery, the tariff scheme is stipulated in an agreement signed between users and the state-owned company AcuaMed.

### 3.3.6.2 Problem and impacts

Problems in the wastewater treatment could affect water quality and produce environmental and economic risks mainly related to:

- Effect of water quality, particularly salts, nutrients, heavy metals, pathogenic (bacteria, viruses, and parasites) microorganism, and harmful organic chemicals on Public health, soil and crops
- Local impacts such as Odour pollution.
- Marketability and public acceptance of crops. The use of regenerated water for intensive crop farming in greenhouses, the products of which were intended mostly for exportation, gave rise to concern about the serious consequences that would be generated should health problems attributable to the type of irrigation water used arise in national and foreign markets.

In addition, two specific problems have affected the normal use of wastewater. Firstly, the wastewater sewer is not properly maintained and wastewater is being affected by sea intrusion. So it is necessary to use reverse osmosis technology to desalinate part of the water and reduce the salinity index.

Another problem is related with the irrigation system, which hasn't been designed to be supplied with WWTP water. Up to now, irrigation associations have not used wastewater, because their irrigation system had not been suitably connected with the water re-use system. New infrastructures are necessary to connect both systems.

### 3.3.6.3 Technical description of the mitigation measure

Different treatments have to be used to achieve wastewater re-use. Firstly and prior to tertiary treatment, at the outlet from the secondary treatment, sufficient physicochemical treatment is being applied to achieve bacteria-free water of suitable quality for re-use and to reduce suspended solids and nutrients. It is also necessary to preserve reverse osmosis membranes.

On the other side, wastewater sewer is not properly maintained, and wastewater is being affected by sea intrusion. Seawater enters in sewers and increases the salinity index at the three WWTPs in Adra, El Ejido and Roquetas de Mar.

Normal tertiary treatment of re-used water for irrigation does not reduce salinity, but reverse osmosis infrastructure that was designed for aquifer recharge was available, so the scheme of treatment has been re-adapted to allow for desalination of part of the water, after microfiltration (to eliminate viruses). See Figure 10 and the Box “Technical Characteristics of the tertiary treatment facilities”.
Chapter 3 Mitigation measures associated with wastewater re-use

The desalinated water is mixed with microfiltration water before the SAR correction and Clorohamines treatment, in order to adapt the salinity index to irrigation crops. Salinity at the outlet from secondary treatment was estimated at 1,000 mg/l. Salinity in the regenerated water was established at around 100 mg/l at the reverse osmosis outlet.

Source: Plan de Reutilización en la Comarca de Campo Dalías (Almería)

**Box Technical Characteristics of the tertiary treatment facilities**

The characteristics of the tertiary treatment facilities constructed were as follows:

- Storage of all water to be regenerated for 6 hours in order to:
  - Eliminate fluctuations in flow arriving at the WWTP and so ensure a constant flow for tertiary treatment.
  - Homogenise water entering tertiary treatment.
- Screening at 500 µ of all water to be regenerated to protect the microfiltration membranes.
  - Effluent from microscreen washing is sent back as raw input to the WWTP.
- Microfiltration, with a selectivity of around 0.2 to 0.1 microns, of all water to be regenerated.
  - Effluent from microfiltration membrane washing is sent back as raw input to the WWTP, optimising the system's overall conversion ratio.
  - Microfiltered water is split into two currents, as shown in the diagram below.
  - One of the currents of microfiltered water is treated by reverse osmosis. The water returned by the membranes is sent to the sea by the WWTP's bypass pipeline.
  - The other current, after being mixed with the reverse osmosis permeate, has its Sodium Absorption Ratio (SAR) corrected and is disinfected by adding chloramines.

The microfiltration systems installed were as follows:

- Roquetas WWTP: Dead-end microfiltration system with 0.2 µ hollow-fibre membranes and air backflush. Manufactured by MEMCOR.
- El Ejido and Adra WWTPs: Tangential-flow microfiltration system with 0.1 µ hollow-fibre membranes, recirculation and backflush using microfiltered, chlorinated water. Manufactured by PALL.

In 2001, the mean cost per m³ of treated water was estimated at €0.10/m³.
The irrigation system in Campo Dalías is very complex, it has been built during decades and its distribution was designed to supply the fields mainly with aquifers, and the new infrastructures have had to be adapted, in order that the new supply can be used.

Therefore, AGUA Programme included works to distribute the above flows to such areas and increase regulation capacity to manage the resource more efficiently. This system has to avoid that re-used water will be discharged into the sea. At present, Golf clubs are already using water re-use.

So, In addition additional tertiary treatment, it was planned to implement or adapt 7 pumping facilities, as well as 9 pipelines (300-400 mm diameter) totalling over 30.2 km in length, to transport the water to consumption and storage sites.

The infrastructure to transport reusable water from the WWTPs in Adra, El Ejido and Roquetas de Mar to tanks in the main consumption centres required the following works to be implemented:

- Force mains and conveyance systems: Pipelines sunk in trenches and protected by in-fill of up to 30 cm over the pipe.
- A building for the pumping station.

Throughout the conveyance system, a series of special elements (flow meters, aeration elements, drains and shut-off valves) have been designed to ensure proper operation. The project includes a regulating tank for water supplied by the Roquetas WWTP. This is sited at the end of the irrigation association’s force main and has a 43,500 m³ capacity.

3.3.6.4 Evaluation of the mitigation measure

Feasibility evaluations

Following the National Hydrological Plan of Spain’s Act 11/2005, a report was prepared in order to review the feasibility of the studied actions in Campo Dalías. In this report the actions were evaluated, revising if their goals followed what it had been established by law, as well as the plans and programs, and also the technical, environmental, financial and economical effectiveness and viability.

As regards the study of alternatives for complementary treatment, it was determined that:

- The alternatives analysed for complementary tertiary treatment did not raise any relevant environmental issues, as in all cases the works would be performed within the boundaries of the WWTPs’ sites.
- A study was carried out to analyse systems at the three WWTPs with the aim of producing the best quality water possible at a cost economically viable to interested parties. The study concluded that most of the time it would be enough for the effluent leaving the secondary treatment facilities to be physicochemically treated, leaving ultrafiltration and reverse osmosis, which are more costly treatment, for exceptional situations. Although inadequate conservation of wastewater sewers and sea intrusion could demand these treatments.
- In any event, in a context in which surface water and groundwater are overexploited, the re-use option is considered optimal in comparison with desalination given the former's lower economic cost. But desalination part of
Chapter 3 Mitigation measures associated with wastewater re-use

water could increase water price of re-use option. If re-used water price will increase to €0.30/m³, irrigation associations could prefer desalination water.

Environmental evaluation

Microfiltration offers the following environmental and health advantages:

- It guarantees that the water is disinfected, as bacteria and nematode eggs cannot pass through the membrane pores.
- The regenerated water is free of suspended material and colloidal particles, virtually eliminating the risk of blockage in modern irrigation systems.
- It greatly simplifies the physicochemical processes involved in tertiary treatment.
- It guarantees constant regenerated water quality, regardless of the quality of the water coming from the secondary settling tanks.
- It wholly eliminates production of sludge in tertiary treatment.
- It reduces the cost per m³ of regenerated water, which unquestionably has a positive effect as regards its use by local irrigation associations.
- It extends the useful life of reverse osmosis membranes, which cuts operating costs.
- If there is no need to reduce the salinity of treated water, then microfiltered water can be used directly for irrigation, increasing the total volume of water regenerated. Reverse osmosis guaranteed that salinity index of re-used water is suitable to irrigation crops, but water cost increases.

Expected environmental benefits

The expected environmental benefits for the Campo Dalías aquifer are as follows:

- Progressive, orderly substitution of water abstracted from the Campo Dalías aquifer, with the aim of contributing to the aquifer's sustainability. The Andalusian water authorities are also drawing up the corresponding plan to govern abstraction, reducing it to 50 hm³/year.
- The ecological status of the coastal water body is improved by reducing discharges from WWTPs.
- Resources currently in an unsustainable state, such as the overexploited aquifer at Campo Dalías and the surface waters held in the Benímar Reservoir, are being partially recharged. This is consequently reducing seawater intrusion and deterioration of other resources' quality.
- This solution improves efficient resource use by managing it according to the quality required by the various users. By reusing wastewater in irrigation, green areas and leisure activities, better-quality resources are made available for urban supply.
- The measures included in the programme have no effects on the Natura 2000 network or on other protected areas which would require adoption of compensatory measures, and there was no need to apply the environmental impact assessment procedure set forth in Royal Decree 1131/1988 (Real Decreto 1131/1988).

Economic and financial analysis

According to the economic and financial analysis carried out in the Feasibility Report, the cost-recovery percentage would be very high. For the works’ financial analysis, the
costs of the actions were estimated at **€14.3 million**. Out of these costs, it is important to mention those corresponding to the piping works (41%) and to the additional treatments in the filter system (10%) to adapt effluent quality to the uses for which it is intended: irrigation, green-area maintenance and leisure activities.

The base data used in the economic-financial feasibility study considered 1 year of works, a 35-year analysis term and a discount rate and RPI of 4% and for the residual financial value at the end of the analysis term equivalent to the value of the sites (0% for facilities and works).

With regards to the updated operative costs during the whole exploiting period, they sum up more than €32.3 millions, of which it is important to mention the energy costs, which make up almost half of the costs (49%).

With these investment, exploitation and maintenance costs data, and taking into account that a total of 26,500 m³/day is going to be invoiced, and considering their production capacity of 365 days, the annual total cost updated in 2007 is above € 46 millions.

This means an investment cost of 0.0004 €/m³ (0.4%) and an operative and maintenance cost of 0.0956 €/m³ (99.6%), with a resulting price of 0.096 €/m³ in order to obtain a full cost recovery.

<table>
<thead>
<tr>
<th>m³/day invoiced</th>
<th>26,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production capacity (365 d.):</td>
<td>9,672,500</td>
</tr>
<tr>
<td>Investment costs</td>
<td>14,315,455.87</td>
</tr>
<tr>
<td>Operating and Maintenance Costs</td>
<td>32,353,481.34</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>46,668,937.21</strong></td>
</tr>
<tr>
<td>Investment cost €/m³</td>
<td>0.0004</td>
</tr>
<tr>
<td>Operating and maintenance cost €/m³</td>
<td>0.0956</td>
</tr>
<tr>
<td><strong>Price at which NPV = 0</strong></td>
<td><strong>0.096</strong></td>
</tr>
</tbody>
</table>

The work was declared to be of general interest by Act 11/2005 and, for its financing and subsequent operation, a framework agreement was signed between ACUAMED, the Andalusian Water Agency and the scheme’s various users under the following terms:

<table>
<thead>
<tr>
<th>Investment financing (thousand €)</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own Funds (State-owned Companies)</td>
<td>5,726.18 40%</td>
</tr>
<tr>
<td>Loans</td>
<td>5,726.18 40%</td>
</tr>
<tr>
<td>EU Funds</td>
<td>2,863.09 20%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14,315.46</strong></td>
</tr>
</tbody>
</table>

The expected annualised return over 35 years amounts to €41,652.58 in income from charges and tariffs for agricultural use (66%) and use for golf courses and council-maintained green areas (34%).

Considering this revenue and the legally applicable amortisation, plus operating and maintenance costs, it is estimated that the cost recovery % comes to 91.24%.

In order to ensure cost recovery, the tariff scheme is stipulated in an agreement signed between users and the state-owned company AcuaMed. For financing and operating, three agreements have been signed between ACUAMED and other public and private entities:

- Adra WWTP agreement was signed between Acuamed, the Andalusian Water Agency and Adra City Council. (10/3/2006).
Chapter 3 Mitigation measures associated with wastewater re-use

- El Ejido Adra WWTP agreement was signed between Acuamed, the Andalusian Water Agency, El Ejido City Council and Poniente Almeriense Irrigation Association (10/3/2006).
- Roquetas de Mar WWTP agreements were signed between Acuamed, the Andalusian Water Agency, Roquetas de Mar, Vícar and Mojonera City Councils and Poniente Almeriense Irrigation Association and La Envía and Playa Serena Golf entities (31/5/2006 and 22/6/2007).

These agreements could be suitable frameworks to improve the guarantee that entities will apply re-used water.

The tariff will establish:

- A 35-year amortisation rate to redeem the bank loan and the resources provided by AcuMed for tertiary treatment facilities. This does not include financial costs and will be updated according to the retail price index.
- Rate for operating costs. If functional operation (personnel, membranes, repairs and other overheads) is assigned to the users’ consortium, operating costs for the supplies assumed by AcuMed will be passed on.

These figures represent a subsidy with a net present value of €3.9 million and a capital sum non-amortised by tariffs of €2.86 million (not including subsidised operating costs). The cost of measures to compensate for environmental impact is estimated at €36,000 and is not included in the tariffs.

The high cost recovery percentage (91.2%) and the high productivity of the greenhouse agriculture\(^{33}\) (6.12€/ m\(^3\)) compared with 0.096€/ m\(^3\) cost recovery price, also assure a good application of the actions.

It is important to remember that reverse osmosis will be required to treat one part of water, because wastewater sewer is not properly conserved and water is being affected by sea intrusion. If this problem is not properly solved, water costs are likely to increase.

\(3.3.6.5\) Conclusions

Main environmental problems and risks of re-used wastewater in Campo Dalías were considered in the works financed by AGUA Programme. As well as typical environmental and economic problems, two specific problems have been affected the normal use of wastewater. Firstly, wastewater has been affected by sea intrusion and secondly, the irrigation system is very complex and hadn’t been designed to be supplied from WWTP.

After assessing the mitigation measures, it is possible to conclude that enough technologies are available to solve the environmental problems that re-used urban wastewater can pose. But to make these technologies competitive with desalination the capacity and state of maintenance of the wastewater systems has to be considered, so that water salinity is as low as possible – otherwise desalination techniques have to be introduced which makes this technology less cost-effective.

\(33\) José Colino Sueiras y José Miguel Martinez Paz (2002). Water in the Spanish South-eastern agriculture: Productivity, Price, and Demand. The XXI Mediterranean Agriculture. Instituto de Estudios Socioeconómicos de Cajamar
3.3.7 Mitigation measure: Corrective measures to minimise environmental impact of implementing water supply improvements

3.3.7.1 Summary

Environmental Report considered that negative impacts were admissible in an area with not much environmental value due to the strong anthropogenic activity (area burdened by considerable agricultural activity (greenhouses and buildings)). Although negative impacts have not been considered in the operative stage, such as:

- energy consumption for pumping facilities or for reverse osmosis
- rejected water for reverse osmosis and other disposal of water treatment.

3.3.7.2 Problem and impacts

The possible local impacts of construction and operation of the project considered are summarised below:

1. Impacts of construction stage

   - **Effects on the atmosphere:** dust emission into the atmosphere, noise pollution by machinery and a reduction in visibility due to earth movements.
   - **Effects on the hydraulic environment:** wash-out of suspended solids due to earth movements during torrential rain, hydrocarbon pollution from machinery use and reduction in water quality due to discharges in affected watercourse (ramblas).
   - **Effects on the land:** loss of farming and forestry land due to siting and construction of infrastructure in greenhouse-cultivation areas; land-use restrictions due to siting of infrastructure; erosion processes due to earth movements and removal of vegetation; soil degradation due to siting and construction of infrastructure; alteration of soil horizons; soil compaction due to machinery use and earth movements.
   - **Effects on vegetation:** destruction of natural vegetation due to removal, clearing and levelling in the only areas where natural vegetation is present; loss of forest area due to construction of infrastructure.
   - **Effects on fauna:** reduction in habitat size due to removal of vegetation and construction of infrastructure, and due to machinery use; alterations in behaviour due to construction of infrastructure and machinery use in the only areas where natural vegetation is present; increased burden of anthropic activity due to construction of infrastructure throughout the intervention area.
   - **Effects on the landscape:** visual impact due to earth movements and removal of vegetation in areas with high-value marshes and dunes; alteration of natural landscape due to earth movements and removal of vegetation.
   - **Effects on social and economic activities:** increase in employment; improved local economy; and increased value of land due to construction of infrastructure.

2. Operation stage

In the operation stage, positive impacts on the hydraulic environment and social and economic activities are considered.

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34 Rambla: river beds usually waterless for most of the year
Chapter 3 Mitigation measures associated with wastewater re-use

- Positives effects on the hydraulic environment in the operation stage: improvement in water quality; reduction of effluent from wastewater treatment.
- The action increases water resources and guaranteed supply and it is expected to enhance the competitiveness and sustainability of farming and leisure activities.
- The action does not foresee increases in the area of irrigated land or in allocations, as it promotes the partial substitution of current supply sources.
- Positives effects on social and economic activities in the operation stage: increase in water resources; increase in productivity; improved performance; increase in economic activity; increase in employment; increase in local income; population stabilisation; and consolidation of agriculture due to operation of infrastructure.
- The subsidies considered are not deemed to affect the current pricing system as they amount to a very limited sum.
- Considering the scale of the work, it is anticipated to have little effect on creating employment. However, it may be expected that direct users may increase production and revenue, allowing them to invest in the irrigation system to boost productivity, thus increasing or maintaining employment in agriculture and services. In any event, improvements are limited by the proportion of resources generated by the action in relation to the area’s total resources.

Negative impacts have not been considered in the Environmental Report in the operative stage. But energy consumption for pumping facilities and for reverse osmosis and rejected water for reverse osmosis and other disposal of water treatment would have been considered in that evaluation.

3.3.7.3 Technical description of the mitigation measure

The Environmental Report accompanying the project includes possible effects on the environment and proposes a series of measures to correct and minimise them. Concerning the planned corrective measures:

- The territory has been classified into three types to determine the optimal sitings for interventions that may cause negative impacts during the construction stages: excluded areas, restricted areas and acceptable areas.
- Currently-existing roads will be used for works access.
- It is planned to set up the auxiliary facilities/machinery depots in areas of little environmental interest. These areas will be fenced off to prevent impact on surrounding areas.
- Atmospheric protection measures will be taken, such as covering trucks and limiting their speed, controlling combustion of on-site machinery, installing silencers in internal combustion engines, enforcing compliance with vehicle roadworthiness tests, etc.
- No activity will take place during night-time (22:00 to 08:00) in the vicinity of inhabited areas.
- Measures will be applied to take advantage of and re-use topsoil.
- For the protection of flora and fauna: effects caused by noise and dust will be controlled; discharges of any type will be prohibited in affected river courses.
- In areas where soil is expected to be moved as a result of the works, archaeological prospection will be carried out beforehand. In the event of discovery of a site of archaeological interest, the Directorate General for Cultural
Assets (Dirección General de Bienes Culturales) reporting to the Andalusian Regional Government's Ministry for Culture (Consejería de Cultura) will be informed immediately.

- A number of replanting actions have been planned, using species adapted to the area, on sites selected for auxiliary facilities/machinery depots, on the embankments created during construction of the regulating pond, and along the route of the re-used-water conveyance system where it crosses areas of environmental interest.

- An environmental monitoring programme has been drawn up to ensure proper application of the protective and corrective measures to be carried out.

### 3.3.7.4 Evaluation of the mitigation measure

Following the National Hydrological Plan of Spain’s Act 11/2005, the study of alternatives for distribution of conveyance system, it was determined that:

- in view of the very nature of infrastructure routed through urban and greenhouse-cultivation areas, the only socially and economically viable solution is to use, to the greatest extent possible, routes following the road network and so minimise the impact on buildings and crops. This is also the measure with the least environmental impact.

Negative Impacts are admissible in an area with not much environmental value due to the strong anthropogenic activity (area burdened by considerable agricultural activity (greenhouses and buildings)). But the minimization of energy consumption in the reverse osmosis process will be recommended so that wastewater sewer should be properly conserved and not would be affected by sea intrusion.

### 3.3.7.5 Conclusions

Local impacts of plants of WWTP and re-used wastewater treatment are admissible if recommendations and mitigation measures of environmental impact assessment are developed in the WWTP plant design. But to make these technologies competitive with desalination the capacity and state of maintenance of the wastewater systems has to be considered, so that water salinity is as low as possible – otherwise desalination techniques have to be introduced which makes this technology less cost-effective.

### 3.3.8 Mitigation measure: Water quality criteria and monitoring

#### 3.3.8.1 Summary

Spanish Royal Decree (RD) 1620/2007 guarantee the quality of wastewater re-use and determines the necessary requirements for the re-use, as well as the proceedings to obtain the granting required by law.

#### 3.3.8.2 Technical description of the mitigation measure

In order to guarantee the quality of wastewater re-use, the Spanish Water Act 11/2005 points out that the quality requirements are established by the Authorities, who defined them in the Spanish Royal Decree (RD) 1620/2007, related to the purified or regenerated wastewater. This RD determines the necessary requirements for the re-
use, as well as the proceedings to obtain the granting required by law and the regulations relative to the accepted quality uses and requirements on a case by case basis.

RD indicates some prohibited uses of wastewater re-use, but irrigation use is not included. Regenerated waters must fulfil the quality criteria at the delivery point. The decisions to grant the re-use authorisations will be prepared by the Basin Authorities, who will be able to set the values for other contaminant parameters which could be present in the regenerated water or, according to the application standards of this industry, depending of the foreseen use for the re-use water. Although on a cause by cause basis, more strict quality levels could be set.

The RD determines that the responsibility for the regenerated water quality, since the purified waters enter the re-use system until the regenerated waters delivery point, corresponds to the re-use granting owner, and that the person in charge of preventing the quality worsening, since the regenerated water delivery point until the usage locations, corresponds to the regenerated water user.

RD defines how controls have to be carried out:

- specific threshold values for different parameters that should not be exceeded in the point of delivery and depending of the sort of use. Parameters that are being monitored are intestinal nematodes, coliform bacteria (escherina coli), suspension solids, turbidity and others (legionella spp.)

- Threshold values are different depending on foreseen water uses: agricultural, urban, industrial, leisure and environmental uses. Within agricultural uses, there are different quality levels, the most demanding when water has a direct contact with human diet of fresh food.

<table>
<thead>
<tr>
<th>Water use</th>
<th>Maximum Admissible Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>intestinal nematodes</td>
</tr>
<tr>
<td>Irrigated crops with regenerated water where water comes into direct contact with edible parts to human food</td>
<td>1 egg / 10 litres</td>
</tr>
<tr>
<td>Pasture irrigation for animals for meat and milk</td>
<td>1 egg / 10 litres</td>
</tr>
</tbody>
</table>

- Controls have to be carried out in the regeneration plant outflow and in all of user delivery points

- The minimum frequency of analysis is depending on water uses and parameters,
### Maximum Admissible Values

<table>
<thead>
<tr>
<th>Water use</th>
<th>Maximum Values</th>
<th>Other criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture use</td>
<td>intestinal nematodes, Escherina coli, suspension solids, turbidity</td>
<td>Basin Authorities assess</td>
</tr>
<tr>
<td>Agriculture use</td>
<td>fortnightly, weekly, weekly, weekly</td>
<td></td>
</tr>
</tbody>
</table>

- Water quality is valued with sample analysis in delivery points. When a non-fulfilment is analysed, Authorities take management measures, and more controls are taken or water supply is suspended.

The Waters Act also points out that the granting or authorisation owner must pay off the water re-use costs.

### 3.3.8.3 Conclusions

Spanish Royal Decree (RD) 1620/2007 guarantee the quality of wastewater re-use and determines the necessary requirements for the re-use, as well as the proceedings to obtain the granting required by law. Basin Authorities prepare the re-use authorisations and regenerated water must fulfil the quality criteria at the delivery point. The re-use granting owner has the responsibility for the regenerated water since the purified water enter the re-use system up to the regenerated waters delivery point, and the regenerated water user has the responsibility from this delivery point up to the usage locations. This law is binding on Waste water re-use in Campo Dalías, so its compliance should be assured.

### 3.3.9 Summary and conclusions

#### 3.3.9.1 Specificities of the case study

The case study analyzes the use of treated wastewater in the “Campo Dalías” in the Almería Province. Campo Dalías is one of the oldest and biggest irrigation area in south east Spain. It is located in a province, Almería, with the lowest rainfall in Spain. Campo Dalías is characterised by a well developed intensive agriculture, mainly greenhouses (30.000 ha), which have partially exhausted the groundwater, allowing salinization of relevant aquifers.

Given the deficit and also the necessity of water quality improvement, the Administration drew up plans for wastewater treatment plants in Campo Dalías with the capacity to supply 320,000 inhabitants-equivalents and works were planned to regenerate 10.1 hm$^3$/year plus 4.4 hm$^3$/year complementary treatment of Reverse Osmosis, for agricultural irrigation, green areas and golf.

Very recently, the Royal Decree 1620/2007 was approved, which set up the legal framework for the use of treated wastewater for agriculture. The lack of appropriate infrastructures to distribute regenerated water from the WWTPs has not enabled to use it in the farms, and it is discharged into the sea via a marine outfall. In order to solve distribution problems and to be able to re-use waste water, AGUA Programme included new works mainly to distribute the flows and increase regulation capacity to manage the resource more efficiently.

#### 3.3.9.2 How were the different problems or concerns addressed

Firstly, problems in the wastewater treatment could affect water quality and produce environmental and economic risks. Main environmental problems and risks of re-used
wastewater in Campo Dalías were considered in the works financed by AGUA Programme.

After going through used mitigation measures, it’s possible to conclude that enough technologies are available to solve the detected environmental problems that re-used urban wastewater can pose. But, so that those technologies relative to alternative water supply as desalination work out competitive, on the one hand, capacity and state of maintenance of wastewater systems have to be considered, so that water quality before treatment is as good as it’s possible, and on the other hand, appropriate infrastructures to distribute regenerated water from the WWTPs to irrigation system are necessary.

Secondly, the impacts of construction and operation of the project have been considered in the environmental report. Although energy consumption for pumping facilities or for reverse osmosis and rejected water for reverse osmosis and other disposal of water treatment haven’t been assessed.

Environmental report assessed that local impacts of plants of WWTP and re-used wastewater treatment are admissible if recommendations and mitigation measures of environmental impact assessment are developed in the WWTP plant design, in an area with not much environmental value due to the strong anthropic activity (area burdened by considerable agricultural activity (greenhouses and buildings)).

In that specific case study, a properly conservation of wastewater sewer will be recommended, so that sea intrusion would be avoided, and reverse osmosis process and energy consumption is minimized.

Finally, with respect to impacts from water quality criteria and monitoring, Spanish Royal Decree (RD) 1620/2007 guarantee the quality of wastewater re-use and determines the necessary requirements for the re-use, as well as the proceedings to obtain the granting required by law. This law is binding on Waste water re-use in Campo Dalías, so its compliance should be assured.

3.3.10 Review of case study achievement and the need for future mitigation measures

The lack of appropriate infrastructures to distribute regenerated water from the WWTPs have not allowed it to be used on farms, and the treated water has been discharged into the sea via a marine outfall at an average annual volume of 10 hm³, equivalent to 26,000 m³/day. As the water is not re-used, tertiary treatment has not been operative.

On the other hand, the irrigation system in Campo Dalías is complex and the new infrastructures had to be adapted, in order that the new supply could be used by farmers. It was planned therefore to implement or adapt the pumping facilities with 9 pipelines to transport the water to consumption and storage sites, so that it would not be discharged into the sea.

It was necessary to adapt the design to specific uses and establish agreements between the supplier and users. Other specific problem have affected the normal use of wastewater, the wastewater sewer is not properly maintained and wastewater is being affected by sea intrusion. So it’s necessary to use reverse osmosis technology to desalinate part of water and reduce the salinity index. Reverse osmosis is a costly treatments and would increase water price of this re-use option. If re-used water price increased to €0.30/m³, irrigation associations could prefer directly desalinated water.
Chapter 3 Mitigation measures associated with wastewater re-use

3.3.11 References

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- AGUA Programme http://www.mma.es/secciones/agua/entrada.htm
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- Domínguez Prats, et al. Situación actual de los acuíferos del Campo Dálías, Un ejemplo de la necesidad de conocer el estado actualizado del funcionamiento en un sistema complejo intensamente explotado.
- Gutiérrez Fernández, Miguel Ángel. Depuración y reutilización de aguas residuales del Campo Dálías

Written Consultations were made to the Sr. Adrián Baltanás García. Director General. AcuaMed

Personal Consultations were made to Javier Valenzuela Sainz and Fermín López Unzu (Project Manager) Regional Delegation Acuamed

3.4 Mitigation measures associated with wastewater re-use: case study
Pornic golf course, France

3.4.1 Introduction

In France, water resources are largely an issue of water demand rather than water supply. However, variations from one year to another (rainwater) and important geographic differences can be observed due to climatic, geographic and demographic features and hydrographic network. This means that water shortages can occur in some regions, particularly for the Atlantic and Mediterranean islands and coastal regions.

Despite available techniques (transfer of technology from French private companies to other parts of the world), France is late in developing wastewater reuse on its territory, especially for the irrigation of golf courses and other “green spaces”. During the 1990s only 20 projects using wastewater was listed. Reused water is used for irrigation on around 23 000 ha, which is rather low compared to other countries (source: Lazarova, Brissaud, 2007). Currently there is a real interest from local decision-makers and water managers for wastewater reuse, especially in the coastal zones. This section presents a specific initiative of wastewater reuse located in Pornic, a seaside resort on the French Atlantic coast.

3.4.2 Main adverse impacts of wastewater reuse

As shown in Task 1 of the present study, wastewater reuse raises potentially the following problems / adverse impacts:
- Potential soil and water contamination due to chemical or micro-biological residues.
• Potential risks to human health: this risk is linked with consumption of contaminated food/vegetables but also to exposure, due to aerosol contamination during irrigation.
• Problems linked to the seasonality of needs: wastewater is produced all through the year, whereas needs for irrigation occurs mainly in the growing season. However, in the specific context of Pornic, as a seaside resort, the growing season also corresponds to the period when growing population in the city produces higher wastewater volume (to be developed further).
• Social acceptance in reusing wastewater for irrigation. However, irrigation of a Golf Course or green spaces inspires less distrust to population than irrigation of growing vegetables for food. Moreover in France, a survey conducted in 2006 has shown that French people were 86% in favour of wastewater reuse for irrigation of golf courses and green spaces (SOFRES, 2006). Interviews with local stakeholders confirm this point in the specific case of the Golf of Pornic.

3.4.3 Relevance of the case study for the EU

The Pornic case study reflects the particularities of the French coastline both in terms of water demand (tourist activities, higher population...) and wastewater treatment (beaches, shellfish growing areas...). Moreover, this case study reveals some specific constraints due to irrigation in a place open to public and situated in an urban areas. Thus, mitigation measures have been selected in a context that could be applied in many other populated and urban contexts. Another interest of this case study comes from the approach of integrated water management: while irrigating the golf course, wastewater reuse in Pornic also aims to help preserve the coastal water quality.

The project started in 1992 and the Pornic golf course has been among the first ones in France to irrigate its greens with wastewater reuse. Lessons can therefore be drawn from this experience.

3.4.4 Presentation of the case study

3.4.4.1 Generic information

Pornic is a seaside resort located on the Atlantic coastline (Figure 11). The population triples from 12 000 during winter to around 30 000 inhabitants during the summer months.
The project has two main objectives:
- supplying water for the golf course irrigation.
- protecting bathing water quality, with an objective of «zero discharge». During the irrigation season, that is from April to October, effluents of the Pornic treatment plant would be no longer disposed of in the city harbour (Figure 12) or at the local beaches.

It is interesting to note that before the project took place in 1992, the treatment station raised some problems due to its location: the plant rejected water directly in the sea, in bathing and shellfish growing areas. It was then decided to take advantage of the existence of a golf course, 4km from the treatment plant. Water reuse by the golf course was considered as an alternative to a direct water discharge to the sea. Moreover, the golf course size doubled from 9 holes to 18, and so wastewater reuse offered a solution to an increasing water demand.

However, it is not possible for the moment to reach the «zero discharge» objective. Three different periods can be distinguished in this regard:

credit :stephanemartin / flikr

Figure 12 Pornic Harbour
During summer, the high density in the city leads to overcapacity in terms of wastewater compared to the needs of the Golf.

Another period when the needs for irrigation meet the wastewater discharge from the city.

A third period (November to March) when there is no need for irrigation of the golf course.

Annual needs for the golf course are 95000 m³ (source: Goraguer, DDASS, 2007) and the surface that is irrigated is 34 ha which make an average of 2800 m³/ha. Three reservoirs give water security for three days for the golf course (15000 m³) and 5 ponds are scattered within the golf course (8m³).

Three partners are involved in this project: the city, which owns the infrastructures, Veolia eau, managing the infrastructure for water treatment and transfer to the golf, and Formule Golf, managing the golf course. The city plans to reuse wastewater for other sports activities and city green spaces too.

For the city, the needed infrastructure required an investment of 2,5 millions of francs (380 000 euros). It has been financially amortised within seven years.

### 3.4.4.2 Context in terms of water supply issues in the EU

When referring to wastewater re-use in France, it seems interesting to focus on a coastal case study, as water shortage impacts mainly coastal areas or small islands, as in many northern European countries. Moreover, projects on the coastlines raises specific key issues which have an obvious European dimension.

Integrated management has become a major approach for coastal zone management at European level, especially since the European recommendation of 2002 on Integrated Coastal Zone Management. Coastal pollution appears to be among the key preoccupations to be addressed through an integrated approach by policy makers along the European coastline. The case study reflects this context, as the decision to initiate the project of wastewater reuse for the irrigation of the golf course of Pornic has been first driven by the objective to reduce wastewater discharge in the small harbour and on the surrounding beaches.

### 3.4.4.3 Brief description of the mitigation measures

Three main mitigation measures have been implemented to reduce various impacts:

- Chlorination / dechlorination process;
- Irrigation by night; and,
- Low pressure irrigation system.

**Human health risk:** in terms of impacts, the main issue relates to human health risk due to aerosol contamination when irrigating. This has to be considered at the different levels/steps of the process, i.e. water treatment and the golf course irrigation. All three mitigation measures address these risks.

**Economical risk:** economic/financial aspects have to be considered when choosing among the various options. Chlorination / dechlorination appears to be a rather cheap water treatment process.

**Environmental risk:** environmental risks relate mainly to coastal ecosystems, due to the location of Pornic. Moreover one major objective of the project is to reduce the discharge on the coast.
According to the literature review, chlorination / dechlorination might have two adverse impacts on environment:
- on the one hand, it improves the microbiological quality of the treated water, diminishing coastal pollution;
- on the other hand, it raises some problems in terms of chemical contamination. However dechlorination is a mitigation measure to counteract this problem.

The following table sums up the links between the mitigation measures and the risks they address. The number of “+” indicates the effectiveness of the measure to address a risk. When the measure does not address a risk, a “-” is used.

<table>
<thead>
<tr>
<th>Mitigation measure/ Technology</th>
<th>Human health risk</th>
<th>Environmental risk (water quality and coastal ecosystems)</th>
<th>Economical risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorination / dechlorination</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Adapted irrigation system</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Table 17 Matrix relating the mitigation measure to a risk*

### 3.4.4.4 Guidelines of the national public health council

Guidelines regarding places open to the general public have been written by a national council for public health issues (Conseil supérieur d’hygiène publique de France (CSHPF)), 1991. However, there is no regulation for the moment and local administrations in charge of health issues for this type of project are still waiting for an implementation decree, which should come from the Health Ministry. Yet, this decree had been announced in the 1992 and 2006 Water Acts. Due to this text lacking, there is still no certainty about which constraints wastewater reuse should respect, especially when applying to places open to the general public.

For the moment, constraints are defined through local administrative orders (called «arrêtés préfectoraux»). The administrative order which authorized wastewater reuse for the golf course irrigation in Pornic was among the first ones in France (1992). It mentioned a number of recommendations:
- high water quality both in terms of microbiological and bacteriological aspects (quality A within a classification from A to D);
- irrigation by night;
- limitation to «aerosol propagation» or minimum distance of 100 meters to houses;
- water treatment station staff wearing masks;
- control of water quality and aerosol propagation.

This text has determined the mitigation measures which have been taken to reduce human health and environmental impacts, for wastewater reuse to irrigate the Golf course of Pornic.

### 3.4.4.5 Available information

General information related to wastewater reuse in France have been collected through a literature review. However, available information focusing on the project is rare, especially in terms of economic evaluation. Further information has been gathered
through interviews and personal contacts with the Water service of the Pornic City, the Golf course manager and the local administration for social and health issues (Direction départementale des affaires sanitaires et sociales de la Loire Atlantique).

3.4.5 Water treatment through chlorination / dechlorination

Wastewater treatment has to be adapted to water reuse. Chlorination and dechlorination has been initially chosen as a treatment process, giving good results in terms of microbiological contamination. Moreover it is a well-known technique with low costs. However, it raises specific environmental problems due to by-products and residual chlorine.

3.4.5.1 Description of the mitigation measure

According to the guidelines (CSHPF 1991), the treatment level should be adapted to water use, the irrigation system and public exposure (through contact, inhalation or ingestion). Water quality «A» is required when irrigating places open to general public. Wastewater treatment is compulsory to obtain a water quality meeting the health constraints. Different processes can be chosen with various technical, economical and environmental characteristics. Current water treatment processes are chlorination-dechlorination, ozonation, UV treatment and lagooning. In Pornic the choice has been made in favour of chlorination-dechlorination.
A chlorination / dechlorination process has been added at the end of the former water treatment process, to obtain water quality meeting the health constraints for the golf course irrigation. At the end of the process, the golf course acts as a natural filter before water discharge in the sea. Different sources show that this tertiary treatment system is also used for water that is finally discharged in the Haute Perche canal.

**The chlorination – dechlorination process as a water treatment**

Chlorine is a strong oxidizing agent that reacts easily with several organic and inorganic substances found in the used waters. It is particularly efficient in destroying bacteria but less efficient against viruses.

For some years, an operation of dechlorination has been more and more widespread worldwide to reduce the noxious effects of the chlorine on the aquatic life. Dechlorination is made through addition of sodium bisulfite.

### 3.4.5.2 Evaluation of the mitigation measure

**Water quality standards**

In terms of water quality standards, water quality A refers to two specific microbiological constraints:

- helminth eggs (tenia, ascaris) <1/liter
The standards for water quality A are met in the Pornic water treatment plant. The water quality control process controls the following parameters: escherichia coli, enterococ, helminth eggs, giardia, legionella, mosquito larvae (Source: Goraguer M.A., 2007). Some of these parameters are supplementary to the water quality requirements.

According to the local public health administration, the water quality meets the constraint levels required in the authorisation for wastewater reuse.

**Economical evaluation**

Costs for chlorination are among the lowest of all the well-tried techniques (source: website of the Quebec Ministry for sustainable development, environment and parks). As compared to other technologies, only lagooning could be cheaper (no cost). Ozonation means an important initial investment. UV irradiation has medium costs, higher than chlorination alone. However, dechlorination raises the costs.

There is a project to develop the water treatment station, giving up chlorination / dechlorination in favour of membrane microfiltration plus UV irradiation. The first choice made in favour of chlorination / dechlorination might have been driven by financial motivation; however, UV irradiation is now a well-known technique.

**Safety issues**

In the literature review, chlorine handling, in particular under carbonated form, requires important safety measures of protection for the water treatment station and constitute a risk for the public safety at the time of the transportation. When dechlorinating, risks are higher both for the water treatment station staff and for the general public during transportation. However, it seems that no security problem has been mentioned for the specific case of the Pornic water treatment plant (source: personal communication, city local authority).

**Environmental evaluation**

Wastewater disinfection with chlorine can have a serious impact on aquatic life, due to the toxicity in the residual chlorine. The chlorination-dechlorination process is less damageable than chlorination alone. In the case of Pornic water treatment station, residual chlorine after dechlorination is between 0.5 and 0.8 g/l.

One complication associated with chlorination is the formation of byproducts during the disinfection process. Chlorination byproducts are chemicals that result from the reaction of chlorine with organic substances in water. However, information related to the formation of byproducts could not be gathered.

**Comparison with other techniques**

Table 18 sums up the evaluation of different water treatment measures, among which chlorination / dechlorination. It shows that in spite of being one of the cheapest, chlorination / dechlorination presents several weaknesses, mainly in terms of environmental risks and public and staff safety. UV water treatment will improve the situation in this regard.
3.4.6 Mitigation measure related to the irrigation system

To prevent from aerosol contamination, the local administration order, which authorized the project of wastewater re-use in Pornic, requested that irrigation practices were restricted:
- a low pressure irrigation system would be used, especially close to houses;
- the golf course would be irrigated at night.

3.4.6.1 Impacts

Aerosol contamination is a key issue due to the specificity of the context: the place is an urban golf, located within the city of Pornic and surrounded by roads, houses and gardens. Moreover, it is open to the general public.

A control process of aerosol contamination has been set up with nine points of controls around the golf, 1,5 meters high. The control points correspond to different conditions in terms of hygrometry and wind force and direction. First controls (before authorisation) show that when using high pressure irrigation system health risks would have been existing in the surroundings, by inhalation or ingestion via vegetables or fruits grown in the surrounding gardens.

These potential impacts have justified the requirements of administrative order for authorisation:
- low pressure irrigation system close to inhabited areas (100 meters zone);
- no irrigation when the wind force is greater than 4;
- irrigation by night;
- vegetable screens where possible;
- no air intake oriented towards the golf, for the buildings close to irrigated areas.

Table 18. Comparison between different water treatment techniques, adapted from http://www.mddep.gouv.qc.ca/eau/eaux-usées/problematique.htm

<table>
<thead>
<tr>
<th>Treatment Technique</th>
<th>Chlorination</th>
<th>Chlorination/dechlorination</th>
<th>Ozonation</th>
<th>UV irradiation</th>
<th>Lagooning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-known technique</td>
<td>Yes</td>
<td>Yes</td>
<td>Under development</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Viral and bacteriologic inactivation</td>
<td>Bacteriologic mainly</td>
<td>Bacteriologic mainly</td>
<td>Both</td>
<td>Both</td>
<td>Bacteriologic mainly</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>Very bad</td>
<td>Bad</td>
<td>Low</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Public and staff security</td>
<td>Bad</td>
<td>Bad</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Costs</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>No (or low)</td>
</tr>
</tbody>
</table>
3.4.6.2 Description of the mitigation measure

A low pressure irrigation system has been implemented on the golf course. 260 underground sprinklers have been set up. The operating pressure is 6 Bar and the carrying-distance is 21 to 27 meters. The system is sectoral, giving the the possibility to adjust irrigation by sectors: different rotations are possible, with different angles. As confirmed by the company managing the golf course, this characteristic is important to control the water carrying-distance, especially close to the inhabited areas.

In conformity with the authorization document, the greens are irrigated when the public is not in the place. Irrigation by night is requested to avoid both the golf customers and inhabitants who could be in their gardens. When asked, the golf manager explained that irrigation by night was more a constraint than a choice. Still irrigation by night is usual for the golf courses.

3.4.6.3 Evaluation

Economic evaluation

It appears impossible to get a precise economic evaluation of these measures. No quantitative information could be obtained on the specific case of the Pornic golf from the golf manager. Contacts with companies providing irrigation system for golf courses explained that investment costs raise from one to double, depending on the whole irrigation system. Water consumption depends both on the irrigation system and on specific local conditions (for instance on the local pluviometry).

Additional costs due to low pressure might be related to a higher number of irrigation sprinklers. Moreover, it has been mentioned that irrigation system by sector could induce an excessive water use. However, no figure could be obtained in this regard either.

Irrigation by night is rather usual for a golf course. No additional costs or constraints have been mentioned during interviews or contacts.

Efficiency in terms of health issues

Health risks linked to aerosol contamination would require controls in the surroundings of the golf course. However it seems that the absence of legal framework makes it difficult to organize these controls. In this context efficiency of the mitigation measure appears to be rather difficult to assess.

Moreover, two problems had not been taken into account when writing the local administration order authorizing the wastewater reuse for the golf course irrigation in Pornic:

- the public health administration (DDASS) did not know about the « integrated project », with people sleeping on the golf site;
- New buildings and houses have been built in the surrounding of the golf course.

Again, there is no possibility to control now because of the absence of legislation (no implementation ministerial decree).
3.4.7 Conclusion

3.4.7.1 Specificities of the case study

The specificities of the case study are first related to its location on the coastal zone, within a seaside resort with high density during summer. This characteristic justifies the double objective of the wastewater re-use initiative (which partly came from the health local authority), i.e. supplying water for the golf course irrigation and protecting bathing water quality. Moreover, the location of the golf itself points out concerns specific to an urban area open to general public.

3.4.7.2 How were the different problems or concerns addressed

The different problems have been first addressed through a local administrative order, which gave the requirements to be met to prevent from health risks. Those requirements then appeared as constraints for the different organizations involved in the initiative. In 1992, chlorination / dechlorination appeared to be a good balance as a water treatment process between the necessity to use a well-known technique with low costs on the one hand and the requirements in terms of environmental and health risks. However it raised safety problems for the staff. The irrigation system on the golf course has been designed to limit health risks, related to aerosol contamination. It does not appear to be very constraining for the golf managers.

3.4.7.3 Lessons and implications for a further use of the technology throughout the EU

First, this case study shows the interest of wastewater re-use in the context of a seaside resort, even when there is no serious water shortage, as wastewater re-use can meet two different objectives. The project to adopt new water treatment process (UV irradiation) might be also interesting in terms of possibility to adapt to new conditions (in this case due to a planned extension of the treatment plant). However, this case study also stresses problems that arise due to the absence of legal framework to clarify health constraints related to wastewater reuse in France.

3.4.8 Literature and sources


Chapter 3 Mitigation measures associated with wastewater re-use


3.5 Mitigation measures associated with wastewater re-use: case study Malta

3.5.1 Introduction

The sewage system in Malta is collecting domestic and industrial waste, as well as some storm water runoff. Although nearly 100% of the Maltese households are connected to this network\(^{35}\), until recent times only about 10 % of the wastewater has undergone treatment (Medd & Marvin 2003, Attard 2007). Nevertheless, some amounts of the treated sewage effluent (TSE) coming from the first and for a long time only wastewater treatment plant in St. Antin have been reused since 1983. Due to some quality problems the amount of reused TSE was very limited. In order to comply with the EU legislation concerning the treatment of wastewater (Urban Wastewater Treatment Directive, UWWTD), new plants have been built and recently started to work. As a result, additional amounts of TSE are now available and their utilisation is currently under discussion.

3.5.1.1 Main adverse impacts

The main risks and impacts related to the reuse of wastewater affect the environment and are linked to its use for irrigation. The remaining pollutants in the TSE can lead to the accumulation of heavy metals and salts in the soil as well as to acidification. The same substances together with nitrate can harm the groundwater quality if washed out in deeper layers. A risk exists furthermore for human health, linked to the potential spreading of pathogenic germs.

The main problem in Malta which hinders the wider use of TSE in the agricultural sector is its high salt content. This can affect crop production and can harm aquifers and soils if used for irrigation (MEPA 2003). Three main factors have been identified which give rise to this situation: The infiltration of sea-water in the sewage-network, illegal discharge of brine from private desalination installations and the use of seawater for toilet flushing in a number of hotels (Sapiano 2006, Ministry of Health 2006).

Other potential risks mentioned in relation with the reuse of wastewater in the Maltese context are its possible virus content as well as new industrial pollutants which cannot be removed with the traditional purification technology (Sapiano 2006). In this regard Mangion (before 2002) states that treated wastewater coming from the St. Antin’s plant is within acceptable parameters, as the amount of heavy metals and other toxins in the raw sewage is insignificant.

As for economic impacts, Malta faces the problem that high investments are needed to create a network leading TSE to its potential users. The main wastewater treatment facility is located near to urban centers in the east and south and rather farther away from agricultural areas which are mostly in the west and north-western parts of the

\(^{35}\) With about 1000 households not connected, but having cesspits emptied every week (Medd & Marvin 2003).
island (Mangion & Sapiano 2005, Sapiano 2006). Furthermore, additional investments in the treatment of wastewater above statutory requirements might be needed to make the effluent more suitable for agricultural use.

3.5.1.2 Relevance of the case study

With Malta being a new EU Member State and only recently investing in larger wastewater treatment facilities, the potential of water reuse will significantly grow in the near future. As reuse on a small scale takes place since 1983, experiences made during more than 20 years are now feeding current discussions. Although mitigation measures are hardly in place, several ideas are currently discussed and can give an impression of the problems related to the use of wastewater perceived in Malta today and potential ways to reply to them.

3.5.1.3 Focus of the study

Although 25% of the TSE produced in Malta is used in the industrial sector, the emphasis of this case study will lie on its agricultural use for irrigation. As salinity is the most cited problem related to the reuse of TSE in Malta, the considered mitigation measures will concentrate on this issue.

3.5.1.4 Structure of the chapter

After a generic introduction in the local context of the case study, existing and possible mitigation measures will be described and evaluated. This will be followed by a final summary and conclusions.

3.5.2 Introduction to the case study

3.5.2.1 Generic information

The first and until recent times only wastewater treatment plant in Malta has been constructed in the early eighties in the St. Antin’s region, in the South Eastern part of the island. Originally, the plant was designed with a capacity of 12,000 m$^3$/day. It was subsequently upgraded to 17,000 m$^3$/day in 1998 (DoA after 2002). The plant has been intentionally built to produce second class water suitable for irrigation use in the southern parts of Malta. Reducing the pollution load discharged into the environment has hardly been considered at that time, as all the sludge extracted within the process as well as all the remaining wastewater was dumped into the sea (Mangion before 2002). Meanwhile, three new treatment plants have been built and recently started to work. The expected amount of effluent output is 14 Mm$^3$ per year from the three new facilities (see Table 19, Mangion & Sapiano 2005, Grech after 2003). According to the requirements of the UWWTD, the aim is to treat all wastewater before discharging it into the environment.

36 The plant in Sant Antin will be replaced by the “Malta South” plant (Mangion & Sapiano 2005).
Chapter 3 Mitigation measures associated with wastewater re-use

<table>
<thead>
<tr>
<th>Treatment Plant</th>
<th>Projected output (Mm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malta South</td>
<td>11.7</td>
</tr>
<tr>
<td>Malta North</td>
<td>1.0</td>
</tr>
<tr>
<td>Gozo</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13.9</strong></td>
</tr>
</tbody>
</table>

Table 19 Projected output of the new sewage treatment plants (Mangion & Sapiano 2005)

Of the 3 Mm$^3$ of purified effluent from the St. Antin’s treatment plant produced in 2003/2004, around 2.1 Mm$^3$ were reused. Approximately 75% (1.5 Mm$^3$) went to the agricultural sector, the remaining 25% to the laundry industry (Sapiano 2006, Kamizoulis et al. after 2002). Figure 14 indicates the origin of the water used for irrigation in Malta today, showing that TSE is currently with 8% only of minor importance. TSE from the Sant Antin’s plant which is intended to be used for irrigation is pumped to five reservoirs. They are situated on high ground and have a total capacity of 11,840 m$^3$. The flow of TSE to the fields takes place by gravity in open channels built on rubble walls that separate the land parcels (DoA after 2002). TSE is currently used to irrigate approximately 240 ha$^{37}$ of agricultural land (Delia 2004a). Mangion (before 2002) states that around 450 full and part time farmers received the second class water from St. Antin.

![Irrigation Water Sources](image)

Figure 14 Irrigation water sources in Malta (Sapiano 2006)

As for the potential of TSE to cover irrigation needs, it is expected that the effluent produced by the new wastewater treatment plants will outstrip the national irrigation demand during the rainy seasons. In dry seasons, however, it will probably stay below the required amounts and the need for other sources remains (Sapiano 2006). Nevertheless, if compared to current consumption, a substantial reduction of the pressure on groundwater can be assumed. The actual impact on the water balance will depend on the further development of irrigated land. The Department of Agriculture expects that the production of TSE by the new wastewater treatment plants will lead to an extension of the irrigated area to a total of about 2,090 ha. This would represent about 34% of the arable land in the Maltese Islands (DoA after 2002)$^{38}$. Although the new plants started to work, reuse is not yet taking place (Mangion pers. comm.). For

$^{37}$ Different figures can be found in literature: Irrigation of 600 ha of crops by furrow and spray irrigation (Kamizoulis et al after 2002), GHK 2006). Irrigation of 280 ha agricultural land (Attard 2007). 346 ha (Mangion before 2002).

$^{38}$ In 2007, only 15% (or 1,508 ha) of the total agricultural land area was irrigated (Attard 2007).
more details on the plants see the box below. The location of the plants is shown in Figure 15.

### The new wastewater treatment plants in Malta

The main treatment facility, the **Malta South**, will be located on the eastern shores of the island (close to Valletta harbour) and will produce an estimated supply of 11.7Mm$^3$ of treated effluent annually. It will have an annual excess of 7.5Mm$^3$ after supplying the irrigated farmland in the south east, today supplied from an existing plant at San Antnin, and other land that can be potentially cultivated with little extra cost.

There are three options for the effluent:

a) dispose the treated effluent into the sea and lose its inherent economic value.

b) lead the treated effluent to the Marsa/Kordin industrial area where there is potential re-use possibilities, by industry, shipyards included.

c) lead the treated effluent to central inland areas where it may be used for agriculture, respecting environmental and health constraints.

d) lead the treated effluent to existing central reservoirs where a distribution centre may be set up to provide water transporters with a controlled supply of water for agriculture and industry. Transfer capacity of existing water bowsers in Malta and Gozo is estimated around 2Mm$^3$ annually. An alternative source of water supply will make future cutbacks from groundwater more acceptable to these operators.

The **Malta North** facility will be located in the north-western tip of Malta is projected to deliver around 1.0Mm$^3$ of TSE annually. The proposed location enjoys a logistic advantage of being close to agricultural land both to the north and south, where currently irrigation demand is met by groundwater. Groundwater abstraction in these areas is envisaged to be relaxed from its current levels and substituted by TSE particularly in the smaller aquifers where reports of wells drying up during the summer period are common. Furthermore, the over-supply of TSE during low irrigation seasons, can be used to recharge artificially small but heavily depleted aquifers such as the one at Pwales.

The **Gozo facility** will produce 1.2Mm$^3$. Most of the product can be easily taken up for irrigation in substitution of groundwater that is heavily overexploited in Gozo.

Extracted from Mangion & Sapiano 2005

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![Figure 15 Location of the sewage treatment plants in Malta and Gozo and their capacity](Micallef_2006)

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3.5.3 Context in terms of water supply issues in the EU

The trend in Malta to reuse wastewater in greater amounts is common for the Mediterranean region (Kamizoulis et al. after 2002). This is due to a growing population and the still prevailing role of agriculture in the national economy. At a global scale, at least 10% of the world’s population is considered to consume foods produced by irrigation with wastewater (Smit & Nasr 1992, in WHO 2006).

3.5.4 Effects of mitigation measures

In the following, mitigation measures in place will be listed (see Table 19). Additionally, some possible measures are cited, which have been identified already, but which are not yet implemented.

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Targeted impact</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Salinity</td>
<td>Investment costs</td>
<td>Health issues</td>
<td>Negative perception</td>
</tr>
<tr>
<td>Distributing TSE free of charge</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Leakage control and investigations in the sewage network</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regulation against discharge of dangerous substances</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Using TSE only outside groundwater protection zones</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 20 Targeted impacts of mitigation measures in place

Mitigation measures in place

_Distributing TSE free of charge._ In order to give an incentive to farmers to use TSE instead of groundwater, TSE has been distributed free of charge. This has also been an answer to the fact that wastewater reuse has a negative reputation in the population. The barrier to use it was intended to be kept low.

_Leakage control and investigations in the sewage network._ Pipes in the sewage network are checked for leakages and leaking pipes are being replaced. This is done for various reasons, one of them being avoiding seawater intrusion into the net. A monthly monitoring of wastewater salinity of pumping stations has been setup. Investigations are taking place in order to identify sea water infiltration points and wastewater discharges with chloride content above the permitted level. In order to focus initially on major salinity contributing areas, pumping stations with high salinity and their respective flows have been identified (WSC 2007).

_Regulation against discharge of dangerous substances._ The Legal Notice 139/2002 is partly intended to protect public sewers by trying to avoid discharge of dangerous industrial pollutants in the public network. Its enforcement should ensure the suitability of second-class water for use in agriculture and industry (Sammut & Micallef 2004). For this purpose, Sewage Discharge Permits are being issued.

_Using TSE only outside groundwater protection zones._ The island of Malta consists mainly of fractured limestone, which is allowing surface water to infiltrate fast through the relatively thin soil cover and which is limiting the elimination of microbiological pollutants (Mangion & Sapiano 2005). Currently, the use of TSE is therefore only

Possible mitigation measures
According to the problems cited, a large list of possible mitigation measures exists. When reflecting on a future water policy, MRA (2004a) identified the following:

- Education and enforcement to prevent dumping of seawater and other harmful substances into the sewers
- Avoiding the mixing of sewers which carry saline water from those with good, non-saline sewage

In addition, some other approaches could be of interest:
- Information campaign against negative perception of TSE by farmers
- Introduce further wastewater treatment steps (e.g. desalination) in order to provide water of better quality. The new treatment facilities provide (only) secondary treatment (Mangion & Sapiano 2006).
- Adapt agricultural management to high salinity in irrigation water
- Finding new financial resources in order to face the problem of high investment costs for distributing TSE to the farmers.

3.5.4.1 Additional issues
A special tool developed in Malta in order to promote sustainable water use in the tourism sector is the Eco Certification for hotels. Different criteria are applied for the certification, aiming to improve the hotels’ environmental performance. This includes the reuse of wastewater. In 2007, two hotel establishments (5 stars) had their own in-house treated wastewater facilities, but a great potential is seen for developing TSE use in this sector (Cardona 2007).

3.5.4.2 Available information
Besides the use of freely available information from the internet, contacts have been built with the Maltese Resources Authority (MRA). Communications took place via email and telephone. MRA supported the provision of further reports. According to the available information, three mitigation measures will be presented in more detail: (1) Providing treated sewage effluent free of charge, (2) Adapting agricultural management to high salinity in irrigation water and (3) Regulating sewage discharge.

3.5.5 Mitigation measure: Providing Treated Sewage Effluent free of charge
As quality problems with the use of TSE for irrigation purposes have been experienced in the past and as a general negative perception of wastewater reuse persists, distributing TSE free of charge to agricultural users was intended to keep the barrier of using it as low as possible. Furthermore it takes into account that farmers are used to
free access to (ground)water re-sources, making it difficult to attract them to other sources where they have to pay for (Man-gion & Sapiano 2005). The greater part of the irrigated area today is located in the Northern and Western regions of Malta. In these areas, shallow groundwater is readily available from the perched aquifer (Vella & Camilleri 2003) and has a significantly better quality (see Table 21 further down).

3.5.5.1 More information on the problem and impacts

As the agricultural sector in Malta is still lacking a comprehensive water metering system, groundwater constitutes still a cheap and reliable water source in many parts of the island. Consequently, payments for TSE are difficult to introduce, unless farmers can be provided with water of higher quality, which is improving the efficiency of their cultivation (Mangion & Sapiano 2005). While an advantage could be seen in the nutrient content of TSE, the salinity problems undo or reverse this effect. Furthermore, as TSE is conveyed to farmers in open channels, part of the water is illegally abstracted and not always all the farmers can be supplied. Moreover, no adequate means of measuring the amount of TSE which is actually used are in place (Mangion before 2002).

3.5.5.2 Description of the mitigation measure

Whereas tariffs exist for TSE provided to the industrial sector (€ 0.09/m³) the distribution to agricultural areas has only been charged from 1984 to 1998 (Micallef 2006). The farmers paid about € 83/ha of irrigated fields (Gauci 1993). Following quality complaints due to high salinity, TSE has been provided free of charge for agricultural purposes. This lasted from 1999 to 2006 (Micallef 2006). In 2007, a charge has been reintroduced, being again around € 80/irrigated ha and year39.

3.5.5.3 Evaluation of the mitigation measure

In the period from 1984 to 1998 nearly € 1.7 Mio were gathered from irrigation charges for TSE (Micallef 2006). Assuming roughly that this would have been constant in the following years, the mitigation measure led to the renouncement of about € 960,000 of charges until 2006 (€ 120,000/year).

Considering the circumstances in Malta – where groundwater is mainly abstracted free of charge and salinity problems prevail – the decision not to charge for TSE used for irrigation seemed reasonable if this water source should be promoted. As the UWWTD demands the treatment of wastewater, the costs of the process (about € 0.40/m³, Micallef 2006) cannot be attributed to the user of TSE. Nevertheless, costs are incurred when distributing the water. Current pumping costs are approximately € 0.06/m³ (MRA 2007a). This will change in the future, when more TSE will be available and investments in wider networks will be needed. The costs of a separate second class water distribution system are estimated to be about € 116 Mio (MRA 2007a).

In order to reduce those costs, existing infrastructure such as unutilised sections of the municipal distribution system and reservoirs should be involved where possible. As for potential financing sources, no decision has been taken so far (Mangion, pers.comm.), but different options ranging from payments of other groundwater abstractors – which are benefitting from the measure – to setting up separate distribution co-operatives emerged in the discussion (MRA 2007a, Sapiano 2006).


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3.5.5.4 Conclusions

As cited in the WHO guidelines on safe use of wastewater (WHO 2006) a “farmer will pay for wastewater only if its cost is less than that of the cheapest alternative water source and the value of the nutrients it contains”. As long as groundwater abstraction by farmers is not metered and charged and as long as quality problems of the TSE are not solved, it is difficult to promote the use of TSE even if it is provided free of charge. Demanding the farmers to pay makes it even more difficult. Having been a good approach in the past, this practice could not last for long. Not only are high investment costs needed to connect the new wastewater treatment plants to potential users, but also the introduction of further treatment steps – above the statutory level might be considered in order to make the wastewater more suitable for irrigation. The additional treatment costs – estimated to be € 0.28/m³ for RO treatment (MRA 2007a) – would have to be covered by the users of TSE. Current plans of MRA to introduce groundwater abstraction charges are advantageous for promoting the use of TSE, but still, the willingness to pay of farmers will depend on the quality of the different water sources available, and further efforts have to be made in this direction.

3.5.6 Mitigation measure: Adapting agricultural management to high salinity in irrigation water

As mentioned before, the main factor hindering the wider use of TSE in Malta is its high salinity content. It affects plant growth and soil quality. There are two potential ways to reply to this problem, either by trying to reduce the salt content in the sewage or by reducing the impact on the fields. The second approach is examined further in the following.

3.5.6.1 More information on the problems and impacts

The main impacts caused by high salinity in irrigation water can be divided into two groups: Impact on soil and damage to crops. They will be shortly addressed in the following. However, it should not be forgotten that high salinity in the irrigation water can also affect groundwater bodies, when winter rains wash the salts out into the aquifers (Kamizoulis et al. after 2002).

Impact on soil

The use of saline water leads to the accumulation of soluble salts of sodium, magnesium and calcium in the soils (AquaTerra 2006). Salinity can be measured using the electrical conductivity (EC). Chemical testing in Maltese soils in TSE irrigated areas has shown that – at the end of the irrigation period – the EC increases by 278% compared to its original value (DoA after 2002). As an approximation – depending on the type of soil and the drainage conditions, problems with salinisation can occur when the conductivity is higher than 3 dS/m. The EC level stated for TSE irrigated areas in Malta lies between 4.99 and 9.56 dS/m (MEPA 2006), with an average of 6.6 dS/m (Sapiano 2006), and is therefore clearly above the threshold. However, due to the good soil permeability (calcareous soils), the salts are effectively washed out during the rainy season (Vella & Camilleri 2003, Mangion before 2002, Kamizoulis et al. after 2002). Another value to measure the quality of the irrigation water is the sodium adsorption ratio (SAR). Problems can be expected if the SAR is between 3 and 9 (Morris & Devitt 2002). TSE in Malta has an SAR of even 50.5 (!) (see Table 21).

Damage to crops

The biggest impact of salinisation on the agricultural sector is the loss of yield. As crops vary in their sensitivity to salinity the cost of increased salinisation to the producer will largely depend on what they grow (AquaTerra 2006). In the South-East region, a large
percentage of farmers reported poor germination rates and crop failure due to excessive levels of salt in the crop root zone (Vella & Camilleri 2003, Mangion before 2002).

3.5.6.2 More information on the problems and impacts

In general the following possibilities to adapt agricultural management exist: Managing salt leaching through irrigation techniques, introducing salt tolerant crop varieties and applying soil improvement techniques to control salinity. The two first ones will be regarded in the following.

Managing leaching
One approach to control salinity problems is to provoke leaching. This means applying enough water to ensure that the salts are carried below the root zone (Mangion before 2002, WHO 2006). According to the Department of Agriculture (DoA after 2002), this is already done today, and the accumulation of salts is prevented by irrigating in excess of the crop requirements. Another possibility would be to dissolve the TSE before applying it on the field. This would demand a respective infrastructure for mixing the two sources and reduce the positive impact of TSE use on the groundwater balance.

Crop selection
Pescod (1992, in WHO 2006) states that it might be necessary to grow more salt-tolerant crops if the irrigation water has a salinity above 3 dS/m. Different crops vary up to 10-fold in their ability to tolerate salt (WHO 2006). Mangion (pers. comm.) indicates that all kind of crops are irrigated with TSE. Kamizoulis et al. (after 2002) report that the effluent is used to grow among other things potatoes, tomatoes, beans, cabbages and cauliflower. According to this information, no big attention is paid to the salt-tolerance of the planted crops, leaving room for adaptations, meaning replacement of salt-sensitive crops with more tolerant ones.

3.5.6.3 Evaluation of the mitigation measure

Leaching
In order to have an effective leaching effect when applying enough water, good drainage properties are needed if irrigation is to be sustainable over a long period of time (Mangion before 2002). This is given in the Maltese case, as most of the island is constituted by fractured limestone, allowing a fast infiltration of water (Mangion & Sapiano 2005). After the irrigation season, soil salinity levels are lowered through the combined leaching action of rainfall and irrigation in excess of crop requirements (see Figure 16).
Mitigation measures associated with wastewater re-use

Figure 16 Electrical conductivity of soils in the South East irrigation region (Vella & Camilleri 2003)

The use of this mitigation measure might be in conflict with water saving irrigation techniques which have been promoted in the past. Drip irrigation is today the most widespread technique (Vella 2006, Vella & Camilleri 2003). However, from an agro-environmental point of view, it shows advantages and disadvantages. Drip irrigation ensures an effective use of water and avoids water loss. At the same time it leads to localized problems with the concentration of salinity near the roots, if salty water is used for irrigation (Vella 2006). In the past, the advantages have outweighed the disadvantages. This may change in the future, as – with the additional amount of TSE available – irrigation water becomes less scarce, making the water saving by the drip irrigation system less important. Furthermore, the higher salinity of the TSE will emphasize the disadvantage of the technique (Vella 2006). A change in the irrigation technique for the respective fields could then make sense.

From an environmental point of view it has to be taken into account, that although leaching might be beneficial for plant growth, negative impacts on the underlying aquifers can be expected. If TSE is used in order to reduce the pressure on groundwater, it should be of a higher quality then the aquifer, in order to avoid its further degradation. This restricts the use of TSE, as 63% of the total irrigated area overlies the mean sea level aquifer (Mangion & Sapiano 2005).

Crop selection

Table 21 is showing that not only TSE is restricted in its use as irrigation water. Also the water stemming from the Mean Sea Level Aquifer has a relatively high salinity. Adapting crop selection can therefore also make sense due to the degradation of groundwater sources experienced in the past. This trend is supposed to continue.
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<table>
<thead>
<tr>
<th>Type of irrigation water</th>
<th>Mean EC dS/m</th>
<th>Mean SAR</th>
<th>Restriction on use based on EC value</th>
<th>Restriction on use based on SAR value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perched aquifer</td>
<td>1.006</td>
<td>10.1</td>
<td>Slight to moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>Run-off (rain)water</td>
<td>1.733</td>
<td>18.1</td>
<td>Slight to moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>Mean sea level aquifer</td>
<td>3.365</td>
<td>28.7</td>
<td>Severe</td>
<td>Severe</td>
</tr>
<tr>
<td>Treated sewage effluent</td>
<td>6.584</td>
<td>50.5</td>
<td>Severe</td>
<td>Severe</td>
</tr>
</tbody>
</table>

Table 21 Restriction on use of irrigation water (Vella & Camilleri 2003)

The crops produced in Malta are shown in Figure 17. Apart from forage, all crops are in different percentages subject to irrigation (Sapiano 2006).

![Figure 17 Production by crop in Malta (Sapiano 2006)](image)

In Figure 18, the EC tolerance levels of those crops concerning the salinity level of the irrigation water are given. The figures show the threshold values above which 50% yield losses can be expected. As can be seen, all the crops have values below the EC level of the TSE of 6.58 dS/m, meaning that applying TSE for irrigation on these crops will lead to a yield loss of 50% compared to ‘normal’ growing conditions (Fipps after 1995). Although these figures might differ, e.g. following different soil conditions, the importance of the impact seems to be evident.

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40 No data could be found for marrows, cauliflowers and citrus.
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3.5.6.4 Conclusions

Different ways exist to adapt agricultural management when recycled wastewater with high salinity contents is used for irrigation. Promoting leaching and changing the crop pattern are two possible ways. Certainly, these two options will be related to costs, either to change the irrigation technique currently in place or because of switching to less profitable crops. The impact of cultivating more salt tolerant crops on the profitability of the Maltese agriculture is difficult to assess. What seems to be clear according to the figures shown in the paragraphs before is, that the use of TSE with its current quality level is not compatible with the crops grown in Malta today.

3.5.7 Mitigation measure: Regulating and controlling sewage discharges

A main problem with the reuse of waste water for agricultural purposes in Malta is its high salinity content as well as its potential content of harming substances. Discharges in the sewage network are regulated in different regulations. The Legal Notice (LN) 340 of 2001 (Urban Waste Water Treatment Regulations) concerns the collection, treatment and discharge of urban wastewater as well as the treatment and discharge of wastewater from certain industrial sectors. The regulation defines acceptable pollutant levels in order to protect the environment against the adverse effects of the wastewater discharges (MRAE 2007).

Another regulation, LN 139 of 2002 (being amended with LN 378 of 2005 and LN 426 of 2007), governs the controls of the sewage discharges. Its enforcement should ensure the suitability of treated wastewater for use in agriculture and industry (Sammut & Micallef 2004).

3.5.7.1 Description of the mitigation measure

The compliance with the L.N. 139 is surveyed by the Sewage Discharge Permit Unit of the Water Service Corporation (WSC) who monitors the discharges into the sewerage...
network. Furthermore the unit issues permits to individuals, catering establishments, industries and/or companies who discharge into the sewers in order to avoid the presence of chemicals (WSC 2006). In order to control industrial behavior, routine and surprise inspections are carried out in catering establishments prior to the issuing of new permits (Ministry of Health 2006). The inspections are complemented through consultation and/or the analysis of the discharge (WSC 2006). WSC’s Wastewater Operations Unit monitors also the sewage treatment plant effluent that is distributed to the agriculture sector (Ministry of Health 2006). Furthermore, it is responsible for ensuring that all industries/companies have a valid discharge permit (WSC 2006). The results of the investigations done by WSC can be used for legal purposes. According to WSC (2006), “it is only through these measures that abuses from the dumping of undesirable chemicals are minimized”. All entities requiring a sewage discharge permit were made aware of their obligations during 2007\textsuperscript{41}.

Furthermore, snap-shots of crude sewage are being collected and analyzed from various catchment areas in Malta and Gozo. The results allow detecting potentially problematic areas, as they give an indication on the existing load and help to focus future efforts (WSC 2006).

3.5.7.2 Evaluation of the mitigation measure

Sapiano (2006) states that the costs of treatment above statutory requirements can be significantly reduced through regulatory measures like discharge control. Information on the costs of this measure and figures to show its effectiveness were not available. However, the fact that problems with the quality of the TSE prevail, indicates that a further amelioration of the situation is desirable. In the preliminary input for the potential Programme of Measures (PoM) required under the Water Framework Directive (WFD), MRA (2007a) states that LN 139 is not sufficient to allow for a good knowledge, control and cost-recovery for industrial discharges in the public sewage network. They propose to issue operating permits for the connection to public sewage and to regulate it by special contracts between WSC and operators of industrial facilities. Nevertheless, although improvements could be expected from the modification of the regulation, positive effects for the environment (as fewer pollutants are discharged) as well as for the use of TSE could be expected by enforcing the existing laws.

3.5.7.3 Conclusions

Regulating the discharge into sewers through laws can be seen as a useful tool to reduce the pollution load. However, the enforcement of the law is a necessary precondition. The responsible authorities in Malta have undertaken new efforts in recent times, making it likely that improvements will soon be measurable. At the same time, possibilities have been identified how the existing regulations could be made more efficient. It remains to be seen if the modifications will be put into practice.

3.5.8 Remaining issues

Some aspects have not been considered in the previous parts. One is related to the value which farmers give to TSE. According to the Department of Agriculture, farmers would be willing to pay a maximal amount of € 0.58/m\textsuperscript{3} of TSE, if the effluent flow would be constant and of good quality (Delia 2004a). Taking the total expected output of the new wastewater treatment plants (13.9 Mm\textsuperscript{3}) and assuming that also in the future 75% will be used for agricultural purposes, selling TSE to farmers could represent an income of about € 6 Mio per year.

\textsuperscript{41} http://d.scribd.com/docs/cy3xsuc3d8seagwiaty.pdf
When regarding the impact of TSE use on the sustainable agricultural management, also the nutrient content of TSE has to be taken into account. For the Malta North plant for example, Vella & Camilleri (2003) calculated that using TSE for irrigation is equivalent to applying 431 kg of nitrogen per hectare and year. The Code of Good Agricultural Practice (DoA after 2002) indicates that farmers must record the amount of TSE applied to their fields, the source of the effluent and its nutrient content. This information has to be considered for the calculation of fertiliser plans and nutrient balances, in particular for nitrate and phosphorus (DoA after 2002). It is unclear to which extent this is currently done. Nevertheless, if done correctly, the use of TSE can contribute to the reduction of chemical fertilisers and therefore helps to minimize the environmental damage and contamination of soil and groundwater. Furthermore, due to the nutrient content, the use of TSE may even increase productivity (Delia 2004a). Another quality point which has not been considered so far is the content of boron in TSE. It has been reported to be above 3.0 mg/L (Camilleri 2000, in Vella & Camilleri 2003). The boron concentration of the soils in the irrigated area was also found to be up to three times higher when compared to non-irrigated soils (Vella & Camilleri 2003).

3.5.9 Summay and Conclusions

In this case study, the following mitigation measures have been described: Providing TSE free of charge in order to promote its utilisation, adapting the agricultural management to the high salinity content of TSE and regulating sewage discharges in order to ensure the quality level of the wastewater. Whereas the first measure has been a temporary solution in order to pro-mote the use of TSE, the last one is existing since several years but has to be enforced more consequently. Adapting the agricultural management – in particular regarding the type of cultivated crops – seems to be indispensable, if the quality of the effluent is not improved, as the use of TSE might imply yield losses up to more than 50%.

3.5.9.1 Specificities of the case studies

In the case of wastewater reuse in Malta, it is in particular interesting that its the use of this source takes place since more than 20 years, but only in a limited extent. Problems which exist since the beginning have not been solved. Recently, the discussion on the use of the TSE water source started again, as the accession to the European Union has led to the building of the new wastewater treatment plants, making much more TSE available for reuse. Another interesting point is that the use of desalination in the country is one factor that hinders wastewater reuse, as the illegal discharges of brine into the sewage network are one of the main causes of the high salinity in the TSE. However, this negative impact could be solved by enforcing existing regulation. Another particularity of the Maltese case is that the high permeability of the soil helps to handle salinity problems in agricultural lands, but on the other hand causes problems for underlying groundwater bodies and restricts the use of TSE on areas outside groundwater protection zones.

Besides those natural constraints, also economic ones exist. The large distance between treatment plants and users of the effluent poses infrastructural and economic problems in terms of investments needed. Furthermore, farmers are used to abstract groundwater free of charge and of relatively good quality and attempts to charge for TSE are therefore difficult to implement.
3.5.9.2 How were the different problems or concerns addressed

As has been mentioned before, several challenges continue to exist in Malta, concerning the use of TSE for agricultural purposes. Ideas on possible solutions have been found in different literature sources but might have been delayed as it has been clear that changes will take place once the new plants working. It remains to be seen, which ways will be followed in the near future to promote this water source. The measures undertaken so far might reflect the lack of adequate financing sources. Instead of increasing the level of treatment in the treatment plant, the decision has been taken to provide TSE free of charge. Besides this decision which was surely based on economic considerations, also regulatory measures exist, concerning discharges into the sewage system. Besides Except for controlling the amount of pollution in the wastewater, only two general mitigation measures seem to exist: either improving the treatment processes in the wastewater plants or adapting agricultural practices to the quality of TSE. Once the quality of the TSE is improved, other problems become less important or even disappear. This is clearly an option which depends on financial sources available, but which could be further considered in the future\textsuperscript{42}.

3.5.9.3 Lessons and implications for a further use of the technology throughout the EU

Based on the experiences made in Malta, one conclusion is that emphasis has to be laid on the quality of the treated wastewater. This seems to be the main factor which is hindering the widespread use of this water source. Economic investments needed to ensure the distribution of the water is a second important factor. The mitigation measures currently in place were not able to ensure a sustainable use of this water supply option. Therefore, no mitigation measure with proven efficiency can be recommended to other countries based on the activities in Malta so far. Nevertheless, it seems to be clear that some preconditions are necessary in order to promote the reuse of wastewater. This includes clearly that abstraction charges for other water sources have to be in place. As long as groundwater constitutes a cheap and (still) reliable source, TSE will be difficult to promote.

3.5.10 Literature and sources

AquaTerra (2006) “Synthetic report on the economic analysis including a sensitivity analysis for each selected study areas, and the link with the conceptual model”, Deliverable No.: I2.4 of the AquaTerra project, unpublished

Attard, G. (2007) “Natural resources in Malta”, CIHEAM analytic note, Nr. 22, Malta


Cardona, C. (2007) “An Analysis of Water Demand in the Tourist Sector”, Presentation for the INWATERMAN project, held the 08.02.2007, Malta


\textsuperscript{42} MRA (2007a) estimates that a tertiary treatment of TSE which would supply 50% of all farm land (corresponding to about 6 Mio m\textsuperscript{3}) would be related to an additional yearly cost of 1.7 Mio €.
Chapter 3 Mitigation measures associated with wastewater re-use


Mangion, M. (before 2002) “Utilization of treated urban waste waters for irrigation purposes in the South of Malta”, CIHEAM – Options Mediterraneennes, Malta


Chapter 3 Mitigation measures associated with wastewater re-use


Personal communication

Mangion, J., Director for Water Resources, MRA, July 2008
4.1 Mitigation measures associated with rainwater harvesting: case study Malta

4.1.1 Introduction

Malta has a long history of rainwater harvesting (RWH) with the first aqueduct dating back to 1610 (FAO 2006). Today, the installation of RWH systems is obliged through the law, although major problems exist due to poor enforcement. Besides harvesting rainwater on roofs, also surface water runoff, in particular the use of storm water is under discussion.

Considering the already prevailing water scarcity problems, the high energy costs of desalination and the expected impacts of climate change and population growth, rainwater harvesting has an important role of securing freshwater supply in Malta (Cardona 2006).

4.1.1.1 Main adverse impacts of rainwater harvesting

The main impacts related to RWH concern potential health risks resulting from inappropriate management and maintenance practices of the harvesting systems. The quality of domestically collected rainwater is depending on the management of the roof as well as on the cleaning of the storage facilities.

For Malta it has been noted that multipurpose use of roofs regularly causes rainwater quality problems. As one particular problem, keeping Pigeon cages under the housetop is resulting in high content of bacteria in the collected rainwater (Cardona 2006). Another technical problem is related to modern buildings with several apartments. Operation and maintenance of an underground rainwater cistern may require regular service by trained personnel which might not always be feasible (Mangion & Sapiano 2005). Another technical problem in the Maltese context is the lack of space to place the harvesting cistern near the buildings.

The high investment costs for new rainwater cisterns are currently presenting an economic as well as a social obstacle for rainwater use. Furthermore, from a social point of view the use of rainwater is strongly linked to negative perceptions regarding its quality. If the technology is to be promoted, these prejudices have to be addressed.

43 Pigeon racing is a very popular sport in Malta (Cardona 2006)
4.1.1.2 Relevance of the case study

Rainwater harvesting systems have a long history in Malta, but their importance is only recently coming back into public discussions. Although required by the law its implementation and current use is rather low. As the situation of water scarcity is expected to aggravate in the future, solutions will have to be found in order to use rainwater to its maximum. Malta can be seen as an example where current discussions are underway although only slowly going forward.

4.1.1.3 Focus of the study

In so far as the problems related to RWH have been identified but not yet tackled, only existing regulations can be presented as well as some possible solutions. The latter includes for example financial investment aids to house owners. Rainwater in Malta is also used in the agricultural sector, but at the present state of the case study focus will be given to the domestic sector. The use of storm water runoff will be dealt with in the chapter on groundwater recharge.

4.1.1.4 Structure of the chapter

After an introduction in the background of rainwater harvesting in Malta, existing regulations and possible mitigation measures will be presented.

4.1.2 Introduction to the case study

4.1.2.1 Generic information

As Malta has a long history of water scarcity, rainwater has been harvested for agricultural and for domestic purposes since ancient times. With the rise of public, more centralized water supplies, the interest in the technology decreased. In the agricultural sector, the importance of rainwater fell with the availability of electric pumps and affordable electricity rates (WASAMED 2004). Due to several factors – including the decrease in quality and quantity of groundwater – RWH techniques are coming back into public discussions.

The mean annual rainfall in Malta is around 550 mm but varies highly between seasons and different years (FAO 2006, Sapiano 2006) (see Figure). About 70% of it falls within October to March (WASAMED 2004). The high variation of the rainfall pattern in Malta can be seen in Figure 19.
In the agricultural sector, rainwater used for irrigation is generally stored in open reservoirs (Sapiano 2006). The average reservoir is rather small in size and often also used for other purposes, e.g. to store abstracted groundwater. A census done in 2001 registered about 9000 agricultural cisterns. Estimations see the total RWH potential for the agricultural sector at about 2 hm³ (FAO 2006). Furthermore, a number of open reservoirs have been built along roads in the 1970s to catch flowing runoff water. Their total volume comprises approximately 250,000 m³ (Cremona 2008). A survey carried out by the National Statistics Office in the agricultural sector registered a reduction in investments in reservoir construction. This is interpreted in that way, that investment in using groundwater sources seem to be more attractive than rainwater harvesting, mainly due to the seasonal character of the latter (Sapiano 2006, FAO 2006).

A study conducted in 2006 (Cardona 2006) revealed that 35 % of the households used harvested rainwater to different extents. Most of them had underground cisterns and only a small number harvested water in plastic containers. According to the same study, 63 % of the uses in households which are currently covered by high quality drinking water require only a secondary water quality. The use of rainwater in households has therefore a high potential. The total potential capacity for urban areas was estimated to be about 2m³ for 2003 (FAO 2006).

As for the optimal size of the cistern, Sammut (1998, in Mangion & Sapiano 2005) defines the tank to be of a capacity or 25m³ for a roof area of 126m². Cremona (2008) states that this size is deemed sufficient in offsetting more than 40% of domestic water demand. The current water use pattern in Maltese households is shown in Figure 20.
Many urban centres and villages have also underground cisterns in place which can store rainwater for landscaping and secondary purposes (Mangion & Sapiano 2005).

### 4.1.2.2 Effects of the mitigation measures

As identified in Task 1, a successful use of RWH requires regulations, guidance, financial instruments and control. In Malta, only regulations exist so far but are lacking enforcement. In terms of mitigations measures currently applied for rainwater harvesting in Malta, only a description of existing legislations can be given. Nevertheless, the responsible water managers know about the problems, and possible solutions have been identified: careful planning (mainly concerning space for rainwater cisterns), enforcement of environmental regulation and education (Cardona 2006). They will also be shortly described. Only a selection of mitigation measures is analysed in more detail below.

The measures listed in the following consider mainly social issues, as the amount of rainwater used in households is heavily dependent on its perception by the population. This applies for the possible educational program as well as for the potential provision of financial aids for the construction of rainwater cisterns. Also some technical issues will be mentioned.

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>In place (Yes/No)</th>
<th>Targeted impact</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulations concerning rainwater harvesting</td>
<td>Yes</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Financial incentives for investing in RWH</td>
<td>No</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Educational campaign</td>
<td>No</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

44 Concerning individual costs.
Chapter 4 Mitigation measures associated with rainwater harvesting

<table>
<thead>
<tr>
<th>Careful planning</th>
<th>No</th>
<th>x</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>First flush devices</td>
<td>?</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Dual system for rainwater and drinking water</td>
<td>No</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**Table 22: Actual and potential mitigation measures for rainwater harvesting in Malta**

*Regulations concerning rainwater harvesting.* According to existing regulations, every building should be equipped with a rainwater harvesting cistern. In a significant number of buildings neither has no cistern at all or does not use it anymore (Cardona 2006). Enforcement of existing laws is therefore an important precondition for the success of RWH.

*Educational campaign.* An informed public is essential for the successful implementation of RWH. A campaign could target different parts of the society in order to inform about the rainwater harvesting potential in order to influence perception. Furthermore, planning guidelines for roof catchment systems are needed, which provides the house owners with step by step procedures for setting up a RWH system (Cardona 2006).

*Financial incentives for investing in RWH.* The investment in new rainwater harvesting systems is high compared to the available household income in Malta on the one hand and to the subsidised public water prices on the other. Financial incentives are needed if RWH shall be further promoted without having negative social effects.

*Careful planning.* For Malta being a highly populated island, space is rare. The physical impossibility of building rainwater cisterns is one of the factors which is limiting rainwater use and has to be addressed during the planning process.

*Use of first flush systems.* Due to the seasonal variability in rainfall the first rains after a prolonged 4-5 month dry period are linked to high pollution of rainwater. First flush systems could be applied to clean roofs of excessive debris before the heavy rains start in September, using the first rains in August (Cardona 2006).

*Dual system for rainwater and drinking water.* In order to maximize the use of rainwater in households, a dual system needs to be installed. But it has to be ensured that second class water cannot incidentally enter into the drinking water network.

The first three mitigation measures will be described in detail below.

**4.1.2.3 Available information**

Among the different documents from MRA staff one has been of particular importance – a dissertation on the rainwater harvesting potential in Malta written by Claudine Cardona (2006).

**4.1.3 Mitigation measure: Regulations concerning rainwater harvesting**

The Maltese law provides regulations which stipulate the construction of rainwater harvesting cisterns for each building. This can be seen as a measure to react to negative perceptions of rainwater for domestic purposes being a widespread opinion and hindering the voluntary application of rainwater harvesting systems. Furthermore, storage and use
of rainwater can help to alleviate the flood risks, as part of the storm water is diverted from the direct runoff. Of course, building and maintenance of the cisterns has to be done according to technical standards in order to maintain a certain water quality.

4.1.3.1 Description of the mitigation measure

The instructions to build rainwater harvesting cisterns is mentioned in three official Maltese documents:

- Code of Police Laws (ratified through the Development Planning Act, 1992)

The Code of Police Laws requires that all dwellings shall have a rain water harvesting cistern in good condition and with a capacity of 3m³ per 5m³ of floor area of each room of the dwelling. The ratification of this code is mainly ensured through the Development Planning Act from 1992 which determines the requirements needed for a permit to develop land (Cardona 2006). Issuing of these permits is the main responsibility of the Maltese Environment and Planning Authority (MEPA). It has to be noted, that the code does not include a specification as to how such water may be used. In consequence, there is often a lack of necessary infrastructure (Sammut & Micallef 2004).

In 2006, a second law has been adopted (LN 238 of 2006 - Minimum Requirements on the Energy Performance Buildings Regulations) which stipulates that every new building (and existing buildings that undergo major renovation or alteration) shall include a cistern with a capacity to collect all the annual rainfall falling on the roofed areas. Moreover the LN requests an installation for the use of the collected rainwater (Cremona 2007)

Furthermore, the Policy Design Guidance document on buildings issued by MEPA in 1998 (and revised in 2005) sets out conditions of rainwater storage for residential and non-residential developments (Cardona 2006, Cremona 2008). The guidance defines how to calculate the capacity of the water cistern relating it to the roof area of the building (see box below).
4.1.3.2 Evaluation of the mitigation measure

Although foreseen in legal regulations, by far not every building owns a rainwater cistern, among different factors (e.g. lack of space), overlapping responsibilities and the absence of a definition of who has to control the implementation of laws play an important role in current enforcement problems (Cardona 2006). The need exists to clarify responsibilities between different stakeholder, namely MEPA, MRA and architects (which are carrying out the construction works) in order to ensure law enforcement.

It has to be taken into account, that obliging the construction of rainwater harvesting systems can impose a significant financial burden on house owners. The enforcement of the law should therefore be accompanied by financial aids in order to avoid cases of hardship (see section below).

4.1.3.3 Conclusions

According to the existing laws, every building should be equipped with a RWH system. The regulations provide therefore officially the conditions for the maximal use of rainwater within households. Nevertheless, due to overlapping responsibilities in the water management sector and the lack of control, enforcement of the regulations does not take place. This situation makes it clear, that in the Maltese context, no need for further legal instruments exists in this regard, but rather institutional changes in responsibility and educational campaigns are needed to ensure the implementation of the existing regulations.

The Malta Environment and Planning Authority – policy and design guidance 2004

Rainwater runoff should be collected and recycled (for those uses which do not require potable water). This applies both to residential and non-residential development, where the collected runoff may be a useful resource. Collection also reduces the amount which needs to be dealt with by the storm water drainage system and so may have wider benefits. Plans submitted with application should show the proposed location of the water cistern.

All new development shall be provided with a water cistern to store rainwater runoff from the built up area. The volume of the cistern (in cubic metres) shall be calculated by multiplying the total roof area (m²) by:

(a) dwellings – x 0.3;
(b) villas – x 0.45;
(c) industrial and commercial buildings – x 0.45;
(d) hotels – x 0.6.

The design of non-built development which paves or hard surfaces large areas should also take into consideration the provision of water catchment for surface water runoff.

For larger scale development, the authority may require the submission of details on how the water collected is to be used.

Source: FAO 2006
4.1.4 Possible mitigation measure: Financial aids for investments in rainwater harvesting

4.1.4.1 Evaluation of the mitigation measure

Although currently not in place, financial aids and economic incentives could help to enhance the implementation of existing laws regarding the building of cistern and finally the use of rainwater within households.

The building of new cisterns for households involves high investment costs, representing a significant burden for households and hindering the expansion of this water source. Some information about costs is presented in the box below.

<table>
<thead>
<tr>
<th>The cost-effectiveness of RWH at household scale</th>
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</table>
| The cost of constructing a cistern ranges from € 11,650 - € 17,470 depending on different contractor quotas. Using 135 litres as the estimate of rainwater consumption per household (taken as 3 members) per day; and the total maximum cost of a cistern of € 17,470; this would imply that the total cost of rainwater in an average lifetime of 50 years would amount to € 11.28/m$^3$ (using an interest rate of 2%). When low construction costs are assumed and a discount rate of 4% is used, this value decreases to € 5.50/m$^3$.

This value is not economically feasible when compared with the subsidized rate for water of € 0.38/m$^3$. Illegal abstraction further makes cistern construction unattractive with offers of only € 3,500 to dig a borehole to the water table. The additional expense of treating rainwater to potable standards, therefore, does not make economic sense either.

Source: Cardona 2006

Taking the implementation of the EU Water Framework Directive into account – including the principle of cost recovery with the internalization of environmental costs – the water price structure can be expected to shift in favor of rainwater harvesting. Nevertheless, considering the average family income being around Lm 6 000 per year (42.7% of population) the building of cisterns is not financially feasible if no further incentives are given (Cardona 2006). Financial aid could be either direct subsidies on cistern construction or the provision of soft loans from banks. One idea would be to give a tax rebate for the purchase of water cisterns, like it is done for investments in energy efficiency devices (MRA 2007a)\(^{45}\). According to this approach, a 20% rebate could be envisaged for the construction of new cisterns.

Aside from the possibility to construct new cisterns it has to be taken into account that many rainwater harvesting installations already exist. The maintenance and renovation of an existing cistern is linked to a cost of approximately € 930\(^{46}\) (Cardona 2006). Taking an average rainwater consumption per household (taken as three persons) of 135 litre/day (49 m$^3$/year), the cost of rainwater over a lifespan of 50 years would be about € 0.60/m$^3$.

\(^{45}\) In 2007, the Maltese Government offered a grant of 20% of the selling price of energy efficient appliances for households. The scheme was very successful as far close to 8,000 applications were submitted in the first six months. (Source: http://www.odyssee-indicators.org/Publication/PDF/nmc_chapter9.pdf)

\(^{46}\) Cost figures have been converted from Maltese Lira (LM) to Euros using the following conversion rate: 1 LM = 2,329 €.
(cf. Cardona 2006). This is in the range of the government’s subsidized water rate of €0.38/m³ and can therefore be seen as an economically viable option. Here again, grants in the range of 20% - as mentioned just before - could be provided as an incentive.

4.1.4.2 Evaluation of the mitigation measure

The provision of financial aids would support people in having access to an affordable water source which can replace a large part of the water uses in households. This would reduce the need for energy intensive desalination and reduce groundwater abstraction. According to the calculations made above, only the rehabilitation of old cistern seems to be an economically feasible option. Introducing a grant scheme as it has been done in the energy sector - meaning that the renovation works would be subsidised by 20% would lead to a price of €0.48 m³ which is only €0.10 more expensive than the current water price.

Assuming that 18,200 households in Malta dispose of cisterns which are currently not used (MRA 2007a) and a household consumption of rainwater is 49 m³ per year (Cardona 2006), then the rehabilitation of old cisterns could lead to water savings of about 892,000 m³ per year.

Taking again the figures above, the costs of this measure for the government would be around €3,385,200. According to MRA (2007a), the government subsidy per cubic meter of drinking water for household supply amounts to €2.19. The government would therefore - through saving water by fostering rainwater harvesting save about €1,953,500. The resulting additional costs for the government would be in total €1,431,700, or about €1.61/ m³.

Providing grants or soft loans for cistern construction could also be linked to maintaining technical standards, ensuring this way also a certain water quality level.

4.1.4.3 Conclusions

The comparison of the costs and benefits of RWH with other water supply sources shows that RWH is rather expensive at the local scale and that some form of government incentive is needed to at least encourage the maintenance of existing RWH systems (Cardona2006). According to the calculations given, emphasis should be laid on the renovation and maintenance of existing cistern, as this can compete under the current water pricing structure.

4.1.5 Mitigation measure: Educational campaign

Social perception of rainwater for uses in households is one key element which influences the use of rainwater. An information campaign has been identified as one necessary action to take action against these circumstances (Cardona 2006, MRA 2007). Besides general awareness raising, a guide is needed to lead home-owners step-by-step through the construction and maintenance of the RWH systems.

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47 This is based on an interest rate of 2%. Taking an interest rate of 4% would lead to costs of €0.88/m³.
4.1.5.1 Description of the mitigation measure

As on how the awareness raising campaign should be carried out, suggestions exist to include it in the educational curriculum as well as to use media and the websites of MRA and the WSC. The information should describe the importance of the water scarcity situation in Malta and should include advices on how to save water. Attention can then be given to the amount of money which can be saved on water bills once RWH systems are in place (Carmen Delia 2006, in Cardona 2006).

A similar awareness raising campaign is included in the propositions for the draft programme of measures required in the context of the Water Framework Directive. It suggests the provision of information on the efficiency of cisterns, the payback period and the benefits for the Maltese population of saving water. It is intended to be carried out via TV advertisement and news insert and to be done at the same time as a campaign on water savings equipment (MRA 2007).

4.1.5.2 Evaluation of the mitigation measure

The educational campaign scheduled in the propositions for the draft programme of measures (focusing rainwater harvesting and water saving measures) is expected to cost around 75,000 Lm. It can positively influence the perception of people vis-à-vis rainwater use leading to a better utilisation and maintenance of existing cisterns and enhancing the building of new ones. Once the infrastructure is in place (eventually supported by financial aids) people will furthermore save money on their regular water bills.

4.1.5.3 Conclusions

The need for an educational campaign has been identified within the Maltese water managers. It can help to change perceptions in the Maltese society concerning the use of second class water in households and – the distribution of corresponding guidelines is include – can support them in the use of the technology.

4.1.6 Summary and Conclusions

4.1.6.1 Specificities of the case studies

Although having a long tradition in Malta and being officially obliged by the law the use of rainwater is far away from reaching its maximum potential in Malta. So far, measures to change this situation are planned, but not yet implemented. The following years will show, whether actions will effectively be put in place. Considerations concerning cost-effectiveness have shown, that emphasis should first be laid on the maintenance and renovation of already existing RWH systems, in order to compete with the current public water supply system.

4.1.6.2 How were the different problems or concerns addressed

Currently, only regulations are in place to foster the use of rainwater harvesting technologies, but efficient controlling mechanisms are missing. Social issues in terms of negative perception as well as regarding investment costs in RWH will need to be solved in the future. Financial incentives – together with the revision of the current water pricing regime – and the distribution of information have been identified as the most promising approaches.
Chapter 4 Mitigation measures associated with rainwater harvesting

4.1.6.3 Lessons and implications for a further use of the technology throughout the EU

The Maltese case study shows that laws are not sufficient to promote RWH technology; at least not if the institutional framework for enforcing the regulations is missing. According to the experiences made in Malta, people’s perception as well as financial constraints might of the most important issues if the technology is to be successfully distributed to a wider extent.

4.1.7 Literature and sources


4.2 Mitigation measures associated with rainwater harvesting: case study promotion of RWHS for households in Flanders Region, Belgium

4.2.1 Introduction

4.2.1.1 Reminder

Modern RWHS is a proven technology that can substitute for mains water supply for non-potable uses in private houses and services. Major concerns relate to potential public health impacts, questions about its cost effectiveness, and acceptability of RW as an alternative for mains water.

- The main issue are concerns over potential health impacts, both for the users of rain water and for contamination of mains water with RW due to bad connections.
- In order to avoid these potential impacts, modern RWHS are required which require a substantial investment. These costs can be recovered through savings on the bill for mains water, but for individual houses, pay back periods will be long
and the net benefits may be unclear as optimal design depends on a wide number of individual and uncertain factors. Some groups like private investors in real estate, tenants or poorer households are unlikely to invest in RWHS as they are unlikely to be able to reap the benefits themselves or don't have the means to invest.

- Benefits to society in terms of avoided costs for storm water management, floods or overflows, are more difficult to assess and may not be reflected in the prices for water services.
- The impact of a larger share of RWHS on long term costs of water supply and rainwater collection and drainage are not clear.
- Because retrofitting is more expensive, the most cost-effective path for introduction of RWHS is a gradual introduction, following the rhythm of investment in new or renovation of real state.
- Consequently, the environmental benefits of a cost-effective introduction of RWHS will only become significant in the longer term;
- Low acceptability: Lack of confidence by households in rain water quality, also for uses for which rain water quality is suited ( ) or is even higher (washing).

Without additional treatment, rain water is not suitable for drinking and personal hygiene. For areas with easy access to secure mains water supply, it is not recommended to use RW for these purposes.

4.2.1.2 Importance of case study

Flanders, Belgium, is an attractive region for RWHS, for different reasons:

- Annual average precipitation is relatively high and well spread throughout the year (see Figure 18 in task 1 report).
- It is a relatively small region, densely populated and with high economic activity. Despite high precipitation and efficient water use by households, pressure on water resources in high and different indicators indicate that it is at high risk for water stress. It is also a net importer of mains water.
- Rain water is rapidly discharged into the sewage system so it contributes to problems related to flooding, sewage overflows and low efficiency of waste water treatment.
- There is already a high penetration of traditional RWH systems (37 % of households have a RW tank) and RW use (more then 50 % of the population), although much more for traditional uses like gardening and cleaning, than for toilets or laundry.

Promotion of RWHS is a part of a long-term strategy to control demand for mains water and pressure on demand for ground and surface waters. In this context, quantitative policy goals have been developed. In the last decade, Flanders introduced some policy measures, especially related to obligatory installation of a dual system for new dwellings and gradually installed and improved procedures for control and inspection. As three quarts of RW use is in households, and as there is still a large potential for further use, it is justified to focus on this sector. In addition, RWHS is part of the evaluation of Best Available Techniques, which is a cornerstone in technical guidance and regulation for industry and agriculture. Consequently, this case study will focus on these issues.

4.2.2 Case study

4.2.2.1 Introduction:

Some key data on water use and water stress in Flanders
The interest for rainwater harvesting and reuse in Flanders, the lower and northern region of Belgium, has been driven by a number of elements:

- On the one hand, all water supply indicators indicate that Belgium is at risk for water stress, which mainly indicates that it uses a relatively high share of the water resources available leading to problems for water supply or conflicts over the allocation of available water;
- Annual average precipitation is relatively high, with a long term average of 780 mm\(^4\)\(^9\)\(^{[1]}\) (see figure 2 in task 1 report). Precipitation is lower in the coastal area and Flanders compared to the higher Ardennes in South-East Belgium (average 1500 mm);
- Measurements over the last three decades indicate that in drier years precipitation is limited to around 70 % of the long term average, in wetter years around 130 %.
- Water use by households is around 100 litre/day/person (mains water only), which is relatively low compared to other industrialised countries. The total use of all water is around 121 litre/day/person.
- (Almost) all people have access to drinking water supply, with a high quality, and have a minimum amount of 15 m\(^3\) of mains water per person for free.
- Flanders and Belgium are net importers of mains water.
- Water prices: In general, the water bill for mains water is based on metered consumption. For many years, the price for drinking water used to be around 1 €/m\(^3\), but with a high variation related to drinking water company, type of household, consumption, etc. Since 2005, the water bill has three components:
  - one for consumption of drinking water, that reflects the average costs to produce mains water, its transportation and distribution;
  - a charge to pay for water services related to sewage, which depends on local conditions and varies between communities;
  - a charge to pay for collection of sewage and sewage water treatment, for which a single price per m\(^3\) for all inhabitants of Flanders is used.
Consequently, consumer water prices have increased significantly, and in 2008, the price for a “typical” household is around 3 €/m\(^3\) (of which one third for the water, around one third to pay for the collection of waste water (municipal sewage) and one third for waste water treatment). It is not clear to what extent these prices reflect the full costs for sewage and waste water treatment.
- Both regional and local governments have taken a number of initiatives to promote rain water harvesting and rainwater reuse.
- The focus of the case study is on rainwater harvesting and reuse for households.

**Some background data on water demand policies**

The Flemish government has some quantitative policy targets which are relevant in this context:

- The Flanders government has set a goal to limit mains water use by households at 98 litre/day/person (215 Mm\(^3\) in total).
- Increase of rainwater use by 5 million m\(^3\) between 2007-2010

**4.2.2.2 Data on current rainwater use and perception issues: households**

Table 23 shows the main data related to current rainwater use for Flanders. The data shows that the importance of RW in current water supply is rather limited, being on average 5 % of the total water supply. The household sector is the most important sector for current rainwater use (72 % of all rainwater use and 10 % of water use by households). It is estimated that a third of the households have access to a RW tank, and
that the average use of RW per rainwater tank is 27 m³ and that RW use by households is around 25 M m³, which corresponds to 10 % of total RW demand by households.

It has to be noted that there is much more uncertainty in the data for RW compared to other water supply sources, and that for example rainwater use in agriculture is probably underestimated (Lauwers et al, 2008).

Table 23 Main indicators related to rainwater use in Flanders (2003)

<table>
<thead>
<tr>
<th>Rain Water (RW) uses</th>
<th>Total</th>
<th>Households</th>
<th>Industry¹</th>
<th>Tertiary</th>
<th>Agric.</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of HH using RW (1)</td>
<td></td>
<td>50 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of HH with RW tank (2)</td>
<td></td>
<td>37 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RW use (m³/RW tank) (2)</td>
<td></td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RW use (M m³), 2003 (2, 3)</td>
<td>36</td>
<td>26</td>
<td>7.1</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>RW use (m³/inhab)</td>
<td>6</td>
<td>4.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>as % of total water¹ use</td>
<td>5 %</td>
<td>10 %</td>
<td>2 %</td>
<td>3 %</td>
<td>3 %</td>
</tr>
<tr>
<td>as % of total rainwater¹ use</td>
<td>100 %</td>
<td>72 %</td>
<td>20 %</td>
<td>4 %</td>
<td>3 %</td>
</tr>
</tbody>
</table>

RW= Rainwater; data for Flanders, 2003
¹ excluding water for cooling
Source: (1) Vrind, 2006,
      (2) Van Tomme, 2005
      (3) Vito, 2007 based on VMM

Table 24 shows some more information on RW use by households in Flanders. For households, two different types of analysis show that the use of rainwater for outdoor uses (gardening and cleaning) and indoor cleaning is very well established. First, a survey of around 1000 families in 2001. From this group a number of households kept a water use diary. This gives detailed results on the use of Rainwater for different purposes, which also allowed to estimate the total RW use and how it relates to total water use for these families. These results are summarized in Table 24. It shows that RW is an important water supply source, especially for outside water uses. These account for two-thirds of all water uses, whereas toilets and laundry account for 25 %. RW is an important source for outside water use (33 % of total water supply for outside uses), but has only a minor share for use of water for toilets (8%) and washing machine (10 %)(Van Tomme, 2005).
Table 24 Rain water use by households in Flanders (2003)

<table>
<thead>
<tr>
<th>Use</th>
<th>Rain Water use litre/year/family</th>
<th>% of total RW use</th>
<th>RW as % of total water use by household for that use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor potable</td>
<td>693</td>
<td>6.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>drinking, cooking</td>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>personal hygiene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>washbasin</td>
<td>185</td>
<td>1.7%</td>
<td>2.0%</td>
</tr>
<tr>
<td>bath</td>
<td>101</td>
<td>1.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Shower</td>
<td>247</td>
<td>2.3%</td>
<td>5.0%</td>
</tr>
<tr>
<td>washing up by machine</td>
<td>47</td>
<td>0.4%</td>
<td>5.0%</td>
</tr>
<tr>
<td>washing up by hand</td>
<td>113</td>
<td>1.1%</td>
<td>2.0%</td>
</tr>
<tr>
<td>indoor non-potable</td>
<td>2991</td>
<td>28.2%</td>
<td>8.7%</td>
</tr>
<tr>
<td>toilet flush</td>
<td>1658</td>
<td>15.6%</td>
<td>7.8%</td>
</tr>
<tr>
<td>laundry by machine</td>
<td>1025</td>
<td>9.7%</td>
<td>9.8%</td>
</tr>
<tr>
<td>laundry by hand</td>
<td>58</td>
<td>0.5%</td>
<td>5.0%</td>
</tr>
<tr>
<td>indoor plants</td>
<td>40</td>
<td>0.4%</td>
<td>19.2%</td>
</tr>
<tr>
<td>Cleaning</td>
<td>210</td>
<td>2.0%</td>
<td>14.4%</td>
</tr>
<tr>
<td>outdoor non-potable</td>
<td>6926</td>
<td>65.3%</td>
<td>36.6%</td>
</tr>
<tr>
<td>Carwash</td>
<td>386</td>
<td>3.6%</td>
<td>27.6%</td>
</tr>
<tr>
<td>Pond</td>
<td>2460</td>
<td>23.2%</td>
<td>40.2%</td>
</tr>
<tr>
<td>Garden</td>
<td>3660</td>
<td>34.5%</td>
<td>type of use 45.7%</td>
</tr>
<tr>
<td>Aquarium</td>
<td>330</td>
<td>3.1%</td>
<td>16.3%</td>
</tr>
<tr>
<td>swimming pool</td>
<td>90</td>
<td>0.8%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Total</td>
<td>10610</td>
<td>100.0%</td>
<td>13.1%</td>
</tr>
</tbody>
</table>

Source: Vito, based on Van Tommelen, 2005; data based on survey of HH in Flanders.

Furthermore, it has to be noted that 3 % of the people indicate that they use RW for personal hygiene (washbasin, shower) and washing-up; although in general it is not recommended to use RW for these purposes, unless additional treatment is added. As none of the respondents indicated that they use RW for drinking or cooking, this suggests that RW is not upgraded to drinking water standards. This may also indicate that the perception of quality of RW among the public is very variable and could be both underestimated and overestimated.

Overall, for these households, RW accounts for 13 % of total water supply. It has however to be noted that this group was selected to give insights into the use of RW and groundwater, and uses more RW then the average Flemish household. On average, it is estimated that RW accounts for 10 % of total water use by households.

This general picture that RW is important for outdoor uses is confirmed by the 5-yearly survey that looks into how the habits of people evolve. More then 50 % of people surveyed indicate that they use rainwater, especially for irrigation of garden (85 %) and in-door plants (75%), carwash and indoor cleaning (52 %) (Vrind, 2006). It is remarkable that despite all the efforts for promotion of RW in the last decade, the 5-yearly VRIND survey reveals that the number of people that use rainwater has declined from 62 % in 2000 to 52 % in 2005 (Vrind, 2006).

As it is estimated that a third of the families has a rainwater tank (Van Tomme, 2005), more people must use RW from water buts. On the other hand, the limited use of RW for toilets and laundry indicates that only a minor share of people have a modern RWHS and indoor RW distribution system connected to toilets or laundry machines.
4.2.2.3 **Data on current rainwater use in agriculture.**

In recent studies, the share of RHWS is estimated around 25% of total water use for agriculture in Flanders, which is higher compared to previous studies (Messely, 2008) (Table 25). There are large differences between sub sectors. Whereas the share of RW is lower for stock breeding (8%), it is higher for horticulture (24%) and especially for greenhouses where it accounts for 62% of total water use. Horticulture and greenhouses account for one third of total water use in agriculture. The amounts for RWHS were estimated using indicator data. These indicator data are given in the right column of Table 25.

**Table 25. Share of RW in total water use in agriculture in Flanders.**

<table>
<thead>
<tr>
<th>sub sector</th>
<th>Rainwater (1)</th>
<th>as % of RW</th>
<th>Total water use (2)</th>
<th>RWH % (1)/(2)</th>
<th>indicator data</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>greenhouses</td>
<td>7855.2</td>
<td>66%</td>
<td>12653</td>
<td>62%</td>
<td>25561</td>
<td>m³/ha</td>
</tr>
<tr>
<td>horticulture</td>
<td>1756</td>
<td>15%</td>
<td>7421</td>
<td>24%</td>
<td>55</td>
<td>m³/ha</td>
</tr>
<tr>
<td>dairy stock</td>
<td>637</td>
<td>5%</td>
<td>7689</td>
<td>8%</td>
<td>1.8</td>
<td>m³/GVE</td>
</tr>
<tr>
<td>cattle</td>
<td>384</td>
<td>3%</td>
<td>4575</td>
<td>8%</td>
<td>1.1</td>
<td>m³/GVE</td>
</tr>
<tr>
<td>pig stock</td>
<td>162</td>
<td>1%</td>
<td>6957</td>
<td>2%</td>
<td>0.3</td>
<td>m³/GVE</td>
</tr>
<tr>
<td>mixed agric. Farms</td>
<td>1100</td>
<td>9%</td>
<td>8278</td>
<td>13%</td>
<td>5.5</td>
<td>m³/ha</td>
</tr>
<tr>
<td>arable farming</td>
<td>80.4</td>
<td>1%</td>
<td>834</td>
<td>10%</td>
<td>1.0</td>
<td>m³/ha</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>11974.6</td>
<td><strong>100%</strong></td>
<td>48407</td>
<td><strong>25%</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GVE = indicator that accounts for the size of the animal (1 cow = 1 GVE; 1 pig = 0.298 GVE)
Source: Messely (2008)

4.2.2.4 **Mitigation options**

In this section we list potential measures, the problem they address, and provide an overview to what extent and for which sectors these measures are applied in Flanders. In the following sections we give more detail.

Table 26 gives an overview of the different potential mitigation measures related to technical, economic and socio-cultural aspects and to which extent they are suited to address problems listed above and that relate to concerns about health impacts, financial issues and perception. Table 26 also indicates if the measures are used in Flanders, and Table 27 indicates for which sector this type of measure is used.

**Table 26. General overview of mitigation measures and issue they address**

| Mitigation measure                                   | in place in FL. | Targeted impact | |
|------------------------------------------------------|-----------------|-----------------|
|                                                      |                 | Health RW       |
|                                                      |                 | contamination MWS | financial | Perception |
| Technical                                            |                 |                 |           |
| technical guidelines and standards                   | Yes             | +               | - / +     | +x         |
| Dual system RWHS-mains water                         | New             | +++             | +++       | -          | +         |
### Chapter 4 Mitigation measures associated with rainwater harvesting

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>in place in FL</th>
<th>Targeted impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Health RW</td>
</tr>
<tr>
<td>Filters, labelling, back-up installations</td>
<td>New</td>
<td>++</td>
</tr>
<tr>
<td>First flush</td>
<td>NG*</td>
<td></td>
</tr>
<tr>
<td>Advanced treatment of RW</td>
<td>NG</td>
<td></td>
</tr>
<tr>
<td>Upgrade of existing RWH systems</td>
<td>no</td>
<td>+</td>
</tr>
<tr>
<td>Optimal design standards/guidelines</td>
<td>New</td>
<td></td>
</tr>
<tr>
<td>Control installations</td>
<td>New</td>
<td>+++</td>
</tr>
<tr>
<td>control maintenance</td>
<td>no</td>
<td>++</td>
</tr>
<tr>
<td>control quality</td>
<td>no</td>
<td>+</td>
</tr>
</tbody>
</table>

#### Financial

|                                                        |                |            |                  |           |            |
|                                                        |                |            |                  |           |            |
| Obligatory installation                                 | New            |            |                  | +/-       |            |
| Optimal design recommendations                          | x              |            |                  | ++        |            |
| Investment subsidies                                    | except New     |            |                  | ++        |            |
| metering rain water use                                  | no             |            |                  | +         |            |
| metering mains water                                    | Yes            |            |                  | ++        |            |
| pricing of water services                               | Yes            |            |                  | - / ++    |            |

#### Perception

|                                                        |                |            |                  |           |            |
|                                                        |                |            |                  |           |            |
| Information campaigns                                  | yes            | +          |                  | +         | ++          |
| labelling RW taps                                      |                | ++         |                  |           | +          |
| guidance to improve amenity aspects of RW (odour,...)   |                |            |                  |           |            |

health RW: potential health impacts for rain water users
New: for new dwelling following recent regulation.
NG: not generally applied
**Chapter 4 Mitigation measures associated with rainwater harvesting**

Table 27. Overview of mitigation measures in place for different sectors in Flanders, Belgium.

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Targeted sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HH</td>
</tr>
<tr>
<td>technical guidance &amp; regulations</td>
<td>HH</td>
</tr>
<tr>
<td>technical guidelines and standards</td>
<td>X</td>
</tr>
<tr>
<td>Dual system/ RWHS &amp; mains water</td>
<td>obligatory</td>
</tr>
<tr>
<td>Optimal design</td>
<td>obligatory</td>
</tr>
<tr>
<td>Control and inspection installation</td>
<td>obligatory</td>
</tr>
<tr>
<td>Financial help</td>
<td></td>
</tr>
<tr>
<td>Investment subsidies</td>
<td>No</td>
</tr>
<tr>
<td>water pricing</td>
<td>yes</td>
</tr>
<tr>
<td>Information campaigns</td>
<td>yes</td>
</tr>
</tbody>
</table>

HH: households; IND: industry; AGRI: agriculture
New&renov: new houses and major renovations, subject to building permits
existing dw: existing dwellings and minor renovations

### 4.2.3 Measure: obligatory dual water supply systems for new buildings

#### 4.2.3.1 Introduction

This measure does not contain a single technical measure but includes a wider package of measures to promote safe RW uses for households. The cornerstone is the obligation introduced since 1999 for new houses and major renovations to install a dual water supply system.

An obligatory dual system means that:
- the mains water system provides water for potable purposes (in kitchen) and personal hygiene (in bathrooms),
- an RWHS may provide RW for non-potable uses, especially toilets, outside uses (garden, car wash) and cleaning and laundry.
- a minimum RWHS is obligatory,
- the RWHS system is optimized, taking into account the availability of RW (e.g. depending on roof area) and RW demand (family size),
- A back-up system to use mains water for non-potable uses in case of insufficient RW is installed, without a physical connection between the RWHS and the mains water system.

4.2.3.2 Problems and impacts addressed

A dual system and technical guidelines-standards addresses the health impact concerns
- Although penetration of RW tanks and RW use was/is traditionally high, it is hardly used for toilets and washing machines, although these represent a large share in the total water demand for households.
- as RW installations and use is widespread, it is not clear to what extent these installations are safe. A relative high percentage (3%) use RW for personal hygiene, whereas it is not clear to what extent this RW has received additional treatment to make it safe for these purposes.
- It is unclear to what extent uncontrolled introduction of RWH systems may contaminate mains water (bad connections, failure of the one-way valve)

The obligation for new buildings addresses concerns related to low penetration and to cost-effectiveness of implementation and control:
- As the payback periods for households are unclear and/or long, dual systems are made obligatory,
- As it is more cost effective to introduce RWHS when buildings are built or renovated, it is only obligatory for these buildings,
- As these are subject to building permits, it allows to account for it in the permitting process and thus control its implementation in a cost-efficient way;
- To promote optimal designs, guidelines were introduced and the minimum size of RW tanks were set in function of the available roof surface.

Inspection on the site is installed to control implementation:
- An obligation to install from the start a safe back-up system, without a physical connection between the RW supply system and mains water supply system avoids that in a later phase unsafe back-up systems are installed;
- Inspection in the planning phase ensures that the RWHS system is planned;
- Inspection on the site before the mains water supply is put into operation ensures that both an operational RHWS is available and that it is safe.

4.2.3.3 Description of technical elements and procedures

First we describe the major elements that distinguish a dual water system with RWHS with a more traditional RW tank and a hand pump. This description builds among others on the information brochure for architects (see also next point). Figure 21 gives a schematic overview of different steps and technologies involved in RW harvesting, storage and use. The major elements relate to:
Figure 21 Scheme for a RWHS system for households (non-potable use for toilets and laundry)

1. To maximize caption of RW, all roofs should be connected to the RWHS. The dimension of the RWHS (tank size) will depend on the roof area and characteristics (see below). As RW from other paved surfaces may be contaminated, it is not recommended/allowed to connect these to the RWHS.

2. It is recommended that water should be filtered before it enters the RW storage tank. A pre-storage filter is one of the important differences with more traditional RW systems and has important advantages:
   - First, it will improve RW quality as it will prevent that debris and organic materials (e.g. leafs) enters the RW storage tank where it may affect the amenity aspects of the RW (odour, colour).
   - It will reduce the cleaning frequency of the storage tank.

There are different types of filters (see Figure 22), and it is recommended to use a self-cleaning filter, as it prevents better that debris and dirt enter the RW water tank, avoids that bacteria grow in collected dirt and requires less frequent maintenance. As some RW is used to clean the filter, self-cleaning filters reduce RW capitation with 5% to 20 %. Downspout Filters (see figure 22B) are easy to add to existing drain pipes but have a higher loss of RW (20 % ) compared to volume. For self cleaning filters, provisions have to be made to capture the debris from the filter, e.g. via a drainage ditch.
Figure 22: Examples of different types of pre-storage filters

<table>
<thead>
<tr>
<th>A. a simple non self-cleaning filter</th>
<th>B. a self cleaning downspout filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="http://www.starkenvironmental.com/index.html" alt="Filter A" /></td>
<td><img src="http://www.starkenvironmental.com/index.html" alt="Filter B" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. a self cleaning cyclone filter</th>
<th>D. A self-cleaning volume filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="http://www.starkenvironmental.com/index.html" alt="Filter C" /></td>
<td><img src="http://www.starkenvironmental.com/index.html" alt="Filter D" /></td>
</tr>
</tbody>
</table>

Sources, Vaes, 2002 based on VMM and starkenvironmental.

3. The storage reservoir has two important functions:
   - it should be big enough to stock water from rainy days to meet the demand for RW; and,
   - it should prevent that the quality of RW stocked decreasing.

Issues related to RW quality:
- A well designed system needs to ensure that RW is kept cool (e.g. underground or in cellars) and in the dark;
- In Belgium, a tank is typically made of concrete or synthetic materials. The first is cheaper and offers the advantage that the lime helps to neutralize the

50 Some Pictures A, C; D from Starkenvironmental, http://www.starkenvironmental.com/index.html
acidity of rainwater. A synthetic tank is lighter and easier to manipulate, and lime stones can be put inside the tank to reduce acidity.

- The filling of the tanks should be designed in a way to prevent that sediments at the bottom of the tank circulate.
- The sediments on the bottom of the tank should be removed, but if good pre-storage filters are used the need for cleaning will be less frequent (every 5 years).

Issues related to RW quantity:
- The size of the tank should be a function of the size of the collection area and demand, and is an important factor for a cost optimal design. In Flanders, the minimum size is regulated in function of the roof area, requiring around 1 m³ per 20 m² of roof area connected to the RWHS. Second, guidelines are made for architects and professionals to balance tank size with roof area and RW demand. (Vaes et al, 20002) A well designed system would aim to ensure that the RWHS can deliver RW for at least 95%.

- Figure 23 shows the graph to be used to optimise RW tanks size and balance RW supply and demand. As an example, point A on the graph indicates e.g.; for a house with a roof of 100 m³, a storage tank of 4m³ will be big enough to guarantee a RW supply of 120 litres per day for 99% of the time. If the RW demand is however 180 litres/day, then in 10% of the time there will not be enough RW and the back up of the mains water will need to be used. The graph also shows that a tank of 14 m³ would be needed to guarantee 180 litre/day for 99% of the times.

For Flemish conditions, rainwater tanks for single family houses are typically between 3m³ and 10m³.

Figure 23  Examples of different types of pre-storage filters

![Graph showing RW use vs Storage](image)

Source: based on Vaes et al, 2002

4. Overflow: the overflow needs to divert RW to drainage of sewage in case the storage tank is full,
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As the overflow connects the storage with sewage, one way valves and grid have to be installed to prevent bad smell and animals entering the RWHS.

5. Water uptake for the pump and in-house distribution: it is recommended to use a floating intake with filter to pump up the water with the highest quality.

6. Pump:
The choice of an energy efficient pump system is required to limit energy use and costs of the RWHS.

7. In-house distribution system: a dual water supply system requires that the two systems are kept apart, which is reflected in:
   - for technicians: a sustainable and clear marking of the RW and mains water supply system in house
   - for the users: RW taps have to be marked with the icon, as indicated in figure 19.
   - additional safety provisions for taps with RW (e.g. to prevent their use by children)

Figure 24 Examples of marking of water source in a dual system

<table>
<thead>
<tr>
<th>marking of RW taps</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEEN DRINKWATER</td>
</tr>
</tbody>
</table>

Source: Vaes, 2002

8. An important element of a dual water supply system is the back-up provision to provide toilets, laundry machines or taps with mains water in case there is not enough RW. As indicated above, an optimal design does not mean that RW needs to be available at all time, so an efficient back-up system is required.
   - The major concern here is to avoid accidental cross-contamination of mains water with rainwater. To this purpose, there may be no physical link between the RW distribution system and the in-house mains water distribution system. Technical guidance and control also ensure minimum distances between mains water refill tap and mouth of the refill.
   - There are several options to install a back-up provision. The technical guidance document gives different options\textsuperscript{51}:
     - a double water circuit to all the different applications. The user has to switch manually for each application from RW to mains water in case the RW tank is empty.

\textsuperscript{51} Samenwerking Vlaams Water, VZW, technische reglementering voor water bestemd voor menselijke aanwending, mei 2005, 64 p.
- The most simple and cheapest solution is to fill the RW tank manually with RW when it is empty. This system however may be less efficient as one is likely to fill the tank with more mains rain water then needed.
- Switch from the RW tank to a second mains water tank when the RW tank is empty. This may be done manually or automatically. Automatic switches that switch between RW and mains water depending on the level of the RW in the tank are more expensive but will consume less mains water.

Figure 25 Back up system: option B: manual refill of TW tank
Figure 26  Back up system: option C: water from small back-up tank, filled with mains water

Source: Vito, based on drawing from Samenwerking Vlaams Water, VZW,
4.2.3.4 Description of procedures and control

The obligation to install RWHS was introduced in 1999. Over the years, a procedure was developed that ensures that the obligation is put into practise. Figure 27 gives an overview of the procedures following the different steps in the process of planning and building a house. There are two cornerstones in the procedure:

- First, an administrative control in the context of the building permit ensures that the RWHS is integrated and planned from the start. To facilitate the process, guidance documents have been developed. To allow control, a number of minimal requirements are specified, especially related to a minimum size of the tank, in function of roof area, and exemptions (e.g. for houses in a closed row, small roof area’s or building grounds). This reflects that the obligation looks for a balance between maximum use of RW and economic costs. This balance is also reflected in guidelines for apartments, where

- Second, an on-site inspection of the final installation of the dual water supply. The drinking water companies needs the inspection report before it will give access to the mains water supply. This procedure guarantees that the RWHS will actually be build as planned and that the RWHS system will meet all the technical requirements.

- As the major costs are related to the installation phase, the potential savings on the water bill will provide a strong incentive to use the RW as much as possible.

Administration costs:

- As the RWHS is an integrated part of the building, the costs of planning, design and control are part of the overall fee for the architect, and can be estimated to vary around 6 % – 15 % (mainly depending on the size of the project, difficulty of the project and market conditions).
- The costs for the second inspection are around 100 euro.
4.2.3.5 Economic evaluation

The costs for collection and use of RW (new installations)
The more systematic information on the costs of the RWHS and its components are relatively old (2001-2002). Based on this information the total investment costs are estimated to vary between 1900 and 2600 euro, (excl. VAT) which is in line with the estimates for the UK. If we add costs for installation, planning and inspection and control, the total investment costs vary from 2800 euro to 4200 euro. These costs are of the same magnitude with those of the UK and Germany.

The total costs per m³ depend very much on:
- discount rates for capital costs;
- expected life time for components
- m³ of RW used throughout the life time of the system.
- installation costs.
- relevant VAT rate
- costs of planning and control.
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The first type of operation costs relate to electricity costs of the pump. For Flanders, Vaes et al give an indicative figure of 0.6 kWh/m³ (Vaes, et al), which is lower then the range of to 1-3 kWh/m³ quoted by Roebuck. The lower range indicates that electricity adds around 0.07 €/m³ to the costs of RW use, or around 5 % of total costs.

The costs of regular maintenance are especially related to costs of inspection and cleaning of filters. If it is assumed that RW-users do that themselves, no costs are accounted for that item. The same argument goes for the cleaning of the tank. If both tasks have to be done by professionals, these costs may become important part of the total costs of a RWHS. Roebuck adds relatively large costs for cleaning of gutters by professionals. It is less clear however if this cleaning should be attributed to the RWHS system, because some cleaning is also required in the reference case without RWHS. In the estimates below, the assumption is made that owners do the maintenance themselves, and no costs for their time is included.

The number of RW used depends on the supply of RW and demand for RW. The supply depends on roof area and capacity of storage tank, and we estimated costs and RW supply scenario’s for roof sizes from 100 m² to 200 m³ and tanks sizes from 3m³ to 8m³. The demand depends on the applications RW is used for, and family size. Contrary to the first, these elements are not fixed to the building, but to the inhabitants, and are likely to vary over time.

Table 28 shows the investment costs of modern RWHS for a single family house, as a function of size of the tank, which range from 3000 euro to 4400 euro. The costs of a total system components excl. installation and VAT are similar to those quoted for the UK (Roebuck, 2007) and account for 60 % of the total investment costs. The costs of the tank take a big share of the costs of the components (25 tot 50 %), but because of their long lifetime, its share in total annual investment costs is more modest (14 %).

Table 29 shows the range of costs per m³ as a function of size of the tank and roof area (m²). Annual investment costs depend on the discount rate, and vary from 200 to 300 euro/year. The total costs, including VAT; per m³ of RW supplied vary from 1.8 euro/m³ to 4 euro/m³. The lower costs are for the larger systems (large roof area’s and storage tanks that produce more then 100 m³ of RW per year) which shows the importance of the economies of scale. However, as on average around 20-25 m³ of RW per person is required to cover the demand for non-potable water use, only larger families will demand the full amount of RW provided by the larger systems. Overall, it is likely that the total costs of RWHS is around 2.5 - 3 euro m³ of RW used.

It has to be noted that the VAT system penalizes investment in RWHS compared to mains water use. In case the RWHS is part of a new building, the capital costs of 21 % VAT on the installation plays an important role in total costs, and can be up to 0.5 €/m³. This has to be compared to a 6 % VAT per m³ for mains water supply, meaning a 15 % VAT penalty for the RWHS.

Finally, it has to be noted that the figure indicate that the costs of a modern RWHS – as part of a dual water supply system – are, expressed per m³ of RW used, of a similar order of magnitude as those of a more traditional RWHS system. If for the latter, investments are made for a storage tank and pump limited to outside water use, especially for garden and cleaning, the investment costs would only be reduced by 50 % compared to a modern RWHS. However, in this case, less RW will be used (only 50 % of the modern RWHS, and costs per m³ RW used will be similar).

Contrary to the Malta case study on rainwater, there is no information about the costs of upgrading existing RW tanks for RW use.
Table 28. Overview of investment costs of modern RWHS as a function of tank size.

<table>
<thead>
<tr>
<th></th>
<th>Investment costs as function of tank size</th>
<th>Share in annual capital cost (3 % discount)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3m³</td>
<td>8m³</td>
</tr>
<tr>
<td>pre-storage filter</td>
<td>505</td>
<td>505</td>
</tr>
<tr>
<td>storage tank</td>
<td>505</td>
<td>1179</td>
</tr>
<tr>
<td>pump</td>
<td>505</td>
<td>505</td>
</tr>
<tr>
<td>pipes</td>
<td>337</td>
<td>337</td>
</tr>
<tr>
<td><strong>Total system, excl install and VAT</strong></td>
<td><strong>1853</strong></td>
<td><strong>2527</strong></td>
</tr>
<tr>
<td>installation</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>Planning</td>
<td>208</td>
<td>262</td>
</tr>
<tr>
<td>Inspection</td>
<td>100</td>
<td>101</td>
</tr>
<tr>
<td>VAT</td>
<td>175</td>
<td>218</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3086</strong></td>
<td><strong>3859</strong></td>
</tr>
</tbody>
</table>

Source: Vito, based on Vaes et al, 2002 and Testaankoop, 2001

Table 29. Overview of costs of modern RWHS per m³ rainwater supplied as a function of tank size and roof area

<table>
<thead>
<tr>
<th>total costs as function of tank size</th>
<th>3m³</th>
<th>5 m³</th>
<th>8 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total investment cost, incl. VAT (euro)</td>
<td>3086</td>
<td>3831</td>
<td>4403</td>
</tr>
<tr>
<td>Annual capital cost (euro/year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3% discount rate</td>
<td>201</td>
<td>230</td>
<td>252</td>
</tr>
<tr>
<td>5% discount rate</td>
<td>246</td>
<td>287</td>
<td>318</td>
</tr>
<tr>
<td>Amount of RW produced (m³/year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 m³ roof area</td>
<td>51</td>
<td>62</td>
<td>69</td>
</tr>
<tr>
<td>150 m³ roof area</td>
<td>77</td>
<td>93</td>
<td>104</td>
</tr>
<tr>
<td>200 m³ roof area</td>
<td>102</td>
<td>124</td>
<td>139</td>
</tr>
<tr>
<td>total life cycle costs per m³ RW (euro/m³)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 m³ roof area</td>
<td>3.9</td>
<td>3.7</td>
<td>3.6</td>
</tr>
<tr>
<td>150 m³ roof area</td>
<td>2.6</td>
<td>2.5</td>
<td>2.4</td>
</tr>
<tr>
<td>200 m³ roof area</td>
<td>2.0</td>
<td>1.9</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Source: Vito, based on Vaes et al, 2002 and Testaankoop, 2001

The savings on the rainwater bill for the user

The savings on the water bill depend on the marginal prices for mains water, and the charges for sewage and waste water treatment that are calculated based on the amount of mains water used. The average water price for a household is around 1.5 euro/m³, and the marginal price – charged to the consumer - is 1.71 euro/m³ (Serv, 2007). In addition, the costs for sewage and waste water treatment are recovered on the basis of m³ mains water consumed. Because the RW user will consume less mains water, he will save in addition 0.9 euro/m³ and 0.85 euro/m³ Table 31. In total, the RWHS will save around 3.5 euro/m³.
Table 30. Savings on the water bill for RWHS user in € per m³

<table>
<thead>
<tr>
<th>Price component</th>
<th>Costs (euro/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>marginal costs of mains water (for the user)</td>
<td>1.71</td>
</tr>
<tr>
<td>sewage charge</td>
<td>0.9</td>
</tr>
<tr>
<td>waste water treatment charge</td>
<td>0.85</td>
</tr>
<tr>
<td>total excl. VAT</td>
<td>3.46</td>
</tr>
<tr>
<td>VAT (6 %)</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Total cost per m³</strong></td>
<td><strong>3.67</strong></td>
</tr>
</tbody>
</table>

Source: based on SERV, 2008

Consequently, the net impact on the water bill for the RW user is positive (cost savings) provided it is a more efficient system (= bigger user with larger roof area and bigger tank), and the costs for sewage and sewage treatment are recovered based on the m³ of mains water used.

Table 31. Savings on the water bill for RWHS user

<table>
<thead>
<tr>
<th>Costs – savings</th>
<th>Net total life cycle costs per m³ RW (euro/m³)</th>
<th>3 m³</th>
<th>5 m³</th>
<th>8 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 m³ roof area</td>
<td>0.23</td>
<td>0.03</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>150 m³ roof area</td>
<td>-1.07</td>
<td>-1.17</td>
<td>-1.27</td>
</tr>
<tr>
<td></td>
<td>200 m³ roof area</td>
<td>-1.67</td>
<td>-1.77</td>
<td>-1.87</td>
</tr>
</tbody>
</table>

Source: Vito, based on Vaes et al, 2002 and Testaankoop, 2001

Remarks on the long term impacts of RW use on prices for mains water.

The costs components do not reflect the real marginal costs for society to replace 1 m³ of mains water with 1 m³ of rain water harvested. The marginal costs for 1 m³ of mains water supply rather reflects different considerations related to recovering the costs of water supply companies in a fair and efficient way that gives an incentive to save water. We have no data on the real marginal costs of water saving in the short or long term. In the short run, these cost savings are likely to be small, as the costs for production and distribution of mains water are to a large extent fixed costs. However, if production and/or distribution is constrained by limitations of water resources or bottlenecks in distribution, the marginal costs savings may be bigger then suggested by the marginal prices.

The impact of RW use on costs for storm water management.

The costs for sewage and waste water treatment are likely to be underestimations of the real costs to society to capture 1 m³ of water and to treat it. We do not have good data to estimate the impact on these costs of reusing 1 m³ of rainwater and sending it to the sewage compared to a reference scenario where the RW goes untreated to the sewage, and where it also contributes to the costs of sewage treatment and problems related to overflows.

RW storage in tanks of a RWHS will contribute to storm water management, avoiding damages from flooding and overflow. There is no indicator data for Flanders to estimate the social value of this additional service of RWHS. The benefit however may be
substantial. In Berlin, the storm water fee is € 1.7/m² of sealed surface, and households that harvest and store RW are exempted from this fee which gives a big financial incentive for the promotion of RWHS. The European Daywater project gives estimates of the costs of storm water management for Germany. These costs vary depending on the storm water management option chosen. Total investment and operation costs for storm sewer system are estimated at around € 1 m²/sealed surface/year. The costs of open trenches may be very small, whereas other options such as permeable hard surfaces may cost around € 2 m²/sealed surface/year. These figures indicate that the benefits of RWHS for storm water management may be substantial, especially if other, cheap options are less available.

**Figure 28 Annual and maintenance costs for different storm water management measures, in DM/m² sealed surface/year**

Van Bohemen estimates benefits for water management companies of green roofs (that offer a similar service of storage of RW), in the order of 5 – 15 euro per m² for water management. This suggest that the storage of RW may offer very significant benefits.
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Conclusions
The costs of RWHS per m³ of RW used are substantial and vary from 2-4 euro/m³, even for well designed systems. In addition, as the costs are predominantly capital costs, pay back is uncertain. With current water prices for mains water and charges for sewage and sewage treatment, the marginal savings on the water bill are similar to the costs of RW-use.

4.2.3.6 Social evaluation
Because costs of RWHS are high, and its use may affect cost recovery of water services, the introduction of RWHS raises equity issues. It has been shown that investments in RWHS are relatively large, so it may be a relatively high cost for lower income households. Costs per m³ of water used will be relatively higher for small families and singles. As the investment costs dominate, it will be especially a burden for those households that have to borrow money for that purpose. This will further increase the costs of RWHS. In the short run, as the obligation for a obligatory dual system, relates to new buildings and major renovations, it is unlikely to affect the households with the lowest incomes.

The equity effects of RWHS will depend a lot on how the costs of public services for mains water, sewage and sewage treatment will be spread over different income groups.

+ Impacts on price for mains water: It is unclear how a larger RW use may affect prices of drinking water and of water services in general. As 30 to 60 % of total mains water use can be replaced by RW, a big penetration of RW will reduce the N° of m³ of mains water sold to households. As production and distribution of mains water are to a large extent fixed costs, a reduction of the m³ sold, is likely to result in an increase in prices for mains water. Households that do not have access to RW will be affected harder by this price increase.

+ Costs for sewage and sewage treatment are now recovered based on the m³ of mains water used, based on metering. As a consequence, users of RW will contribute less to the financing of this public service.

+ On the other hand, users of RWH generate profits for society, in terms of avoided damages and costs for water shortages, and in terms of lower costs for storm water management and damages from flooding.

It is recommended that pricing of water services accounts for all effects of RWHS, so that users of RW pay their fair share for use of public services, while at the same time they are rewarded for making private investments to avoid costs for society.

Review of current practise indicate that RW is used for personal hygiene and as drinking water, although studies indicate that RW quality may not be good enough for these uses. The obligatory introduction of dual systems will contribute to the capacity in society to understand how to use rainwater in a safe way.

The obligatory introduction and inspection of the RWHS will reduce the risk of bad installation of RW, as well for contamination of mains water supply. Although it was legally forbidden, it was not uncommon to install a back-up system with a physical connection between the RW system and the mains water distribution system.

4.2.3.7 Environmental impact

Environmental Benefits:
The major contribution of a further use of RWH will be to:

+ Reduce the use of mains water for non potable uses, thus reducing all environmental impacts from mains water production and distribution, including
energy uses and pressures on water resources. In Flanders, this may be important to safeguard groundwater reservoirs and its quality.

+ Reduce the total volume of water that goes into the sewage system, and thus lower the costs of sewage and sewage treatment,
+ Reduce urban storm events.
+ Reduce the amount of washing powder used by as much as 38% (Bronchi et al, 2000), if soft RW replaces relatively hard mains water for laundry use.

A cost-effective introduction of RWHS follows the rhythm of investment in private housing and renovations. As a consequence, the benefits listed above will only become important in the longer term. This makes RWH a good measure for an adaptation strategy and to stepwise adapt the water management systems to cope with the impacts of climate change, as it contributes to the prevention of droughts and flooding. In the long run, it has a large potential as 30 to 60% of water use by households can be replaced (only for non-potable uses). On the other hand, it is not well suited in solving urgent problems. To have large effects in the short run would require retrofitting houses and large buildings, making RWHS much more expensive per m³ RW used.

**Effectiveness of regulation and financial aids**

The obligatory introduction of RWHS in new housing and large buildings is an effective way promote technology uptake. It has to be noted that this does not only require legislation, but also inspection, both before the building phase (to ensure it is planned) and after the building. The additional costs of these control is relatively limited, as discussed above. If we assume that the average life time of a building is around 50 years, then it will take a few decades before the measure has significant impacts on total water demand. However, in one generation, RW could be the main source for non-potable water uses in households.

Three quarters of local communities in Flanders have introduced subsidies for retrofitting existing buildings with RWHS (Mira, 2007). Between 2002 and 2007, 8000 RWHS were installed with the use of a subsidy grant (MIRA, 2007). Compared to the obligatory dual system for new buildings, the impact of the subsidy scheme on the penetration of RWHS is negligible (Table 32).

### Table 32. Impacts of obligatory installation of RWHS for new buildings and subsidies for existing buildings on number of RWHS installed per year.

<table>
<thead>
<tr>
<th>yearly Nº of new RWHS</th>
<th>New houses and renovations</th>
<th>Existing houses subsidies granted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.000 – 40.000</td>
<td>1300</td>
</tr>
</tbody>
</table>

Source: Vito and Mira, 2007

**Potential negative impacts**

The use of rainwater requires additional investments for RW tank and pumps, that require use of raw materials and energy. Studies using life cycle analysis have shown that the total impacts of RW on materials and energy use are higher for rainwater. However, these methods usually do not account for the potential benefits from RW use on water resources, draughts, floods,….

As there are to our knowledge, there are no specific LCA studies for specific conditions in Flanders, we can use some data from literature. Hallman et al, (2003), has compared overall impacts from relatively small RWHS (an 0.6 and 2.2 m³ RWHS system (scenario 2 and 3) with mains supply in Australia. He has added up the different types of emissions and impacts using the Eco-Indicator methodology (Figure 29). It shows that the impacts of the smaller tank are similar to that of using only mains water. Using the bigger tank
Chapter 4 Mitigation measures associated with rainwater harvesting

(2.2 m³ and pumping the RW) increases the impacts for all categories except for eutrophication. The total environmental burden of water use almost doubles. To put this additional impact into perspective, it is noted that it is equivalent to driving 50 km with an average car.

*Figure 29 Overview of life cycle impacts of scenarios using rainwater in Australia, compared with other activities*

Legend:  
scenario 1: only mains water  
sc. 2: mains water + 0.6 m³ RW tank (8 % of mains water consumption)  
sc 2b: mains water + 2.2 m³ RW tank (15 % of mains water consumption)  
sc: production of 1 kg of aluminium ingots  
sc. transport = 100 km with average car  
Methodology used: eco-indicator, adapted to Australia  
source: Hallmann M, Grant T, Alsop N. 2003

There are however situations where RWHS have lower environmental impacts compared to mains water use.  
a. This is the case if RWHS is used to avoid that desalination has to be used to produce mains water (Hallman, et al, 2003)  
b. If RW is used for washing, the benefits of using less washing powder (38 %) because RW is softer outweigh the additional impacts from RW harvesting systems. (Bronchi et al, 1999)

c. If RW is used in collective systems (a university in the case study by Bronchi et al, for toilet flush, the RW scenario has lower overall impacts for the collective systems (Bronchi, 1999), but not for the individual house. For the latter, the LCA-impacts of the RW tank have a big impact on total environmental burden.
Contamination with heavy metals

Rainwater may be contaminated with heavy metals from roofs, roof-gutters and drainpipes. Because rainwater is corrosive, heavy metals on roofs roof gutters and drainpipes will leak to the RW. In addition, heavy metals (copper) may be added through the in-house RW distribution system (PIH, 2007). For Flanders it is estimated that via this pathway 6.4 ton of copper, 1.4 ton of lead and 74 ton of zinc enters the RWHS systems, RW infiltration systems and/or sewages systems. This is an important pathway for these emissions (35%, 21% and 75% of all emissions of these pollutants) (Vito, 2008).

The net impact on dispersion of heavy metals depends on the use of RW in the baseline scenario and in the RWHS scenario. If the RW is used for irrigation in the garden, the heavy metals will enter the ecosystem. If RW is used for toilet flush, they will end up in the UWWTP. If RW would be infiltrated in the baseline, heavy metals would also enter the ecosystem.
4.2.4 Additional mitigation options

4.2.4.1 RW treatment for specific uses to further reduce health risks

Several studies in Flanders have shown that currently people do use RW for personal hygiene and even for drinking water, although it is not recommended to use RW for these purposes because of health risks (PIH, 2008). These risks may increase as RW becomes more widely used.

Roebuck has shown that further treatment of RW with for toilet flush in a school hardly affects total life cycle costs for the RW system (Roebuck, 2006).

4.2.4.2 Cleaning of roofs and first flush devices

Especially in areas with longer dry periods the roofs get contaminated with elements such as excreta from birds, which enter the RWHS when it rains. First flush devices divert the first water of a rain which contains these into the sewage. As in Flanders, rainfall is well spread over the year, there is no need to install these devices.

4.2.4.3 Upgrading of existing RW tanks

The case study for Malta illustrates that use of existing rain water tanks may be more cost-effective, and this option has received less attention in Flanders. As we have showed that around one third of existing homes has a rain water tank, this option may offer a large additional potential, that may also attract lower income households.

4.2.4.4 Ensuring maintenance

As experience with widespread use of modern dual water supply systems, little is known about the long term maintenance of these installations.

4.2.5 Summary and conclusions

Notwithstanding relatively high precipitation, Flanders region is at risk for water stress because it is densely populated and intensively industrialised. It has a widespread tradition of using RW, and one third of the houses has a RW tank, mainly for outside uses. A modern dual water supply and use of RW for toilet flushing and washing was however much less widespread. Rainwater is also important for other sectors, e.g. greenhouse horticulture.

This case study describes and evaluates the introduction of an obligatory dual water supply system for new buildings and renovations in Flanders. A key feature of the system is the integration of the obligation with system of building permits and control of mains water supply system. The additional costs of this control are relatively small, whereas it is a cornerstone in the prevention of misuse of RW for potable uses and for contamination of mains water.

RWHS for private households requires a large investment and the price amounts to € 1.8 to 4 /m³ of RW used. On the other hand, the savings amount to € 1.7 per m³ for avoided
use of mains water, and another 2 €/m³ for avoided costs for sewage and sewage treatment. Little is known about the real impact of scenario’s of more substantial RW use on the long term costs of mains water, sewage, storm water and sewage treatment.

RWHS will make the water supply system gradually more sustainable and climate change proof. The water system is currently at risk of water stress, so precautionary actions are needed to safeguard future water supply and improve storm water management. The obligatory dual water supply system plays a much more important role to that purpose, compared to subsidy schemes for existing homes. The use of RW however also comes at financial and environmental costs and may raise equity concerns about the cost recovery of water services.

Because of high costs of RWHS, and potential big impact on costs recovery for other services, pricing and costs recovery of water services should account for RW use in order to ensure a fair sharing of the costs of these public services, while stimulating the cost-efficient use of RW.

The use of RW has also environmental costs, especially related to energy and material uses for RW tanks and pumping. There are no specific studies for Flanders, but literature indicates that the overall additional impact may be limited, and RW may score better if more energy intensive water sources would be required. The life cycle impacts of using RW for washing are more positive, because the soft RW also saves on washing powder.

Compared to the obligation for new houses, little attention has been given to a more effective and efficient use of existing RW tanks, to long term maintenance issues and to measures needed to safely use RW for personal hygiene and drinking water, because surveys indicate that some people use RW for these purposes.

### 4.2.6 Literature and sources


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Chapter 4 Mitigation measures associated with rainwater harvesting


Marsden Jacob Associates (MJA). 2007b. The economics of rainwater tanks and alternative water supply options, (commissioned by the Nature conservation council of NSW, Marsden Jacob Associates , 2007-

Roebuck, R.M1, Ashley, R.M. (2007b) , Predicting the hydraulic and life-cycle cost performance of rainwater harvesting systems using a computer based modelling tool, Water Practice & Technology, 2007, issue 2


5.1 Mitigation measures associated with ground water recharge: case study
Torreele Project, Belgium

5.1.1 Introduction

5.1.1.1 Reminder

A detailed description on the different technologies, and the associated risks and impacts, was given in the task 1 document on groundwater recharge. The main concerns, in case of the use of reclaimed water, are that adverse health risks could result from the introduction of pathogens or trace amounts of toxic chemicals into the groundwater, that is eventually to be consumed by the public. Every effort should be made to reduce the concentrations of specific organic constituents in the applied water. Extreme caution is warranted because of the difficulty in restoring a groundwater basin once it has been contaminated.

Furthermore, a potential social barrier is the perception of the water quality of reclaimed municipal wastewater. People might feel uncomfortable drinking water that –although rigidly purified- originates from municipal wastewater.

5.1.1.2 Importance of case study

Natural replenishment of underground water occurs very slowly. Excessive exploitation and mining of groundwater at greater than the rate of replenishment causes declining groundwater levels in the long term and leads to eventual exhaustion of the groundwater resource. Management of the aquifers, as a results, is becoming increasingly important.

The Torreele project aims at a replenishment of the freatic groundwater in the Veurne regions in order to compensate partly for the extensive actual dune water catchment. This way, groundwater levels are restored, implying an improvement of the natural value of the dunes. In the specific case of Torreele, reclaimed water from a municipal wastewater treatment installation is used, requiring extensive treatment to make it suitable for infiltration.

The use of reclaimed water, linked to the stated health risks and associated with important investments and operational costs, makes this case study highly relevant. This multi-barrier approach of Torreele is exactly what is recommended as a safe treatment technique.
Chapter 5 Mitigation measures associated with ground water recharge

Topics
This document will mainly zoom in on the technology used in order to make the effluent from the existing municipal waste water treatment suitable for infiltration. This tertiary treatment can be seen as a mitigation measure itself, however leading as well to secondary risks that need attention (creation of concentrate flows, high energy consumption,...).

5.1.1.3 Structure and links

After the introduction of the case study a more technical description follows of the tertiary treatment itself. Investments and operational costs will be given, linked to the flow rate. Besides the tertiary treatment, as such, attention is paid to the possible creation of side streams that need treatment.

5.1.2 Case study

5.1.2.1 Introduction

In July 2002 the Intermunicipal Water Company of the Veurne region (I.W.V.A.) has started producing infiltration water. The source is wastewater effluent, the techniques are a combination of membrane filtration steps. The water is used for groundwater recharge of a dune water catchment. The production centre is called ‘Torreele’. This is the name of the local area. The final filtrate recharges a sandy unconfined aquifer in the dune water catchment ‘St-André’. The residence time of the recharged water in the aquifer is minimum 40 days.

Figure 31 Photo of the Torreele filtration pond that recharges into the unconfined aquifer
5.1.2.2 Importance of Torreele in the context of sustainable drinking water supply in the West coast of Belgium

The Torreele infiltration project plays an important role for the water production for the IWVA water company. This company is responsible for production and distribution of drinking water within 6 communities in the western part of the Flemish coast of Belgium near the French border.

The Torreele infiltration plant has a capacity of 2.5 million m³/year for the production of infiltration water. The aquifer used by the drinking water production unit of Sint-André is by far the most important production centre for drinking water for the West coast of Belgium. Over the last years, around 40% of the total drinking water distributed in the communities supplied by the drinking water company IWVA, is based on re-use of waste water (figure 2). If the Torreele project can work at full capacity, it may increase to 45%.

Figure 33 shows that since the 1980ies, the region had to rely on imports to meet growing demand for drinking water, whereas the local production of drinking water from groundwater led to overexploitation of the aquifer. In addition, the water companies that supply water to the other communities along the Belgian coast have to rely on transfer of water from other parts of Flanders and the Walloon region.
5.1.2.3 Occurrence in EU

At the start-up in July 2002, the combination of an extensive tertiary treatment of municipal waste water and groundwater recharge for further final filtration and remineralisation at the Torreele installation, was European’s first. However, the techniques used (microfiltration, reversed osmosis, recharge,...) are well-known concepts itself. The uniqueness lies within the specific combination of the different treatment units and the infiltration step.

5.1.2.4 Mitigation options

Table 33 summarises the mitigation options in relation to the most relevant risks and impacts.
<table>
<thead>
<tr>
<th>Risk/Impact</th>
<th>Mitigation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contamination of groundwater</td>
<td>multibarriere treatment</td>
<td>complete solution</td>
</tr>
<tr>
<td>Malfunctioning of treatment</td>
<td>intensive process and technical follow-up</td>
<td>reduced risk due to quick response</td>
</tr>
<tr>
<td>High energy consumption</td>
<td>use of alternative energy sources</td>
<td></td>
</tr>
<tr>
<td>Discharge of side streams</td>
<td>specific treatments</td>
<td></td>
</tr>
<tr>
<td>Intolerance towards reclaimed water</td>
<td>intense communication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>campaigns towards society</td>
<td></td>
</tr>
</tbody>
</table>

Table 33. Mitigation options

5.1.2.5 Sources

Data on this case study was gathered from (scientific) publications, internet and available presentations. Part of the information results from an interview with one of the the responsible engineers from IWVA. This section of the report was sent to IWVA for comments after completion.

5.1.3 Mitigation measure: tertiary treatment

5.1.3.1 Introduction

The multiple-barrier treatment of the Torreele project is recommended as the best approach to reduce the environmental and health impact of groundwater recharge using reclaimed water. As it implies an important investment and operational cost, the main driving force lies within the need of restoring the groundwater level and improving the natural value of the dunes.

5.1.3.2 Problem & Impact

As described in detail in the Task 1 Groundwater Recharge document the major environmental and health concern, related to the use of reclaimed water in aquifer management, lies within the risk of contaminating the groundwater with microbial pathogens and toxic trace elements. In case the groundwater is finally used as a source for drinking water production, the most stringent water quality is required. On top, even if potable re-use is not intended, special attention is needed in case of possible inhalation of aerosols and dermal exposure to the extracted groundwater.

Because routine monitoring for pathogens is not feasible, expensive and not real time, it is more important to design multiple-barrier systems to assure continuous production of safe water. This is the idea behind the Torreele project approach. In between the ‘old’ municipal wastewater treatment plant and the infiltration, several tertiary treatment steps are implemented to guarantee optimal removal of the contaminants.
5.1.3.3 Technical description

The flow scheme of the wastewater treatment plant (WWTP) of Wulpen, operated by Aquafin who is responsible for all wastewater treatment in Flanders, is as follows: primary settlement, predenitrification, aeration and finally a clarifier. To reduce the phosphorous content iron is dosed at the inlet of the WWTP. The wastewater is mainly domestic.

Afterwards the effluent from this WWTP flows into the tertiary treatment. Figure 34 illustrates the different steps of the Torreele project. Based on the experience of the pilot tests the I.W.V.A. has chosen the following steps to further treat the effluent: ultrafiltration (UF), cartridge filter, reverse osmosis (RO), ultraviolet irradiation (UV).

Figure 34. Schematic presentation of the Torreele project

The choice for membrane filtration – ultrafiltration and reverse osmosis are both membrane filtration techniques - was based upon the quality parameters set for the infiltration water. As this water is recharged in a dune area, which is of high ecological value, the infiltration water must have low levels of salts and nutrients. Reverse osmosis is the only technique capable of achieving these goals in one step. As reverse osmosis membranes are very susceptible to pollutants, ultrafiltration was chosen for the pretreatment. Ultrafiltration membranes have pore sizes of 0,1 μm and therefore remove suspended solids and bacteria from the WWTP effluent.

The Torreele plant is designed to produce 2.500.000 m³ of infiltration water each year. The total investment cost was 6 million euro. In 2005 and 2006 respectively 2.170.000 and 2.199.000 cubic meter of infiltration water was produced, being 41% of I.W.V.A.’s drinking-water demand that is demanded in the dune water catchment.

Ultrafiltration (UF) is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained, while water and low molecular weight solutes pass through the membrane. This separation process is used in industry and research for purifying and concentrating macromolecular (10³ - 10⁶ Da) solutions, especially protein solutions.
Reverse osmosis (RO) is a separation process that uses pressure to force a solution through a membrane that retains the solute on one side and allows the pure solvent to pass to the other side. More formally, it is the process of forcing a solvent from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. This is the reverse of the normal osmosis process, which is the natural movement of solvent from an area of low solute concentration, through a membrane, to an area of high solute concentration when no external pressure is applied. The membrane here is semipermeable, meaning it allows the passage of solvent but not of solute. The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most separation occurs. In most cases the membrane is designed to allow only water to pass through this dense layer while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–70 bar (600–1000 psi) for seawater, which has around 24 bar (350 psi) natural osmotic pressure which must be overcome. This process is best known for its use in desalination (removing the salt from sea water to get fresh water), but it has also been used to purify fresh water for medical, industrial and domestic applications since the early 1970s.

From the WWTP effluent reservoir the pre-treated water flows to 5 parallel ultrafiltration basins, each containing 3 120 m² of ZeeWeed® membranes. A ZeeWeed®module (ZENON) contains supported hollow fibres with outside-in flow (Figure 35). The permeate (or filtrate) is drawn by suction on the inside of the fibres. The fibres are aerated during 30 to 50% of the time. This ‘air scouring effect’ keeps the membranes clean. The maximum pore size is 0,1 μm. To remove the contaminants out of the UF basins, the membranes are periodically backwashed by a reverse permeate flow. The basins are built in concrete and open to the air. As they are beneath ground level they can be fed gravitationally. The UF compartment of the Torreele plant can treat a maximum of 450 m³/h of effluent. The minimal recovery (ratio ‘flow of filtrate’ to ‘inlet flow’) should be 85 %. The filtrate of all UF skids is piped to a reservoir with a capacity of 160 m³. Before entering this reservoir free chlorine and ammoniumchloride, reacting together forming monochloramines (NH₂Cl), can be dosed to the filtrate. This is done to prevent bio-fouling on the RO membranes.
Figure 35. Hollow fibre module (ZENON)

From the UF filtrate reservoir the water is pumped to the reverse osmosis system. To prevent scaling, both antiscalant and acid, for pH adjustment, are dosed. The water first passes cartridge filters with pore sizes of 15 μm. This is an extra protection for the RO membranes. High pressure pumps then feed the two RO skids, which are identical. Each skid contains 7.872 m² of membrane area and can treat a maximum of 205 m³/h of UF filtrate. The recovery of the RO system is minimum 75 % and is varied according to feed water conductivity. The filtrate produced with RO is stored in a RO filtrate reservoir with a capacity of 70 m³.

Figure 36: RO membrane skid

The infiltration water is composed of RO filtrate corrected for pH by adding sodium hydroxide. UV irradiation (dose of 40 mJ/cm²) is present as extra disinfection step but it is not operational in normal circumstances.
Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than soft X-rays. It is also named because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet. UV radiation can be an effective viricide and bactericide. Disinfection using UV radiation is commonly used in wastewater treatment applications and is finding an increased usage in drinking water treatment.

Table 34 provides a comparison between the actual effluent quality of the WWTP and infiltration standards as a reference. As the concentration of some of the parameters is too high it is clear that additional treatment was needed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean value</th>
<th>Infiltration standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ph</td>
<td>7.7</td>
<td>6.5 – 9.2</td>
</tr>
<tr>
<td>Temperature [°C]</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Sulphate [mg/l]</td>
<td>145</td>
<td>250</td>
</tr>
<tr>
<td>Chloride [mg/l]</td>
<td>320</td>
<td>250</td>
</tr>
<tr>
<td>Nitrates [mg/l]</td>
<td>23</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 34. Effluent of WWTP to infiltration standards (Van Houtte, 2001)

5.1.3.4 Process-technical evaluation

The Torreele plant has been build in order to artificially replenish a freatic groundwater layer as a compensation for the actual dune water catchment and to restore natural value.

Membrane filtration offered in this case the best option as it forms a physical barrier. Interesting as well is the ease for future modular extension of such an installation. Reverse osmosis offered the best solution for an extensive removal of all contaminants out of the reclaimed water.

Membrane filtration is a state-of-the-art technique within wastewater treatment. It is proven technology and it has known a broad introduction in drinking water production and industrial applications. As stated above, the uniqueness of the Torreele project lies within the combination of the different treatment units and the infiltration step.

An intensive process follow-up is required to guarantee a constant good quality of infiltration water. Table 35 provides an overview of the different parameters that are screened in the Torreele plant.
Chapter 5 Mitigation measures associated with ground water recharge

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UF filtrate</th>
<th>RO filtrate</th>
<th>Infiltration water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On-line</td>
<td>Routinely</td>
<td>Routinely</td>
</tr>
<tr>
<td>Turbidity</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Residual chlorine</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redox</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Temperature</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Conductivity</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>TDS</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>TOC</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Total hardness</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total alkalinity</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphates</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microbiological</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 35. Monitoring control parameters at Torreele (Van Houtte, 2007)

The constant follow-up of the process performance provide the operators of the Torreele plant with a very good understanding of the plant. This offered the basis for a further optimisation of the process in order to reduce its environmental impact. Several mitigation measures were taken.

A detailed analysis campaign in 2006 showed that the RO filtrate is of very high quality (organic compounds, nutrient, heavy metals,...) Secondly, as pathogen removal needs to be complete, the membranes are required as well for complete disinfection. Both the effluents from ultrafiltration and those from reverse osmosis were found to be free of total coliforms and fecal coliforms as well as *Streptococcus*.

Estrogen activity was measured as well at the membrane outlet. At laboratory level, it was demonstrated that RO membranes retain 17β-estradiol, the natural hormone with the greatest potential for endocrine disruption.

An important point of attention when using membrane technology is the cleaning of the membranes. First of all intermittent aeration of the UF membranes is used in order to create turbulence around the membrane surface that prevents fouling. For the UF unit, a backwash every 8 to 10 minutes is foreseen using UF filtrate. After 25 to 35 backwash cycles, an extended backwash is required using chlorinated UF filtrate. A maintenance cleaning, using chlorine, is needed every month. A every 6 months, a cleaning with citric acid is required. The RO-skids need to be cleaned every 2 to 3 months. The cleaning in place (CIP) is performed using sodium hydroxide alternated with biocide or sodium hydroxide alternated with citric acid.

The cleaning sequence has been optimised, based on a critical follow-up of its effect. This can be seen as a mitigation measure in order to reduce the plant’s environmental impact.
5.1.3.5 Economical evaluation

The investment cost of the Torreele project was around 6 million euro. For a design flow rate of 2 500 000 m³/year of infiltration water and given a depreciation over a period of 15 years (33 years for civil works), this equals a cost of around 0,15 euro/m³. IWVA did not receive subsidies for this project.

For the operation of the plant, the following cost estimates were provided by IWVA (per 1 m³ of infiltration water in 2005-2006):
- 0,15 euro/m³ for chemicals, analysis and energy;
- 0,10 euro/m³ for maintenance, including membrane replacement every 10 years;
- 0,06 euro/m³ for discharge.

As a result, the total cost, including investment and operation, to produce 1 m³ of infiltration water equals ~0,5 euro. This cost is lower compared to what it takes to purchase water from neighbouring companies.

5.1.3.6 Social evaluation

A potential barrier in using reclaimed water as a source in the production of drinking water is the perception of the quality. It is of great importance to foresee a detailed and clear communication campaign towards local society on the treatment process and the incorporated security measures.

Since the Torreele project was implemented, the results are presented to the public and the information is yearly renewed. Guided walks to the infiltration area, which is normally closed for the public, are organized to give the public an impression.

5.1.3.7 Environmental impact

As stated above, the most important environmental benefit of the Torreele plant is the replenishment of the groundwater aquifer to restore sustainable groundwater management of the dune water catchment. This way, the groundwater quality is preserved, e.g. the risk of saltwater intrusion is non-existent.

Since recharge of the aquifer started, many changes occurred. The salinity of the recaptured water gradually decreased from 800 µS/cm and currently stabilized around 300 µS/cm. There is a gradual decrease of organic content, as well as of iron and manganese. Decrease of iron content resulted in longer filtration times for the sand filters and consequently less backwash water. The hardness lowered from around 35°F to currently 12-15°F. This benefits to the customer and to the environment, as less soap is needed.

However, a waste water treatment installation like the Torreele plant, implies as well several negative environmental impacts:
- an important energy consumption;
- the use of chemicals for cleaning and to prevent fouling;
- the production of concentrates and cleaning side-streams.

These different points of attention have all been evaluated on potential mitigation measures to reduce their environmental impact. This is further discussed.

Another point of attention is the increased temperature, compared to the previous low and constant groundwater temperature (11-12°C). It now varies between 9 and 18°C. At higher temperatures, the drinking water produced is more susceptible to bacterial re-growth and as a prevention IWVA installed a UV-disinfection prior to distribution. In certain periods, preventive chlorination is performed.
5.1.4 Mitigation measure: intensive process control

5.1.4.1 Introduction

The Torreele plant has been running now for six years and the performance has been evaluated carefully. This was done by putting analysis results and electrical and chemical consumption into data sheets. The process has been optimized during this period in order to reduce the operational cost and the environmental impact.

5.1.4.2 Problem and impact

Associated with this type of tertiary treatment are the high energy consumption, partly due to the aeration of the membranes to prevent fouling, and the use of chemicals for anti-fouling and cleaning. The latter implies an important operational cost and an increase of the contamination of the concentrates.

5.1.4.3 Technical description

On the UF system, the use of air has been reduced. Initially, the aeration was 50% of the time. Now, it is reduced to 30%, resulting in a substantial reduction of energy consumption for a comparable amount of production. The energy consumption per m³ of UF filtrate produced has been reduced from 0,185 kWh/m³ in 2003 to 0,150 kWh/m³ in 2006.

On the RO system, the recovery is no longer constant (initially 75%) but is varied according to the conductivity of the UF filtrate. It was called ‘recovery control’ and means that the recovery is higher when the conductivity is lower. Lower conductivity means less risk for scaling. This action resulted in an increased recovery up to 77% in 2005 and 2006, without any additional dosing of chemicals.

The chemical consumption was further reduced as chloramination was no longer continuous. The ratio between dosing and no dosing varies according to the season. More specifically to the temperature of the water. It resulted in a 20% reduction of sodium hypochlorite usage and 35% for ammonia chloride. No negative influence on the bio-fouling prevention was observed until now.

Finally, based on analysis results that indicated that the RO filtrate is free of micro-biological contamination, it was decided that the UV-unit could be put in standby in stead of constant operation. This way, an important reduction in energy consumption is achieved as well.

5.1.5 Mitigation measure: treatment side-streams

5.1.5.1 Introduction

A typical effect of a cross-flow membrane filtration process is the formation of a concentrate or retentate stream. The contaminants are all ‘concentrated’ in a small side stream of the process. This side stream needs specific attention as it could lead to exceedings of the discharge limits.
In case the concentrate could not be discharged, additional treatment will be needed. There are two options here:
- recycle and treatment within the existing plant;
- additional treatment of the retentate.

5.1.5.2 Problem & Impact

In case of the Torreele project the ultrafiltration is a submerged filtration. As can be seen the concentrate is pumped out of the MF tank, due the fact that clear water is continuously extracted from this tank and too high concentration of the contaminants need to be prevented.

The reverse osmosis process on the other hand is a cross-flow technology implying the continuous formation of a retentate in the module itself. For a RO installation the flow rate of the retentate equals 20 to 40% of the incoming flow rate.

Both retentates are, in the Torreele case, discharged together with the remaining effluent from the WWTP towards a canal that discharges a few km’s further on into the sea.

The concepts of submerged (semidead-end) and cross-flow are illustrated in Figure 37.

![Figure 37. Cross-flow vs dead-end/submerged filtration](image)

5.1.5.3 Technical description

In case the concentrations of one or more contaminants in the retentate exceed the discharge limits, action is required.

A first solution could be the recycling of the retentate towards the beginning of the WWTP in order to give it a second pass through the secondary treatment plant. This way certain difficult organic compounds could be partly further degraded. Salts will however concentrate over the installation towards a steady-state situation.

In case this option is excluded, due to the risk of salt concentration towards unacceptable values, an additional treatment on the retentate could offer the solution.

Evaporation is a state-of-the-art technology for the treatment of retentate streams.

Technical description and evaluation of evaporation technology

Evaporation installations are based on a simple principle and are actually state of the art technology. They have a great potential to treat process streams. Evaporation technology has been evolved strongly during the last decades towards more energy friendly methods, as there are multiple effect evaporation and mechanical vapor recompression (MVR).
In a multiple effect evaporator the hot vapours from an evaporator (effect) are re-used to evaporate the liquid in a following effect, operating at a lower pressure (implying a lower boiling temperature). In case of ‘n’ effects, the energy consumption will decrease more or less factor ‘n’. In average 1 kg of steam is used for the evaporation of 1 kg of water in one effect.

The biggest energy saving can be realised using a mechanical vapour recompression. The vapour is lead through a turbine, where the pressure (and temperature as a result) is increased. The compressed vapour is then used fully as an energy source. The vapour condensates on the outside of the evaporation tubes. As a result the condensation heat is fully recovered. The functioning of the MVR can be compared with a heat pump. The produced condensate is often of high value and can be re-used as process water.

5.1.5.4 Economical evaluation

Due to the principle of multiple effects and MVR the operational cost can be reduced to ~2 euro/m³ treated. The investment cost however remains very high.

5.1.5.5 Environmental impact

An important problem of a side stream treatment is the replacement of the contamination from one environmental media towards another, for instance from water towards solid waste. This waste needs further treatment as well (combustion, disposal,...). This offers on the other hand the opportunity to treat it in more controllable circumstances.

5.1.6 Summary and conclusion

The multiple-barrier treatment of the Torreele project is recommended as the best approach to reduce the environmental and health impact of groundwater recharge using reclaimed water. The combination of UF and RO membranes guarantee an excellent quality of infiltration water.

The implementation of the infiltration facility improved the quality of the drinking water produced. Organic load and salinity have decreased significantly. Hardness lowered as well, giving benefit to the customer and to the environment.

Membrane filtration is however associated as well with several negative environmental impacts such as an important energy consumption, the use of chemicals and the production of concentrates.

Energy and chemicals consumption have been optimized throughout the years of operation by means of an intensive process follow-up leading towards a continuous optimisation of the plants performance. The formed concentrates at the Torreele plant can be discharged with the remaining effluent of the waste water treatment plant. However, if needed on the long term, these side stream could be treated using specific techniques.
5.1.7 Literature and sources

Presentations:
- ‘Waterhergebruik Torreele’ – IWVA
- ‘Infiltratiepand Oostzijde’ – IWVA
- Membrane technology – VITO
- Concentrate streams – VITO

Flyer on Torreele – IWVA website.


Van Houtte E. and Verbauwhede J. (2007): Torreele’s water re-use facility enabled sustainable groundwater management in the Flemish dunes. 6th IWA Specialist Conference on Wastewater reclamation and Re-use for Sustainability.

5.2 Mitigation measures associated with ground water recharge: case study Malta

5.2.1 Introduction

At present, artificial groundwater recharge finds only limited application in Malta. Although dams have been constructed throughout the valleys with the twofold aim of providing a source for the agricultural sector and increasing the recharge of aquifers (MRA 2007b), they are primarily used for the former. A Storm Water Master Plan is currently under discussion which – besides mitigating flood risks – will also consider the recharge of the aquifers\(^{52}\). The importance of this issue might therefore grow in the future.

5.2.1.1 Main adverse impacts

Problems related to artificial groundwater recharge could arise because of infiltrating pollutants and salts. This risk is in particular present in Malta as the islands are composed of frac-tured limestone, being characterized by a short infiltration time (Mangion, pers. comm.). As long as only rainwater is intended to recharge the aquifers, this does not represent a problem. Treated sewage effluent (TSE) is so far not used for this purpose, but might be considered in the future (Mangion, pers. comm., Sapiano 2006). If this is the case, the mentioned impacts might get important.

5.2.1.2 Relevance of the case study

Being only recently considered, the case study cannot rely on long experiences with artificial groundwater recharge. Nevertheless it can indicate the current considerations which are carried out in Malta on this topic.

\(^{52}\) The Storm Water Master Plan is not yet accessible as it has not yet been finalized (Cardona, pers. comm.).
5.2.2 Introduction to the case study

5.2.2.1 Generic information

Infiltration of rainwater is the main source of natural replenishment of aquifers in Malta. The runoff of rainwater to the sea is comparatively small, due to the island’s morphology, the good water absorption by the soil and infiltration into the rock (MRA 2007b). However, evapotranspiration constitutes by far the highest share in the natural water balance in Malta (see Figure 38).

Artificial groundwater recharge in Malta can be attributed to water infiltrating from a large number of dams and reservoirs, which collect rainwater runoff. Although most of these storage facilities are rather small in size (234 m$^3$ to 9,068m$^3$, MRA 2005), they are estimated to be able to harvest around 4 Mio m$^3$ of freshwater annually (MRA 2007b). This corresponds to one sixth of the annual potential surface runoff flow in Malta, which is assumed to be around 24 Mio m$^3$ (excluding coastal areas) (FAO 2004, in MRA 2007b).

The recharge potential of those dams is not clear. MRA (2005) specifies that only dams located in the inliers of the Lower Coralline Limestone could present recharges of more than 10m$^3$/day$^{53}$. Furthermore they indicate that “artificial groundwater recharge” in Malta is often taken to include leakages from the public water distribution system. The authors give for this an annual amount in the order of 6.6Mm$^3$. This is one fifth of the total amount of groundwater abstracted per year (32.5 Mm$^3$, Mangion & Sapiano 2005). As the Water Service Corporation (WSC) which is managing this network is constantly investing in reducing leakages, this amount can be expected to diminish. Nevertheless, the unavoidable loss in the distribution system is estimated to be 300m$^3$/hour (MRA 2007b). This implies a certain ‘artificial’ groundwater recharge in the amount of 2.63 Mm$^3$/year.

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$^{53}$ No information on the number of dams lying in these parts could be found.
Chapter 5 Mitigation measures associated with ground water recharge

5.2.2.2 Additional issues

One obstacle limiting groundwater recharge today is the high siltation rate of dams due to lacking maintenance. Cleaning of dams and valley beds would be needed, if groundwater recharge is to be enhanced (Mangion, pers. comm., MRA 2004b). The periodic maintenance done by the government so far is apparently not sufficient (MRA 2007b).

The storage of surface runoff has been included in the list of proposals for the Programme of Measures (required under the Water Framework Directive). Several steps have been identified which would be necessary to enhance water recharge. They are listed in the following, indicating also the estimated costs (MRA 2007a):

- Carrying out a survey to establish the state of the present dams and water channels (Lump sum € 23,300)
- Cleaning and transporting of silt from watercourses (€ 35,000/year)
- Construction of concrete roofs for open reservoirs to prevent evaporation of water reserves (€ 10.5 Mio)

It has to be taken into account that these measures are directed to 4.500 reservoirs which are used for water storage and which are assumed to need upgrading. A campaign for the rehabilitation of water storing infrastructure in the major valley lines on the island has already been initiated by the government (Cardona 2007, MRA 2007b). Additional to the mentioned purposes, the programme aims to reduce problems related to flooding (MRA 2007b). It remains to be seen how far these measures would actually influence groundwater recharge.

5.2.2.3 Available information

Only very few information was available as artificial groundwater recharge is often only mentioned as a secondary effect of the agricultural dams.

5.2.3 Mitigation measures

So far, no problems related to artificial groundwater recharge have been observed. The negative impacts related to leakages from the public water net, e.g. in terms of energy consumption for water production, will not be further considered, as this is no intended recharge.

When considering the use of TSE for recharging purposes, the problems might resemble those which are currently experienced when reusing wastewater for irrigation, being mainly related to its relatively salinity content. The following mitigation measures could be considered:\n
\textit{Using TSE only outside of vulnerable groundwater areas:} This could include for example fringe areas of the Mean Sea Level Aquifer (MSLA) or decommissioned perched aquifers. Potential areas include Rabat-Dingli, Mgarr or Ghajsielem (Mangion & Sapiano 2006).

\textit{Introducing further wastewater treatment steps:} Additional treatment of wastewater would increase the potential use of TSE. In particular removing salts is an important issue.

\textsuperscript{54} See the case study on wastewater re-use in Malta in this document for more information.
**Chapter 5 Mitigation measures associated with ground water recharge**

Avoiding the discharge of salts and chemicals into the sewage network: Enhanced enforcement of existing legislation concerning the discharge into the sewers would improve the quality of the wastewater and reduce the need for further treatment.

### 5.2.4 Summary and conclusions

Artificial groundwater recharge does not play an important role in the Maltese context today. Several dams exist, but they are primarily used for irrigation purposes. In order to enhance recharge within the present infrastructure, a cleaning of dams and valley beds is necessary. At present, no negative impacts of groundwater recharge have been observed. Using TSE for re-charge purposes might be one option in the future. If this is done, possible mitigation measures would then depend on the quality of the TSE provided. They could include applying it only outside vulnerable groundwater zones, introducing further wastewater treatment steps or the further enforcement of existing regulations concerning discharges in the sewer network.

### 5.2.5 Literature


**Personal communications**

Cardona, C., MRA, July 2008

Mangion, J., Director for Water Resources, MRA, July 2008
5.3 Mitigation measures associated with ground water recharge: case study Berlin

5.3.1 Introduction

After the Second World War Germany and Berlin were divided into an Eastern (Soviet controlled sector) and a Western part (controlled by the Western allied forces USA, UK, and France). In 1949, the Western part of Berlin was shut off and from 1961 on isolated from the surrounding Soviet sector by the Berlin Wall. It took until the late 1950ies that West Berlin became independent from water supply transfers from the Eastern part, which had been cause of much trouble (Herbke et al. 2006). Because of this specific history the Western part was forced to rely on its own water resources to cover all water demands. When the wall came down, this policy was continued for the reunited city. It is now stated in the Berlin Water Law, that public water supply shall be covered from sources within the city limits (BWG, 2005).

So Berlin relies for the production of its drinking water exclusively on groundwater abstracted, almost entirely, from within the city boundaries. Of the average precipitation of 570 mm/a (478 Mio m$^3$/a), 152 mm/a (128 Mio m$^3$/a) contribute to natural groundwater recharge (SenGesUmV 2007). This is not enough to satisfy Berlin's drinking water demand of 209 Mio m$^3$/a (in 2006) and at the same time maintain the groundwater level in all parts of the city. Therefore, Berlin water supply management builds on natural recharge only to the minor extent, but instead includes induced bank filtration and artificial recharge via infiltration structures. On average for the whole of Berlin, the quantity of bank filtered water is estimated to make up for about 60%, artificial recharge for 10% and natural groundwater for the remaining 30% of the total groundwater abstraction (Möller & Burgschweiger 2008). The abstracted groundwater is a varying mix of induced bank filtration, artificial infiltration, and natural groundwater. After abstraction and final treatment it is delivered to the end users. The resulting waste water is collected and directed to six waste water treatment plants that discharge the treated effluent into Berlin’s rivers and canals. Therefore, surface waters contain varying amounts of treated waste water. The exact proportion depends on space (proximity to waste water treatment plants) and time (seasonal variation of natural discharge), but can reach more than 20% (Ziegler 2001) for certain times and locations. Because surface water is then again taken for bank filtration and infiltration the Berlin water supply and treatment system is sometimes referred to as a semi-closed water cycle or as a system relying on indirect wastewater reuse.

For this system to work reliable it is essential that surface water as the supply source is of good quality. Risks arise from surface water pollution coming from several sources including waste water, storm water overflow, accidental chemical spills, algae toxins, and others. Pollutants may not all be eliminated or attenuated by the soil filtration process or may break through under certain conditions. Varying hydrological conditions may pose an additional threat in the future in terms of supply source availability.

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55 The sewerage system was never separated due to the technical complexity of such a process. It was, however, secured by fences to prevent escape attempts from east to west (Herbke et al. 2006);
56 Only the water work Stolpe (figure 1) is situated just outside the city limits. It is run and maintained by the the Berlin Water Works and provides water to Berlin and Brandenburg. It accounts for 10% of Berlin’s total water supply.
5.3.1.1 Current situation of water supply and availability of resources

The Berlin Utility for Water Supply and Sewage Treatment and Disposal (BWB) are the biggest service provider for water supply and treatment in Germany. They provide 3.4 Million people in Berlin and about 300,000 people in Berlin’s hinterland with drinking water.

The surface water system in Berlin is shaped by the widened stream courses of the rivers Spree, Dahme, and Havel, parts of which resemble lakes rather than rivers (Figure 39). The surface water discharge is low, as is the hydraulic gradient of the rivers.

In principle, two water sources can be considered for Berlin’s drinking water supply, surface water and groundwater. Direct surface water abstraction was gradually abandoned beginning in the late nineteenth century due to increasingly deteriorating water quality. In 1991 the last water work in Berlin (Friedrichshagen) ceased using surface water for drinking water production and turned to groundwater as supply source.

Today, Berlin relies exclusively on abstracted groundwater. However, native groundwater, i.e. groundwater built by natural recharge, does neither fit quantitatively (on average 130 Mio m³ recharge per year, SenGesUmV 2007) nor qualitatively (many contaminated sites) Berlin’s water demand. Water abstraction wells were therefore installed closely to river banks and lake shores to enhance groundwater supply artificially by induced bank filtration.

About 800 wells deliver ground water to currently 9 water works where it is simply aerated and sand filtered to produce drinking water.

58 Mostly vertical wells that pump between 40 m³ and 400 m³ water per hour from a depth of between 30 m and 170 m. There are also 2 horizontal wells that can pump up to 1.600 m³ per well and hour (www.bwb.de).
The exploitable groundwater resources for Berlin have been estimated to be in the order of 300-380 Mio m$^3$ per year\textsuperscript{59} (SenGesUmV 2008). This includes natural recharge, bank filtration, and artificial recharge via infiltration. In 2006, 209 Mio m$^3$ ground water were abstracted\textsuperscript{60}, of which artificial recharge via infiltration accounted for about 20 Mio m$^3$ (Möller & Burgschweiger 2008). As can already be concluded from this numbers, water is available without restrictions throughout the year. In addition, the BWB calculated the water balance for the summer of 2003 (exceptional dry year) in order to learn more about the limits of the Berlin water supply scheme. The survey found that a secure water supply could be ensured even under dry conditions without compromising environmental objectives such as minimum environmental flow in surface waters (Möller & Burgschweiger 2008).

The operative cost of Berlin’s drinking water production amount to 1.04 € per m$^3$. This includes raw materials and supplies, external services, personnel cost, and other, not detailed operating cost including energy consumption (BWB 2007). It does not include

\textsuperscript{59} The exploitable groundwater resources for each water work are very different according to its catchment area, the technical capacity of the water work and the environmental needs for water. This has been calculated separately;

\textsuperscript{60} www.bwb.de
imputed cost like depreciation for investments (wells, water treatment plants, clear water cistern, pumps, water mains, etc.), taxes and interests, or calculatory risks. Including this, customers pay 2.071 € per m$^3$ in 2008 altogether.

5.3.1.2 Technical description

Generally speaking, surface water infiltrates into the soil under natural conditions whenever the groundwater level lies below the surface water level. This process can be induced or accelerated artificially by (Figure 40)

a) lowering the groundwater table below the surface water level by abstraction from boreholes adjacent to the banks of a river or lake;

b) constructing a surface water structure artificially like a pond, a ditch or a canal.

Bank filtration with its effective natural filter and attenuation processes has the following advantages over direct surface water abstraction: elimination of suspended solids, particles, biodegradable compounds, bacteria, viruses and parasites; part elimination of adsorbable compounds; and the equilibration of temperature changes and concentrations of dissolved constituents in the bank filtrate.

Bank filtration can also have some undesirable effects on water quality including increases in hardness, ammonium and dissolved iron and manganese concentrations and the formation of hydrogen sulphide and other malodorous sulphur compounds as a result of changing redox conditions.

Until just some years ago, the governing biological and hydro-geochemical processes of bank filtration were not entirely understood. For some changes in water quality during the underground passage the system resembled a black box – with the results being right in terms of good water quality. In the last about 15 years, however, many processes were analysed in detail and the underlying mechanism revealed.

5.3.2 Problems, risks and relevant mitigation measures

As the surface water infiltrates into the ground, natural filter, degradation, and dilution processes remove most substances of concern for human health. Due to early industrialisation and World War Two Berlin’s soil is littered with old contaminated sites which are still not all accounted for. This poses a threat to drinking water supply from groundwater, because as mentioned earlier the abstracted water consists not only of bank filtrate and recharged water but to a varying degree of ambient groundwater. Moreover, the awareness of dangerous and persistent substances in the surface water raised the question to which extent and under which circumstances this could impact on drinking water quality. As Berlin relies exclusively on groundwater abstraction (of which 70% stems from bank filtration and artificial recharge via infiltration) with little alternative supply options in place, BWB and the Senate of Berlin aim at managing the water supply system sustainable and understanding all associated risks (Pekdeger & Sommer von Jammerstedt 1998).

The following table lists the main risks that bank filtration and infiltration can pose to drinking water quality. **It does not indicate pending risks for the Berlin case study.** Instead it lists all risks associated in general with bank filtration and infiltration, most of which can be averted by a proper design of the scheme. Accordingly, some of the related risk mitigation measures described in the table constitute common good practice. All risks
and mitigation measures are further detailed in sub-chapters. Also their efficiency and remaining risks in the Berlin case study are illustrated.
## Chapter 5 Mitigation measures associated with ground water recharge

<table>
<thead>
<tr>
<th>Risk</th>
<th>Description</th>
<th>Mitigation measure</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollutant breakthrough</td>
<td>Pollutants contained in surface water may not be removed/reduced sufficiently during soil passage</td>
<td>General design: sit the well in minimum transition time distance to bank/shore</td>
<td>All natural cleaning processes can take full effect</td>
</tr>
<tr>
<td>Pollutant breakthrough</td>
<td>Effluent from WWT plants bears various contaminants</td>
<td>Monitoring efficiency of treatment; According design and sitting of abstraction scheme; Add another treatment step</td>
<td>Detect flaws in time Sufficient dilution and biodegradation before water infiltrates; Reduce content of persistent pollutants</td>
</tr>
<tr>
<td>Pollutant breakthrough</td>
<td>Storm water overflows bear various contaminants</td>
<td>Adapting and improving sewerage system to contain more water Waste water control system (LISA)</td>
<td>Reducing occasions and amounts of storm water overflow Uses free capacities of WWTs</td>
</tr>
<tr>
<td>Pollutant breakthrough</td>
<td>Accidental chemical spills</td>
<td>Monitoring of water quality; Alarm &amp; Action plans Abstractive contaminated ground-water and discharging it again after post-treatment;</td>
<td>In time warning;</td>
</tr>
<tr>
<td>Point pollution</td>
<td>pollution from activity on land surface near abstraction well</td>
<td>Circular protection zones around the abstraction wells Monitoring</td>
<td>Prevent pollution within the protection zone Detect pollution in time</td>
</tr>
<tr>
<td>Diffuse pollution</td>
<td>Known and unknown contaminated soil areas and aquifers</td>
<td>Monitoring of groundwater; Control of flowpaths by altered operation; Hydraulic barrier; Remediation of contaminated sites</td>
<td>Detection</td>
</tr>
<tr>
<td>Quality deterioration</td>
<td>High levels of Manganese and Iron in abstracted water</td>
<td>Post-treatment</td>
<td>Reduce concentration of Manganese and Iron to desirable limits</td>
</tr>
<tr>
<td>Future risk</td>
<td>Low flow conditions in surface waters may limit amount of water for bank filtration and infiltration</td>
<td>Model future scenarios of natural discharge/recharge and drinking water demand</td>
<td>Define quantitative limits of sustainable supply and adapt water management in time</td>
</tr>
</tbody>
</table>

*Table 36: Overview of risks to drinking water production by bank filtration and infiltration, relating mitigation measures, and their effect*
5.3.2.1 Mitigation measure A: Technical measures

Mitigation measure to reduce risks from waste water treatment effluent
Waste water treatment plants in Berlin treat the waste water according to the standards defined in European legislation. In fact they treat it to much higher standards with 95% of all suspended solids and Phosphate are eliminated. Nevertheless, some persistent organic trace substances, which are resistant to the biological treatment step find their way in low concentrations into the receiving surface water (Massmann et al. 2004; Heberer et al. 2006).

- **Monitoring system**: The German waste water ordinance details the required standards for contaminants and nutrients that have to be complied with prior to discharging the effluent into the surface water;

- **Additional treatment step for WWTs**: Berlin considers enhancing waste water treatment with Microfilters. The filter holds back many trace substances like pharmaceuticals and pathogens. One test side is currently run;

Mitigation measures to reduce risk from storm water overflows
In Berlin, waste water and rainwater is usually treated before it is discharged into surface water. In cases of heavy rainfalls, the storage capacity of the sewerage system is transgressed and a mixture of waste water and surface runoff washes untreated into Berlin’s surface waters. Such events can produce considerable peaks in pollutants of all kinds from pathogens in the waste water to heavy metals stemming from urban surfaces.

- **Waste water control system** (LISA): The BWB established an automated computer-monitored routing system for waste water streams. In case of heavy rain falls it allows coordinating all 148 waste water pumps to shift waste water through the connected sewerage system to the treatment plants that still have treatment capacities. By this the overall amount of storm water overflow is reduced by about 20%.

- **Increase the storm water capacity of the sewers**: Berlin took several measures to increase the storage capacity of the sewerage system (e.g. by raising the overflow thresholds). The stored combined sewage and rainwater can be treated in the treatment plants after the storm event.

Mitigation measures to reduce risk of pollutant break through after accidental chemical spill
Accidental chemical spill can arise for example from navigation, accidental industrial spill, or from illegal dumping. In general, pollution peaks in surface waters are dampened during the transition through the sub-soil system (Schmidt 2003 and Figure 11 in the Annex to this Task 2 report). However, there is a risk, depending on the spilled substance, that the drinking water may be impacted. Mitigation measures include:

- Abstracting contaminated groundwater and discharging it into the sewers so that it is treated in the waste water treatment plant. In this way the soil system is “washed”;

- Post-treatment with disinfectants after abstraction.

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61 http://www.bwb.de/content/language1/html/4158.php
62 Not all pollutants can be treated with disinfectants like chlorine. This is, however, the technology that is installed in every water work to fight drinking water infection with pathogens if necessary;
Mitigation measures to reduce risk of pollution from known and unknown contaminated soil areas and aquifers

Due to early industrialisation and World War Two Berlin’s soil is littered with old contaminated sites which are still not all accounted for. Mitigating measures include:

- Monitoring of water quality and quantity: The Senate and the BWB operate a dense groundwater quality and quantity monitoring network (Fehler! Verweisquelle konnte nicht gefunden werden. and Fehler! Verweisquelle konnte nicht gefunden werden. in Annex). This enables them to detect pollution early on and adjust groundwater levels and flow paths to a certain degree over the operation modus;

- Progressive remediation of contaminated sites: The Senate is running a remediation program, but many sites still pose a potential threat to groundwater quality;

- Hydraulic barrier: A hydraulic barrier can seal of the catchment of an abstraction well from the plume of a contaminated site. It can consist of a sheet pile wall or of other engineered solutions. Infiltration ponds placed between the pollution plume and the well catchment can also create a hydraulic barrier where the infiltrating water alters the hydraulic gradient and pushes the plume in another direction. Both methods are used in Berlin (Dlubek 2008);

Mitigation measures to reduce quality deterioration during the subsoil passage

Oxygen becomes significantly depleted in the bed sediments after only a few meters of filtration. Denitrifying and sulfate-reducing bacteria favour these anoxic conditions and their microbial activity further decreases the redox potential of the system. In such a highly reduced environment mineral surface coatings such as ferric and manganese oxyhydroxides usually destabilise (Figure 11 in the Annex to this Task 2 report). Iron and Manganese enter the soil water and show up in the abstracted water in elevated concentrations.

5.3.2.2 Evaluation of the technical mitigation measures

Technical evaluation (mitigation efficiency)

The combination of technical measures applied work together to provide the following levels of protection:

- improve the quality of the source water,
- reduce the risk of break through of remaining contaminants,
- keep the decision makers informed about the status of the groundwater and drinking water quality, and finally
- take action if quality of abstracted drinking water is impaired.

The measures comply with technical and legal standards and can all together be considered to provide a very good protection level. Moreover, the Senate and the Berliner Water Works constantly think about new and additional measures to increase surface water quality and the protection of the groundwater resources.

Economic evaluation

It was not possible to retrieve detailed cost calculations for river bank filtration and artificial recharge via infiltration from the BWB. In parts this is because structures like the near natural infiltration pond in Berlin Spandau were built in the 1980ies and numbers were not readily available. Another reason is a reluctance of the BWB to provide detailed cost figures on distinct production processes. This can be attributed to the current lively debate in Germany on the adequacy of water price differences

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throughout Germany (Holländer et al. 2008). However, the following economical aspects can be evaluated:

- **Affordability**: In a comparative study of the 100 largest cities in Germany\(^63\) cost for Berlin drinking water per m\(^3\) rank in the lower middle field\(^64\). One m\(^3\) drinking water costs 2,071 € which can be considered an affordable price in relation to the average income in Germany.

- **Sustainability**: Drinking water production by bank filtration and artificial recharge via infiltration is considered a method that requires low effort, energy, and maintenance (esp. bank filtration). It is therefore regarded an inexpensive method, especially for Berlin where most substances of concern are effectively filtered out and water needs only little post-treatment (aeration and rapid sand filtering) before it is distributed to the customers. Little energy and maintenance effort also mean a small environmental footprint of this method.

- **Subsidies**: Berlin’s drinking water runs on full cost recovery. Subsidies are not granted. However, the usual water abstraction fee of 0.31 € per m\(^3\) abstracted water (in Berlin) has not to be paid for water coming from artificial recharge via infiltration.

**Social evaluation**
The public perception of the Berlin drinking water is very positive. Since 2005 the BWB ran a different image campaign every year. They place advertisements in the media and the public that emphasis the effort of the BWB to secure high quality drinking water supply and to protect the environment.
In terms of equity all customers have full time access to drinking water of continuous high quality.

**Environmental evaluation**
So far, no information of negative environmental impacts has been reported.

5.3.2.3 Mitigation measure B: Non-technical measures

Non-technical measures include soft tools like adapting the operation mode of the wells, defining legal standards and monitoring the compliance. It also includes protection strategies and action plans.

**Mitigation measures to reduce risk of pollutant break through after accidental chemical spill**
A description of the problem and technical measures are provided in the previous chapter. Non-technical measures adressing this risk include:

- Emergency monitoring network to detect and react to accidental and dangerous pollution of surface water. This is run by the Senate of Berlin;
- Alarm and action plans, which are implemented by the Senate of Berlin in coordination with the BWB;

**Mitigation measures to reduce risk of point pollution from land surface close to abstraction wells**
Drinking water production needs not only to be protected from the water-bound pollution, but also from contamination that enters the well catchment from the landside. Certain activities can potentially contaminate the soil surface with pollutants which than infiltrate into the ground and finally pollute the groundwater.

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\(^{63}\) Which only looked at the final prices per m\(^3\) and did not analyse regional differences in cost factors.

\(^{64}\) [http://www.verivox.de/News/ArticleDetails.asp?aid=22839](http://www.verivox.de/News/ArticleDetails.asp?aid=22839)
Chapter 5 Mitigation measures associated with ground water recharge

- **Protection zones:** For the protection of the well catchment the Berlin Senate designated 16 circular drinking water protection zones around the wells (cf. Figure 39), which are divided into different categories. Together, all zones cover ¼ of the total city area. A comprehensive list of bans and instructions ensure good protection. Regulations get stricter with proximity to the well\(^5\).

- **Monitoring:** Groundwater in the well catchment is monitored with a dense monitoring network to detect pollution in time.

5.3.2.4 Evaluation of the non-technical mitigation measures

**Technical evaluation (mitigation efficiency)**

It must be stressed, that the most crucial factor for a secure and reliable water supply using bank filtration and artificial recharge via infiltration is the optimal design of the whole system. The non-technical measures described supplement the technical measures by providing two additional layers of protection. One is the precautionary approach of the protection zones that aim to avoid any pollution incident from the beginning. The other is the state of preparedness, that enables to react in short time after a pollution event occurred. Because the processes of bank filtration and artificial recharge via infiltration is a rather slow process (minimum transition time has to be 50 days between bank/shore and well) there is enough time to take appropriate counter measures if the pollution is identified in time. Thus, the non-technical measures contribute essentially to the reliability and efficiency of the water supply scheme of Berlin.

**Economic evaluation**

The non-technical measures have to be understood as the complementary part to the technical measures. As such they also impact on the economical aspects of affordability and sustainability described in the previous chapter. There are additional economic aspects that could be addressed for the non-technical measures, like cost for monitoring systems and emergency plans or opportunity cost for the land that is designated as protection zone and can not be economically developed. However, no financial data on these aspects were available for this study.

**Social evaluation**

The non-technical mitigation measures do not have prominent social impacts. Some effects of the non-technical measures can be regarded as positive social impacts, such as contributing to a safe drinking water supply of good quality, or providing large drinking water protection areas that also serve as recreation areas. No negative social impacts of non-technical mitigation measures are reported.

**Environmental evaluation**

The described non-technical mitigation measures of monitoring systems, protection zones, and emergency plans secure a continuing good ground water quality and an early detection and coordinated reaction in case of pollution events. Moreover, the extensive groundwater protection zones provide urban retreats for animal and plant species and can be used for recreation. No negative environmental impacts of non-technical mitigation measures are reported.

5.3.2.5 Other and remaining issues not dealt with

**Climate change adaptation**

Climate change constitutes a risk for the performance of bank filtration and infiltration in Berlin. It can alter the known framing conditions for the water supply system in Berlin and trigger an adaptation process of the management system.

Berlin is rich in surface waters but considered to be a water scarce region. Precipitation is about 570 mm per year and actual evaporation is calculated to be 290 mm per year. (SenGesUmV 2007).

Results from regional climate models indicate that average precipitation per year might drop to below 450 mm within the next 50 years (Stock 2004). At the same time it is possible that water demand will rise due to Berlin’s demographic and economic development (“Boom-scenario”). However, in two other scenarios the water demand will fall (see Annex). Thus, depending on the actual development, water stress in Berlin might possibly increase. Low flow conditions in surface waters in combination with an increased demand could then limit the available amount of water for bank filtration and infiltration if environmental flows have to be taken into account.

**Climate change mitigation**

From the viewpoint of energy consumption, bank filtration in Berlin can be regarded a very low-energy drinking water production technology. Infiltration runs on the hydrological gradient that is induced by groundwater abstraction. After abstraction water is simply aerated and rapid sand filtered. Compared to other drinking water production methods discussed in this report, the energy demand of the outlined processes for bank filtration can be considered rather low.

The picture for artificial recharge via infiltration is slightly different. The two currently actively used sites for infiltration in Berlin, Tegel and Spandau, need different pre-treatment. In Tegel, the surface water quality is so good that water has to be simply filtered in summer to hold back the suspended organic material. It is then pumped directly into the technically designed ponds. In Spandau, the abstracted water from the Havel has to be pre-treated, mainly to reduce nutrient contents, before it can be directed to the near-natural infiltration pond. Maintenance on the other site is higher for the technically designed ponds in Tegel, which have to be cleaned several times a year to maintain high infiltration rates. Still, the energy demand for treatment and maintenance of both sites does not carry much weight since the overall share of artificial recharge via infiltration is rather low in Berlin (10% of total abstraction).

5.3.2.6 Review of case study achievements and the need for future mitigation measures

The Berlin water supply scheme by using bank filtration and artificial infiltration is a very reliable near natural supply option, that needs low energy and maintenance, in the production process. The main risks exist for drinking water quality and come from various sources, including the surface water (as source water), contaminated ambient groundwater, and polluted and contaminated soil (surface or subsurface). The BWB and the Senat of Berlin deploy a highly sophisticated groundwater management scheme that includes:

- 3-D models for groundwater flow,
- a dense groundwater monitoring network,
- abstraction wells placed at distances that ensure minimum transition times
- groundwater protection zones,
- a soil decontamination program, and
- plans and programs in case of groundwater / surface water contamination;
With all these measures in place, a continuous high drinking water quality can be provided. Further efforts are taken to maintain and further improve surface water quality like for example reducing stormwater overflows. Future pressures may come from deteriorating surface water quality (with the same amount of waste water discharges, but reduced river flow under climate change), or in the specific case of Berlin from an increased amount of sulfate in the surface water (from coal mining areas upstream). These risks remain very uncertain today, but are already taken into consideration in strategic planning process.

5.3.3 Summary and conclusion

Berlin is rich in surface waters but considered to be a water scarce region. Natural groundwater recharge is not high enough to make it the sole sustainable water supply source. Moreover, many contaminated sites in the urban area of Berlin make the use of natural groundwater a risky business. Berlin turned to bank filtration over a century ago. The hydrological and hydro-geological conditions are very favourable for this method. All problems of pollution breakthrough in endangering concentrations are under control. Some risks remain but seem to be managed well.

In Berlin, direct technical measures to compensate risks of bank filtration or aquifer recharge via infiltration are scarce due to the sound natural cleaning process of bank filtration and infiltration, respectively.

In order to meet quality standards stringent precautionary measures for the water resource management (groundwater and surface water) are implemented. Further all problems are tackled in a very open manner. Several research projects addressed open questions, analysed processes and suggested solutions. Especially the NASRI project and the successor project aim at providing guidance on an optimal design of a supply scheme based on bank filtration.

However, study the following concerns remain and need to be looked at:

- extra treatment steps to remove certain persistent pollutants that are currently occurring at very low levels and posing no threats to humans according to EU- and national standards and expert evaluations;
- measures to handle a possible future increase in sulphate in surface water;
- strategy to maintain environmental flow and manage increased water stress due to a scenario of reduced precipitation and increased water demand;

The hydrological and hydro-geological conditions are decisive premises for the possibility to use this method for drinking water supply. For a reliable and secure supply scheme to run successfully, a very thorough modelling and planning of the complete surface water & subsoil system is indispensable.

River bank filtration and artificial recharge via infiltration is probably most attractive in regions where water stress derives from high demand due to dense population and industrialisation.

In consequence, the discussed methods of bank filtration and artificial recharge via infiltration can be seen as a very in-expensive, near natural drinking water treatment method.

5.3.4 Acknowledgements

The authors gratefully acknowledge the support of the BWB – Berliner Wasserbetriebe (BWB) and of the KWB – Kompetenzzentrum Waser Berlin (Berlin Centre of Competence for Water).
We would like to specially mention Ms Heidi Dlubek (BWB) and Ms Gesche Grützmacher (KWB), who provided a lot of key information and their expert knowledge on the Berlin model of bank filtration and artificial recharge via infiltration.
In this section we provide an overview of the mitigation options for each technology, on the basis of the case studies, in order to assess whether there are differences and whether these are significant. The costs of individual mitigations options are difficult to assess because it depends on the scale of the water supply option and the particular concerns in a given area. However, where possible we collate the general costs of producing water from the technological options to give an overview of how the costs differ between technologies and case studies.

### 6.1 A review of mitigation measures associated with desalination, on the basis of case studies

Table 37 provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular.

**Table 37 Mitigation options identified in each case study concerned with desalination**

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Desalination in Southern Spain</td>
</tr>
<tr>
<td></td>
<td>(AGUA and AQUASOL projects)</td>
</tr>
<tr>
<td>Reducing adverse impact on land use</td>
<td>X</td>
</tr>
<tr>
<td>Reducing adverse impact of brine discharge</td>
<td>X</td>
</tr>
<tr>
<td>Improved efficiency to reduce energy</td>
<td>X</td>
</tr>
<tr>
<td>Leakage control to rivers and aquifers</td>
<td>X</td>
</tr>
<tr>
<td>Use of sea wells for feed water intake</td>
<td>X</td>
</tr>
</tbody>
</table>

nr = not relevant in that area

A mitigation option to reducing the adverse impact of desalination plants on land use is used in Spain and Cyprus, but not in Malta. This could be related to the fact that in Malta, the options for locating a desalination plant are so limited that this is not a serious consideration. In Spain and Cyprus special planning permission has to be sought to
ensure the location is appropriate, and is not contravening conservation laws for Natura 2000 sites.

There are also mitigation options to reduce the adverse impact of brine discharge in Spain and Cyprus, but not in Malta. In Cyprus a discharge pipe for brine is installed that transfers the brine to a point in the sea where it can easily disperse. In Malta a recent study (World Bank, 2004) indicates that the rapid dispersion at the sea outlet is rapid enough to ensure few environmental impacts. In Spain (Aquasol Project) an experiment is demonstrated to use a solar dryer to produce salt from the brine, which is then sold on the local market.

In all three case study areas there have been considerable efforts to improve (or upgrade) technology which is more efficient and so reduce the energy demand. There are a number of technical options implemented that improve plant efficiency. In some cases the use of renewable energy sources (such as solar energy) has been investigated. The long term economic costs of using renewable energy instead of fossil fuels are difficult to estimate due to the large fluctuations and uncertainty in fossil fuel prices and the extent to which external environmental costs are recovered in the consumer prices. The estimation of the reduction in GHG emissions is more clear-cut. The European CASES project estimates that private costs for electricity from fossil fuels varies from 0.03 to 0.05 €/kWh (for hard coal, lignite and gas)\(^{66}\). The total costs of electricity from fossil fuels, including environmental damage costs are around 0.06€/kWh. The total costs of renewable electricity varies a lot between technologies. Total costs of electricity from wind or hydro are estimated to vary around 0.06 to 0.11 €/kWh. The total costs of electricity from solar systems are significantly higher, and especially for Photo Voltaics (0.36 €/kWh for PV open space). The costs of solar electricity from “parabolic through” are cheaper (0.12 €/kWh). Although the costs of solar are likely to decrease in the coming decades, they will still be up to an order of magnitude higher then conventional technologies\(^{67}\).

The control of leakages to rivers and aquifers is not listed as a mitigation option for the Lanarka case study in Cyprus because the plant is located on an area which is part of a salt lake – therefore this mitigation option is not relevant. Using sea wells for feed water intake is only relevant to Malta because of the specific geology of the area. The limestone substratum means that the sea water is filtered, reducing costs related to pretreatment, and sea wells can be bored close to the desalination plant.

The general costs of desalination powered by electricity from the electricity grid have fallen in the past 10 to 15 years due to improvements in the energy efficiency of the adopted technology, but the price of electricity has also seen large rises and falls in the last years. In Cyprus the unit cost of desalinated water mixed with conventionally supplied mains water is 1.02 €/m³ and households pay 0.77 €/m³. In Malta the cost of producing desalinated water is 1.28 €/m³, but households pay only 0.38 €/m³ for the first 11m³ consumed. In Spain the cost of producing desalinated water is 1 €/m³, with farmers charged between 0.3 to 0.4 €/m³.

Concern remains about the health impact if boron concentration levels reach too high, and more research is needed in understanding the marine ecology impact of discharging brine into the sea.

\(^{66}\) [http://www.feem-project.net/cases/](http://www.feem-project.net/cases/)

\(^{67}\) Philip Reiss, external costs of solar energy, solar power for sustainable energy, international symposium, Stockholm, May 2008
### 6.2 A review of mitigation measures associated with wastewater re-use, on the basis of case studies

Table 38 provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular.

**Table 38 Mitigation options identified in each case study concerned with wastewater re-use**

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Waste water re-use in Campo Dalias (Southern Spain)</td>
</tr>
<tr>
<td>Legal standards</td>
<td>X</td>
</tr>
<tr>
<td>Public and user awareness</td>
<td>X</td>
</tr>
<tr>
<td>Treatment improvements</td>
<td>X</td>
</tr>
<tr>
<td>Improved efficiency</td>
<td>X</td>
</tr>
<tr>
<td>Financial incentives</td>
<td>X</td>
</tr>
</tbody>
</table>

In each case study there are legal standards and monitoring to ensure that treated wastewater in irrigation water meets several parameters and standards to protect soil, crops, groundwater and hygiene. There is not a European Directive specifying the standards for treated wastewater in irrigation – so each case study follows either national (Cyprus, Malta, Germany, Spain) or local laws (France). In addition in all case studies there have been public awareness campaigns to highlight the benefits of using treated wastewater in irrigation (not only to users, but also the general public), but also to make people aware of some of the public health risks. In this regard there are local laws to restrict public access to irrigation areas or recommendations to irrigate only at night. In some cases improved treatment techniques are introduced to either deal with a certain local problem (such as high salinity in Campo Dalias and Malta) or to test out a cheaper alternative techniques (such as in Pornic). To encourage farmers to use wastewater re-use in their irrigation systems (rather than conventional water supply) financial incentives have been introduced. In Cyprus the unit cost of producing waste water for irrigation is 0.146 €/m³, whereas the tariffs that farmers pay is 0.068 €/m³.

### 6.3 A review of mitigation measures associated with rainwater harvesting, on the basis of case studies

Table 39 provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular.
The quality of RW harvested and stored following good practise is good enough for non-potable uses, but surveys show that people may also use RW for personal hygiene and drinking water. In both countries, the focus of regulation and information is to encourage the use of RW for non-potable uses, both outside and inside the house.

In Belgium and Malta there are regulations and standards in place to ensure that rainwater harvesting systems are of good standard and that the mains water supply is not contaminated. In Malta rainwater harvesting is a very old technology that has been neglected in favour more modern options such as desalination. Therefore there is a potential to bring in financial incentives and an education campaign to support the technology in Malta. In the Flanders regions of Belgium rainwater harvesting is actively being promoted – not just to conserve mains water supply, but also to reduce urban storm runoff events. A regulation requires that all new houses constructed or renovated have to include a rainwater harvesting tank with a dual water water distribution system so that toilets are flushed using rainwater instead of mains water. This regulation is enforced in two stages and is linked with building permits and control of mains water installations. The latter also ensures that RW cannot be used for uses where drinking water quality is required.

The case studies confirm that the costs of RWH are relatively high per m³ RW used, but the general costs of rainwater harvesting are quite different between Malta and Belgium. In Belgium a RWHS for private households requires a large investment and the price amounts to € 1.8 to 4 /m³ of RW used. The regulation specifies minimum requirements that aim at a cost-efficient introduction of RW. On the other hand, the savings amount to € 1.7 per m³ for avoided use of mains water. As with current regulations, the costs for sewage and sewage treatment are recovered on the basis of m³ of mains water used, the RW user benefits from an additional 2 €/m³ for avoided costs for sewage and sewage treatment. Little is known about the real impact of scenarios of more substantial RW use on the long term costs of mains water, sewage, storm water and sewage treatment.

In Malta the estimated cost of a rainwater harvesting system ranges between 5 to 11 €/m³ depending on the construction costs. This difference is mainly due to larger size of water supply tank required in Malta, which is in most cases constructed rather than prefabricated. The larger tank size needed is due to less and more unevenly distributed rainfall.

In Belgium, there is also a subsidy grant in place for households to retrofit a rainwater harvesting system, but its contribution to the penetration of RWH is very limited compared to the impact of regulation for new buildings. In Berlin, there is a storm water fee of € 1.7/m² of sealed surface, and households that harvest and store RW are exempted from this fee, which gives a large financial incentive for the promotion of RWHS, in addition to providing savings for main water.
6.4 A review of mitigation measures associated with ground water recharge, on the basis of case studies

Table 40 provides a matrix of mitigation options versus case study to indicate, which mitigation options are prevalent and which are particular. In Malta the intention is to only use harvested rainfall as input for recharging aquifers – so the mitigation options related to the Belgian coast and the Berlin case studies are not relevant.

Table 40 Mitigation options identified in each case study concerned with ground water recharge

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Ground water recharge at Belgian coast</th>
<th>Ground water recharge in Berlin</th>
<th>Ground water recharge in Malta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary treatment</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Intensive process control</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Treatment of side streams</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The main concern in groundwater recharge is to ensure that there is no pollution of the aquifer. There are differences in the recharging process used in the Belgian coast and Berlin case studies. The Belgian coast case study uses treated waste water directly from the UWWT plant for recharging, whereas in Berlin use is made of surface waters from rivers to recharge aquifers using bank infiltration. Therefore the source of the water used for recharging is of differing quality. However in both case tertiary treatment has to take place and there is a need to monitor and control the system continuously. In the case of the Belgian coast case study an additional concern is the treatment of side streams out of the UWWT – which is bi-product of the technology.

The general costs of supplying drinking water in Berlin is 1.04 €/m³ (although consumers pay close to 2 €/m³). In the Belgian case study cost of producing water from ground water recharge is estimated to be 0.5 €/m³, which is cheaper than transferred water from outside the region (0.77 €/m³).
Chapter 6 Discussion
Overall, the case studies confirm the conclusions from the Task 1 report, that the four alternative water supply options are proven, reliable technologies. One still needs to take into account that the use of the produced water may not be suited for uses that require drinking water quality. The case studies also confirm that the list of environmental, economic and social issues identified in Task 1 Report covers the mains issues.

The case studies indicate that the mitigation measures used were successful to address potential and locally specific environmental concerns. Potential problems and mitigation options differ between locations and technologies – meaning that mitigation measures have to be designed to deal with local conditions. The case studies therefore do not provide a single set of best available mitigation options or recommendations for good practise, but rather provide check-lists of potential problems and a catalogue of potential mitigation options, with illustrations about successful applications.

The mitigation options are very diverse. They include case specific choice of location and ex-ante procedures (e.g. environmental impact studies) to define the framework and conditions for the water supply to operate. The following issues need to be addressed:

- Potential land-use and noise impacts from desalination and wastewater treatment plants;
- Impact of brine discharge on coastal and marine ecosystems;
- Contamination of soil and groundwater from treated wastewater which is re used.
- The added investment in distribution networks to transfer treated waste water from UWWT plants to agricultural land for irrigation, desalinated water from desalination plants to the mains water supply, harvested rainwater to toilets and washing machines (dual household distribution system).

This last issue needs extensive monitoring and control. One point of note is that there is still no EU wide directive on the use of treated wastewater for irrigation.

Mitigation measures to avoid public health impacts from misuse of rain water or treated waste water not intended for potable use include the setting up of national or local standards for water to be used or for equipment and installation procedures, defining guidance for good practise, labelling of tap points, information and education,... The case studies give examples of implementing monitoring or control, also in cases where many users are involved.

Compared to conventional water supply sources, some alternative water supply options require more energy (desalination) or more materials for equipment (rainwater harvesting) per m³ of water. This leads not only to higher costs, but also a higher burden on the environment. These issues are difficult to solve in the context of water supply decisions, and therefore need to be addressed in a wider environmental framework.

As desalination requires more energy compared to other conventional water supply sources, it will result in a higher carbon footprint, if it uses energy from fossil fuels directly or electricity from the mains grid generated by fossil fuel power stations. Although the designated use of renewables, such as solar or wind energy, may reduce the carbon footprint of desalination this problem, the current total costs of renewable energy per kWH are significantly higher. During 2008 the market price of crude oil
Chapter 7 Conclusions

peaked at 147 USD per barrel in July and then fell to 40 USD per barrel by December. Comparisons therefore between the short and long term economic costs of renewables and fossil fuels remain uncertain. It should also be remembered that desalination plants need a steady supply of energy to function optimally - this means that renewable energy supplies from wind and solar, which fluctuate depending on wind and solar conditions, and therefore need to be backed up by the mains electricity grid (or a fossil fuel powered generator). An alternative set up is to power the desalination plant continuously from the mains electricity grid, that is powered partially by renewables connected by a "smart" grid. Therefore, the costs of renewables and the need for a steady energy supply have to be considered.

Rainwater harvesting systems require a relatively large investment in rainwater tanks, which is not only reflected in being an economic obstacle, but also in the relatively high environmental life cycle impacts embedded in material and energy use. There are no mitigation options to deal with this apart from guidelines to promote an optimal sizing of RW tanks.

Alternative water supply options may be more expensive than more conventional options, especially if water prices do not recover all private and environmental costs. The case studies illustrate that in these cases the promotion of alternative water supply options are likely to use subsidies to compensate for price differences. However, these may in the long term not be the best way to deal with this situation, as it does not promote overall efficiency of water use. Therefore, it is recommended that promotion of more expensive alternative water supply options is accompanied by a revision of water pricing towards a full recovery of all private and environmental costs.

Higher water prices give rise to concerns about the affordability of mains water for the low income groups. Furthermore, higher water prices also raise concerns about the affordability for agriculture and industries that have been used to having access to cheap, high quality water. Although subsidies can help these users in the transition towards a more sustainable use of water resources, the final goal should be to have sustainable water use where price of water reflects its true cost, efficiencies are improved, and water demand reduced.

The case studies illustrate that the mitigation measures addressed have allowed alternative water supply options to be established. However, as the knowledge and experience on a number of issues is limited, further research on potential impacts and mitigation options are required. This is the case for:

- Discharge of brine into marine and coastal ecosystems;
- Accumulation of boron from desalinated water in the water system and ecosystems;
- Contamination of soil and groundwater from treated wastewater;
- Scopes to improve energy efficiency of desalination;
- Scope for more cost-efficient use of rainwater harvesting systems, including upgrading of existing tanks and use in collective systems;
- Net costs of rainwater harvesting systems, accounting for short- and long term impacts on investments for mains water supply and distribution, sewage and sewage treatment and storm water management;
- Risks for human health of dual water supply systems and re-use of treated wastewater for irrigation;
- Capability of mitigation options to adapt to climate change scenarios

The potential for the further establishment of these alternative supply options will depend on local conditions including the specificities of the water supply problems to be addressed, water resources at hand, the economic costs of the alternatives and capacity to pay for specified uses. In the Task 3 Report, the potential of alternative water supply options to solve real world water supply problems is evaluated.