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# RECLAMATION AND AGRICULTURAL REUSE OF WASTEWATER: THE EXPERIENCE OF CAGLIARI SEWAGE TREATMENT PLANT (SARDINIA – ITALY)

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**SUMMARY –** In Sardinia, like in many other Mediterranean regions, the recurrent droughts and climate change have dramatically reduced the available water resources. As a result of this critical situation, in 1995 the Italian Government declared a state of emergency and drew up a programme for financial provision by the State and local government authorities with the aim to reduce such a serious deficit. One of the actions has been focused on reclaiming and reusing the effluent coming from the sewage treatment plant of Cagliari. In the present work the multidisciplinary research preliminarily carried out by the Ente Autonomo del Flumendosa (EAF - Sardinia – Italy) to evaluate the suitability of Is Arenas effluent in irrigation is illustrated.

**Keywords:** effluent, reclamation, reuse, sewage, lysimetric column

## 1. INTRODUCTION

Sardinia, like most other Mediterranean regions, suffers from shortage of water, especially good quality water, on account of recurrent droughts. In addition, and in spite of the fact that traditional surface and groundwater resources continue to diminish, little has been done in the way of recycling effluents from waste water treatment stations which are usually discharged into rivers or the sea, creating also environmental problems associated with eutrophication.

As a result of this critical situation, exacerbated by the droughts of 1990 and 1995, in 1995 the Italian government declared a state of emergency and drew up a programme for financial provision by the State and local government authorities with a view to reducing, at least in part, this serious deficit. Among the actions envisaged there is water reuse in agriculture, especially the effluents from traditional sewage treatment plants.

Of the existing sewage treatment plants, the plant which serves the city of Cagliari and its suburbs (known as Is Arenas plant), produces every year about 40 millions $m^3$ of effluents, which is predicted to rise to 60 millions $m^3$/year over the next few years.

In the light of the above, and within the framework of the programme of local government and EU for coping with the water supply emergency that has arisen over the last 15 years, the Ente Autonomo del Flumendosa has prepared the project for the reuse in agriculture of the wastewater from the Cagliari purification plant.

Regarding to the Middle Flumendosa–Campidano System, Figure 1 shows a confirmation of the recent serious last droughts phenomena and last climate change, with a heavy runoff reduction. Consequently the erogation has dramatically dropped, with the deficit almost entirely loaded onto the agriculture sector.

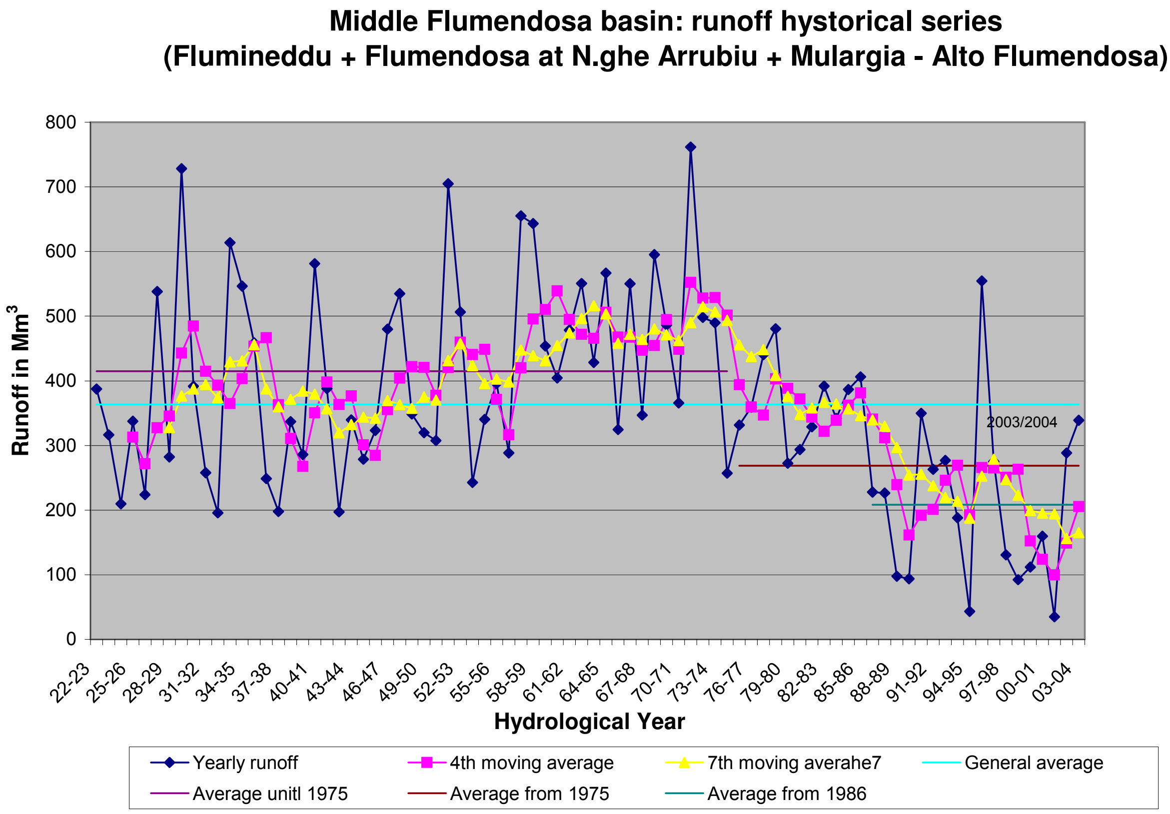


Figure 1. Middle Flumendosa Basin discharge historical series

## 2. PROJECT DESCRIPTION AND MAIN OBJECTIVES

In view of reusing the effluents of Is Arenas the project foresees the realization of a tertiary treatment line located downstream the Is Arenas plant for the reduction of phosphorus and bacterial content in the treated effluent before discharging it in the Simbirizzi reservoir, which acts as storage basin prior to the reuse of the polished effluents. The collected cleaned effluents is mixed with water derived from the upper Flumendosa-Campidano hydraulic system and kept in lake Simbirizzi for the use in agricultural irrigation of the district area of Southern Sardinia (Figure 2).

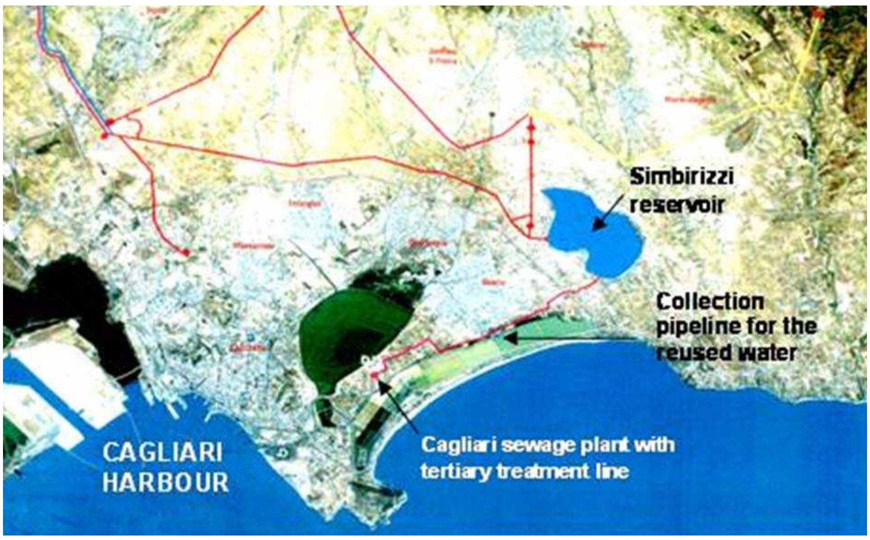


Figure 2. Cagliari wastewater reuse scheme

The wastewater accumulated in the reservoir is destined to irrigate the irrigation district of southern Sardinia (about 7900 hectares). In general, the wastewater from the purification plant of Is Arenas can either be destined to direct reuse in irrigation (without storing the treated wastewater in the reservoir) or used indirectly. The project has been completed in 2001 and the tertiary treatment plant has been operating since may 2002.

As part of this project, about ten years ago EAF started experimental activities and environmental impact studies in collaboration with qualified scientific institutions such as the Universities of Cagliari, Sassari, and Naples, the Superior National Health Institute of Rome, the JRC (Joint Research Centre of the European Union) of Ispra, and the CNR of Pisa. The main purpose of these activities was the study of the two priority aspects that are considered fundamental to the success of the project: i.e. i) not to compromise the already precarious trophic state of the Simbirizzi reservoir by adding recovered wastewaters, and ii) to assess the ability of the soils of the irrigation district of southern Sardinia to be irrigated with wastewater without having their chemical-physical and hydraulic properties altered. Therefore the main experimental activities may be summed up as follows:

- determination of the chemical-physical and microbiological quality of the wastewater from the purification plant of Cagliari and definition of the most suitable tertiary water treatment techniques through experimentation on a pilot plant.
- physical-chemical and hydraulic characterisation of the soils of the irrigation district of southern Sardinia through experimentation on undisturbed lysimetric columns.
- preliminary assessment of the public consensus on the reuse of recovered wastewater in agriculture.

## 3. WATER QUALITY MONITORING AND COMPLIANCE WITH EXIXTING STANDARDS, RELIABILITY OF TREATMENT AND STORAGE AFFILIATIONS

The first pre-requisite for a successful water recovery operation on a given waste water treatment effluent source in view of its reuse is the in-depth knowledge of the effluent quality and its short- and long-term quality changes, likely to occur on a periodical basis and reflecting the input of chemicals somewhere in the network.

It is therefore advisable to monitor the effluent source quality for all kinds of potentially adverse substances which might later on interfere with the correct use of the recovered water, e.g. in agricultural irrigation.

While a number of inorganic compounds which may be formed such as $CaSO_4$ ($SrSO_4$, $BaSO_4$), $CaHPO_4$ and $CaCO_3$, $FePO_4$, $AlPO_4$ and $MgNH_4PO_4$ are certainly not of toxicological concern, the sheer quantity added to the soil over longer application periods, e.g. >10 years, might increase the hydraulic resistance of the soil layer by, e.g., gypsum formation.

In the present case of Cagliari’s water depuration plant, it was decided that a monitoring period of three years would have been sufficiently long to detect abusive and temporarily appearing irregular contaminant releases.

The work burden of the monitoring operation was shared between Ente Autonomo del Flumendosa at Cagliari (EAF) and Environment Institute Ispra (EI).

With regard to the effluents of Is Arenas the results are summarized in Table 1.

Table 1. Multiannual monitoring of the Is Arenas effluents. List of monitorands

| Parameter | Unit | Data | N. of det.* | Min | Max | Mean | Median | CV (%) |
|---|---|---|---|---|---|---|---|---|
| COD | (mg/L $O_2$) | 61 | 61 | 10,00 | 35,00 | 24,24 | 22,50 | 21,69 |
| TOC | (mg/L) | 61 | 61 | 4,00 | 30,40 | 9,98 | 8,53 | 40,20 |
| AOX | (µg/L) | 61 | 61 | 27,00 | 1208,00 | 196,63 | 177,70 | 79,27 |
| pH | | 61 | 61 | 6,49 | 8,28 | 7,40 | 7,38 | 4,88 |
| Conductivity | (µS 20 °C) | 61 | 61 | 1470,00 | 5260,00 | 2599,03 | 2060,00 | 39,50 |
| Cl | (mg/L) | 61 | 61 | 344,00 | 1556,00 | 629,00 | 453,00 | 45,06 |
| $SO_4$ | (mg/L) | 61 | 61 | 98,50 | 317,00 | 177,56 | 182,00 | 26,24 |
| Na | (mg/L) | 61 | 61 | 204,00 | 1082,00 | 438,13 | 295,00 | 58,18 |
| K | (mg/L) | 61 | 61 | 17,00 | 120,00 | 31,19 | 26,00 | 50,51 |
| Ca | (mg/L) | 61 | 61 | 53,50 | 194,00 | 95,04 | 89,80 | 34,27 |
| Mg | (mg/L) | 61 | 61 | 42,00 | 125,00 | 65,22 | 55,00 | 35,03 |
| N Kjeld | (mg/L) | 42 | 40 | 0,09 | 9,80 | 1,48 | 0,80 | 141,07 |
| $N\text{-}NH_4$ | (mg/L) | 61 | 44 | 0,01 | 10,00 | 1,06 | 0,12 | 237,09 |
| $NO_2$ | (mg/L) | 61 | 52 | 0,01 | 5,00 | 0,71 | 0,17 | 157,20 |
| $N\text{-}NO_2$ | (mg/L) | 61 | 52 | 0,00 | 1,52 | 0,21 | 0,05 | 157,51 |
| $NO_3$ | (mg/L) | 61 | 60 | 10,00 | 113,00 | 61,93 | 65,70 | 39,25 |
| $N\text{-}NO_3$ | (mg/L) | 61 | 60 | 2,26 | 25,53 | 13,99 | 14,84 | 39,30 |
| $P_{tot}$ | (mg/L) | 51 | 51 | 0,40 | 2,61 | 1,65 | 1,60 | 30,58 |
| $PO_4$ | (mg/L) | 59 | 50 | 0,10 | 9,30 | 4,87 | 4,50 | 44,12 |
| $P\text{-}PO_4$ | (mg/L) | 59 | 50 | 0,03 | 3,03 | 1,58 | 1,46 | 44,09 |
| Toluene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Isopropyltoluene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Ethylbenzene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| m- + p-Xylene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Stirene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| o-Xylene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| n- Propylbenzene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 1,3,5-Trimethylbenzene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Terbuthylbenzene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 1,2,4- Trimethylbenzene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Sec-Buthylbenzene (+1,3 Dichloro-benzene) | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| n-Buthylbenzene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Naphtalene | (µg/L) | 56 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Chloroform | (µg/L) | 60 | 55 | 0,33 | 128,00 | 5,47 | 1,85 | 312,50 |
| Bromoform | (µg/L) | 60 | 49 | 0,55 | 352,00 | 71,74 | 28,30 | 125,95 |
| Bromodichloro-methane | (µg/L) | 60 | 50 | 0,20 | 335,40 | 15,16 | 5,00 | 310,79 |
| Dibromochloro-methane | (µg/L) | 60 | 52 | 0,80 | 439,00 | 37,74 | 14,45 | 177,74 |
| Tetrachloro-ethylene | (µg/L) | 52 | 36 | 0,03 | 32,00 | 1,62 | 0,30 | 341,15 |
| Trichloro-ethylene | (µg/L) | 60 | 1 | 2,30 | 2,30 | 2,30 | n.d. | n.d. |
| Dibromo-methane | (µg/L) | 58 | 22 | 0,20 | 10,10 | 2,33 | 1,85 | 92,20 |
| 1,2,3-Trichloro-benzene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 1,2,3-Trichloro-propane | (µg/L) | 41 | 4 | 1,10 | 3,70 | 2,20 | 2,00 | 52,75 |
| 4-Chloro-toluene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| VOX | (µg/L) | 60 | 58 | 0,50 | 1040,20 | 114,78 | 41,20 | 153,83 |
| 2,4,6-Trichlorophenol | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2/3/4 Nitroanilin+ Dibenzofuran | (µg/L) | 37 | 3 | 0,04 | 0,10 | 0,07 | 0,07 | 42,86 |
| 2-Methylnaphtalene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |

| Parameter | Unit | Data | N. of det.* | Min | Max | Mean | Median | CV (%) |
|---|---|---|---|---|---|---|---|---|
| 2-0r3-0r4-Nitroanilin | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 4-Chloroaniline | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Aniline | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Acenaphthene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Acenaphthylene | (µg/L) | 41 | 2 | 0,05 | 0,08 | 0,07 | 0,07 | 32,64 |
| Anthracene | (µg/L) | 41 | 4 | 0,01 | 0,03 | 0,02 | 0,03 | 42,55 |
| Benzo(a)anthracene or Chrysene | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Benzo (b or k) fluoranthene | (µg/L) | 36 | 4 | 0,03 | 0,30 | 0,13 | 0,10 | 95,34 |
| Benzo(ghi)perylene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Benzo(a)pyrene | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Crysene or Benzo(a)anthracene | (µg/L) | 41 | 2 | 0,06 | 0,12 | 0,09 | 0,04 | 0,09 |
| Dibenzo(a,h)anthracene | (µg/L) | 41 | 1 | 0,19 | 0,19 | 0,19 | n.d. | n.d. |
| Fluoranthene | (µg/L) | 41 | 2 | 0,03 | 0,03 | 0,03 | n.d. | n.d. |
| Fluorene | (µg/L) | 41 | 2 | 0,04 | 0,05 | 0,05 | 0,05 | 15,71 |
| Indeno(1,2,3-cd)pyrene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Naphthalene | (µg/L) | 41 | 6 | 0,02 | 0,11 | 0,08 | 0,10 | 57,66 |
| Phenanthrene | (µg/L) | 41 | 2 | 0,05 | 0,11 | 0,08 | 0,08 | 53,03 |
| Pyrene | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Bis(2-chloroetoxy) methane | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Bis(2-chloroetoxy) ether | (µg/L) | 41 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Bis(2-chloroisopropyl) ether | (µg/L) | 41 | 1 | 0,01 | 0,01 | 0,01 | n.d. | n.d. |
| Bis(2-ethylhexylyl) phtalate | (µg/L) | 25 | 21 | 0,19 | 1,32 | 0,56 | 0,49 | 57,70 |
| 4-Bromophenylphenyl-ether | (µg/L) | 41 | 1 | 0,09 | 0,09 | 0,09 | n.d. | n.d. |
| Butylbenzylphtalate | (µg/L) | 36 | 6 | 0,08 | 0,45 | 0,26 | 0,26 | 51,55 |
| 4-Chlorophenylphenyl-ether | (µg/L) | 41 | 1 | 0,12 | 0,12 | 0,12 | n.d. | n.d. |
| Diethylphthalate | (µg/L) | 25 | 2 | 0,55 | 0,66 | 0,61 | 0,61 | 12,86 |
| Dimethylphthalate | (µg/L) | 34 | 4 | 0,05 | 2,35 | 0,64 | 0,08 | 179,10 |
| Di-n-butylphthalate | (µg/L) | 34 | 28 | 0,07 | 2,67 | 0,52 | 0,28 | 129,51 |
| Di-n-octylphthalate | (µg/L) | 36 | 4 | 0,09 | 0,54 | 0,38 | 0,46 | 53,28 |
| N-Nitrosodi-n-propylamine | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| N-Nitrosodipheny-lamine | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Azobenzene | (µg/L) | 36 | 1 | 0,03 | 0,03 | 0,03 | n.d. | n.d. |
| Carbazole | (µg/L) | 36 | 3 | 0,01 | 0,05 | 0,03 | 0,03 | 66,27 |
| 2-Chloronaphtalene | (µg/L) | 36 | 1 | 0,02 | 0,02 | 0,02 | n.d. | n.d. |
| 1,2-Dichlorobenzene | (µg/L) | 36 | 2 | 0,02 | 0,02 | 0,02 | n.d. | n.d. |
| 1,3-Dichlorobenzene | (µg/L) | 36 | 5 | 0,02 | 0,03 | 0,03 | 0,03 | 15,97 |
| 1,4-Dichlorobenzene | (µg/L) | 36 | 5 | 0,02 | 0,03 | 0,03 | 0,03 | 15,97 |
| 2,4-Dinitrotoluene | (µg/L) | 36 | 1 | 0,10 | 0,10 | 0,10 | n.d. | n.d. |
| 2,6-Dinitrotoluene | (µg/L) | 36 | 2 | 1,74 | 1,83 | 1,79 | 1,79 | 3,57 |
| Hexacholorobenzene | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hexacholorobutadine | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hexachlorocyclo-pentadiene | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |

| Parameter | Unit | Data | N. of det.* | Min | Max | Mean | Median | CV (%) |
|---|---|---|---|---|---|---|---|---|
| Hexachloretane | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Isophorone | (µg/L) | 36 | 1 | 0,05 | 0,05 | 0,05 | n.d. | n.d. |
| Nitrobenzene | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 1,2,3-Trichlorobenzene | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Aldrin | (µg/L) | 36 | 1 | 0,40 | 0,40 | 0,40 | n.d. | n.d. |
| Alpha-BHC | (µg/L) | 36 | 1 | 0,32 | 0,32 | 0,32 | n.d. | n.d. |
| Beta-BHC | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Gamma-BHC | (µg/L) | 36 | 1 | 0,43 | 0,43 | 0,43 | n.d. | n.d. |
| Delta-BHC | (µg/L) | 36 | 2 | 0,21 | 0,40 | 0,31 | 0,31 | 44,05 |
| 4,4-DDD | (µg/L) | 36 | 1 | 0,10 | 0,10 | 0,10 | n.d. | n.d. |
| 4,4-DDE | (µg/L) | 36 | 1 | 0,09 | 0,09 | 0,09 | n.d. | n.d. |
| 4,4-DDT | (µg/L) | 34 | 1 | 0,26 | 0,26 | 0,26 | n.d. | n.d. |
| Dieldrine | (µg/L) | 36 | 2 | 0,12 | 0,22 | 0,17 | 0,17 | 41,59 |
| Endosulfan1 | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Endosulfan2 | (µg/L) | 36 | 1 | 7,61 | 7,61 | 7,61 | n.d. | n.d. |
| Endosulfan sulfate | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Endrin | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Endrin aldehyde | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Endrine ketone | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Heptachlor (isomer B) | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Methoxychlor | (µg/L) | 36 | 1 | 0,11 | 0,11 | 0,11 | n.d. | n.d. |
| 2-(PCB) | (µg/L) | 36 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,3-(PCB) | (µg/L) | 36 | 1 | 0,06 | 0,06 | 0,06 | n.d. | n.d. |
| 2,4,5-(PCB) | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,2',4,4'-(PCB) | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,2',3',4,6-(PCB) | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,2',4,4',5,6'-(PCB) | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,2',3,3',4,4',6-(PCB) | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,2',3,3',4,5',6,6'-(PCB) | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Benzidine | (µg/L) | 34 | 2 | 2,32 | 3,07 | 2,70 | 2,70 | 19,68 |
| 3,3'-Dichlorobenzidine | (µg/L) | 34 | 1 | 0,47 | 0,47 | 0,47 | n.d. | n.d. |
| 2-Methylphenol | (µg/L) | 39 | 3 | 0,02 | 0,04 | 0,03 | 0,02 | 43,30 |
| 2,4,5-Trichlorophenol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Phenol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Benzoic acid | (µg/L) | 34 | 1 | 0,16 | 0,16 | 0,16 | n.d. | n.d. |
| 2-Chlorophenol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,4-Dimethylphenol | (µg/L) | 30 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 2,4-Dichlorophenol | (µg/L) | 39 | 2 | 0,02 | 0,02 | 0,02 | 0,02 | 0,00 |
| 4-Chloro-3-methyl-phenol | (µg/L) | 39 | 3 | 0,02 | 0,39 | 0,15 | 0,04 | 138,72 |
| 2-Methyl-4,6-dinitro-phenol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Pentachlorophenol | (µg/L) | 39 | 1 | 0,28 | 0,28 | 0,28 | n.d. | n.d. |
| 2-Nitrophenol | (µg/L) | 19 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 4-Nitrophenol | (µg/L) | 39 | 1 | 1,34 | 1,34 | 1,34 | n.d. | n.d. |
| 2,4-Dinitrophenol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Benzyl alcohol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| 4-Methylphenol | (µg/L) | 39 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hydrocarbon C10 | (µg/L) | 39 | 4 | 0,05 | 0,07 | 0,06 | 0,06 | 16,65 |
| Hydrocarbon C11 | (µg/L) | 25 | 10 | 0,10 | 0,35 | 0,22 | 0,22 | 33,70 |
| Hydrocarbon C12 | (µg/L) | 25 | 10 | 0,07 | 0,52 | 0,18 | 0,11 | 90,02 |
| Hydrocarbon C14 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |

| Parameter | Unit | Data | N. of det.* | Min | Max | Mean | Median | CV (%) |
|---|---|---|---|---|---|---|---|---|
| Hydrocarbon C16 | (µg/L) | 25 | 2 | 0,13 | 0,15 | 0,14 | 0,14 | 10,10 |
| Hydrocarbon C17 | (µg/L) | 25 | 1 | 0,14 | 0,14 | 0,14 | n.d. | n.d. |
| Hydrocarbon C18 | (µg/L) | 25 | 1 | 0,21 | 0,21 | 0,21 | n.d. | n.d. |
| Hydrocarbon C20 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hydrocarbon C24 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hydrocarbon C26 | (µg/L) | 25 | 3 | 0,11 | 0,18 | 0,14 | 0,12 | 27,70 |
| Hydrocarbon C28 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hydrocarbon C30 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hydrocarbon C32 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Hydrocarbon C34 | (µg/L) | 25 | 0 | n.d. | n.d. | n.d. | n.d. | n.d. |
| Fe | (µg/L) | 61 | 59 | 15,00 | 150,00 | 45,83 | 41,90 | 51,08 |
| Mn | (µg/L) | 61 | 58 | 2,30 | 320,00 | 41,90 | 21,15 | 149,99 |
| Zn | (µg/L) | 61 | 61 | 5,00 | 250,00 | 84,65 | 70,00 | 68,02 |
| Cu | (µg/L) | 61 | 61 | 0,38 | 18,00 | 1,84 | 1,58 | 120,49 |
| Cd | (µg/L) | 61 | 61 | 0,00 | 1,86 | 0,23 | 0,23 | 107,55 |
| Ni | (µg/L) | 61 | 61 | 0,69 | 8,21 | 2,30 | 1,65 | 66,02 |
| Pb | (µg/L) | 61 | 61 | 0,48 | 10,25 | 2,31 | 1,65 | 88,42 |
| Cr | (µg/L) | 61 | 60 | 0,02 | 19,03 | 2,21 | 1,45 | 128,75 |
| Al | (µg/L) | 61 | 61 | 3,00 | 143,00 | 27,67 | 24,20 | 79,70 |
| Ba | (µg/L) | 61 | 61 | 12,59 | 237,06 | 45,66 | 31,94 | 108,55 |
| Co | (µg/L) | 61 | 61 | 0,28 | 1,45 | 0,59 | 0,55 | 40,87 |
| Li | (µg/L) | 61 | 61 | 1,83 | 106,00 | 25,54 | 5,45 | 133,69 |
| Mo | (µg/L) | 61 | 61 | 0,52 | 5,70 | 3,02 | 3,19 | 41,89 |
| Sn | (µg/L) | 61 | 60 | 0,00 | 4,52 | 1,36 | 0,40 | 100,75 |
| As | (µg/L) | 61 | 60 | 0,87 | 7,51 | 3,95 | 3,81 | 39,95 |
| Sb | (µg/L) | 61 | 60 | 0,17 | 3,20 | 0,93 | 0,67 | 77,64 |
| W | (µg/L) | 61 | 33 | 0,00 | 0,98 | 0,22 | 0,08 | 126,21 |
| Tl | (µg/L) | 61 | 33 | 0,00 | 0,32 | 0,06 | 0,04 | 137,90 |
| Bi | (µg/L) | 61 | 46 | 0,01 | 1,32 | 0,17 | 0,12 | 126,85 |
| Te | (µg/L) | 61 | 19 | 0,00 | 0,24 | 0,02 | 0,01 | 212,94 |
| Hg | (µg/L) | 61 | 25 | 0,01 | 0,30 | 0,10 | 0,09 | 71,34 |

* N. of det. = Number of determinations

It can be observed that most critical, in view of the reuse of the Is Arenas effluents, are the concentrations of simple salts, sodium chloride first of all. The periodical appearance of high conductivity values, accompanied by high concentrations of sulphate, magnesium and boron, suggests the massive input of seawater into the Cagliari sewer system. A series of sampling campaigns in the sewage collection network, executed at specific weather condition, confirmed the hypothesis and the city technical services is taking the appropriate countermeasures.

### 3.1. Reliability of tertiary treatment plant text

To predict the bacterial and phosphorus removal efficiency and the main design parameters of the additional treatment line, some preliminary experimental studies were conducted on dephosphatation and disinfection of the Is Arenas effluent. The tests were carried out in the Simbirizzi pilot plant and for UV disinfection a mobile unit set up in collaboration with the Environment Institute of the Joint Research Center of the European Commission at Ispra has been employed.

Figure 3.1 shows the phosphorus removal efficiency of the process, expressed as the ratio of total phosphorus content of the water entering the pilot plant and that of the treated water. The figure has been divided into two parts to differentiate the additions of flocculating agent. In the first series of tests between 15 and 30 mg/l of flocculant was added with pH of 7-7.5, Phosphorus removal efficiency averaged around 70% for small additions rising to 90% for additions of 30 mg/l. In the second series of tests the proportions were increased to between 30 and 40 mg/l keeping flocculation pH at 7-7.5. Average phosphorus removal efficiency in this case was around 90% for additions of 30 mg/l increasing to 98% at 40 mg/l.

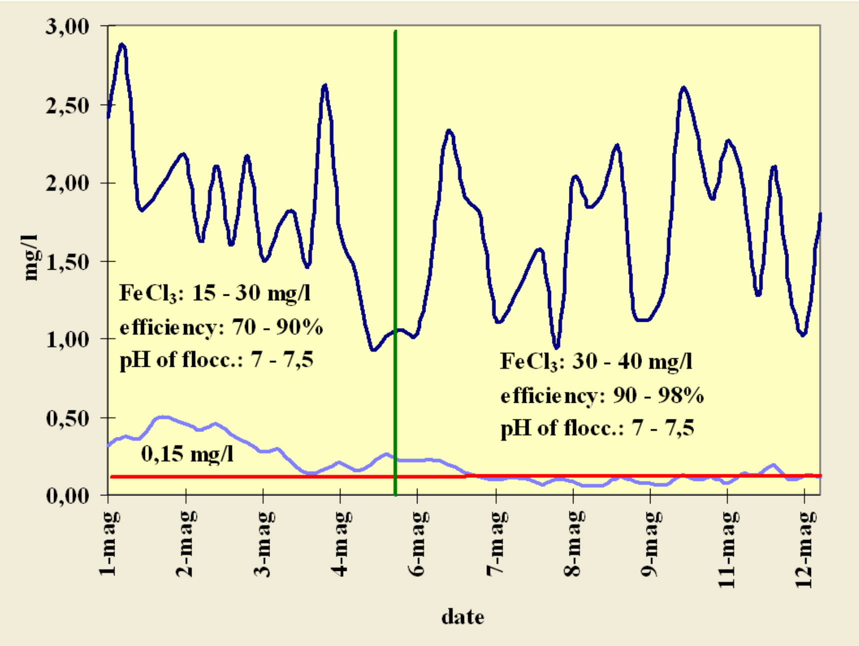


Figure 3. Total phosphorus in the raw water and treated water

The mean total phosphorus concentration of the treated water was 0.3 mg/l and 0.15 mg/l respectively for flocculant additions of between 15 and 30 mg/l and 30 and 40 mg/l.

Figure 4 shows the average bacteria content at the entrance of the filtration section and after disinfection. After disinfection, the overall, total reduction of the bacteria content amounted on average to 98%, equating to roughly two orders of magnitude, with average total residual chlorine of about 0.1 mg/l. Note that for higher residual chlorine concentrations (0.15-0.2 mg/l) the number of bacteria can be reduced on average by three orders of magnitude.

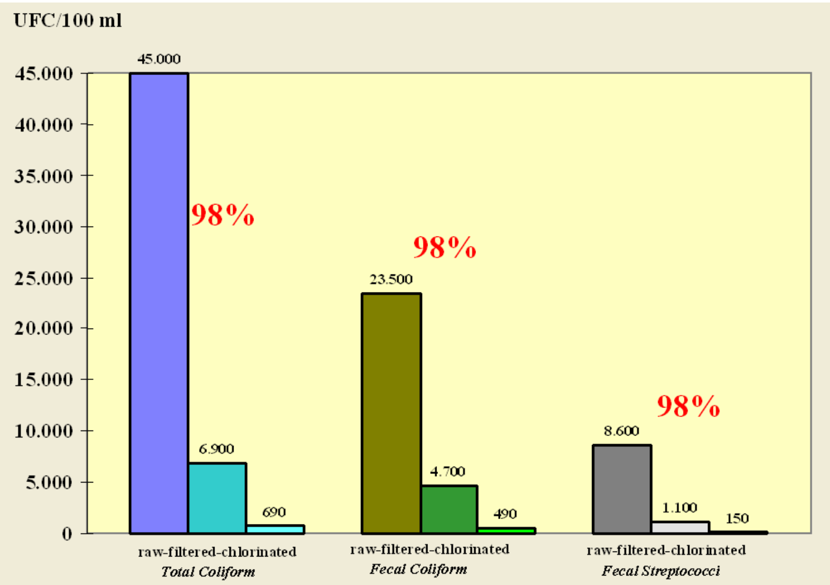


Figure 4. Removal efficiency for coliform bacteria and Streptococci with chlorine dioxide

## 4. IMPACT OF IRRIGATION ON SOIL STRUCTURE AND PROPERTIES AND FIGURES

Besides the problem of compatibility of the wastewater with the water of Simbirizzi reservoir, another critical issue is that of assessing the effects of the use of irrigation wastewater on the physical, hydrological and chemical properties of the soils of the irrigation district of south Sardinia.

The effects one may expect, fall into different categories: 1) altering the layering of soil particles by washing smaller particles in lower horizons leading to compactation of the soil and hence, to decreasing hydraulic conductivity; 2) the intercalation of ions such as Na+ into the structure spaces of clay minerals and micas causing the swelling of the particles with subsequent reduction of open interparticle spaces and again, reduced hydraulic conductivity; 3) accumulation of chemical pollutants like heavy metals; 4) modification of stable humo-enzimatic complexes.

To verify the effects of the reused Is Arenas effluents and its components on the soils an extended series of lysimetric experiments on undisturbed soil samples with diameter of 0.4 m and depth of 1-1.5 m, have been carried out. The experimental study has been carried out on different kinds of soil representative of the Southern part of Sardinia (Campidano plane).

The area to be irrigated with the effluents discharged by municipal wastewater treatment plant of Cagliari-Is Arenas is characterised by soils related to three major kinds of landforms, which have been classified taxonomically using the Keys to Soil Taxonomy (1998) and WRB (1999) systems.

The hydrological behaviour of soils has been monitored through the measurement of soil water content and water potential. Also the chemistry of circulating soil solutions has been checked by irrigating the soils with the wastewater with aid of a rain simulator at different intervals, with the intention to simulate processes under field conditions. The soil water content and the solutes transport have been evaluated with the Time Domain Reflectometry technique (TDR).

At last the water potential, that means the hydraulic conductivity of soils, has been evaluated using measurements of water flux into a tensiometer, while the circulating solution to be analysed after irrigation has been separated from the soil using extractors located at the base and in different layers of the columns.

At each site two monoliths have been picked up, so a total of 10 lysimeters, 5 arranged for destructive checks on soil, such as verification analyses of texture, organic matter and others, and 5 lysimeters with undisturbed soil layers to be examined for the hydrological parameters, have been obtained (Figure 5).

Figure 5. Soil cylinder sampling

It is important to underline that the irrigation was made with pure wastewater, that is, without any dilution by “fresh” water, in order to carry out an experiment in extreme conditions that are unlikely to occur on the field, where as has been said, wastewater mixed with fresh water of the Simbirizzi reservoir is used.

The test conditions have been selected in such a way to simulate as close as possible the hydrological cycles of effluent application-evaporation. Each pedon was therefore exposed to five irrigation cycles, the first conducted until stationary flux conditions have been reached and the following cycles adding water lost by evaporation until the end of each infiltration test. Each cycle was followed by 2 weeks of evaporation during which water content and water potential were systematically monitored at different depths.

During the irrigation tests, measurements of the water content and potential have been conducted and samples of the circulating water and at the exit were taken for the monitoring of the dynamics of nutrient chemical species. Altogether 44 chemical and microbiological parameters have been monitored (Table 2) recording the following bacteria at the entrance and the exit of the lysimeter columns:

- Total coliforms, faecal coliforms, *Escherichia coli*, and enterococci, used as fecalization markers;
- Bacteriophages anti-*Escherichia coli*, used as virus markers;
- Helminth eggs, used as aquatic parasite markers.

Table 2. Chemical parameters monitored in the water at entrance and exit of columns

| | | | | |
|---|---|---|---|---|
| pH | Conductivity | Redox potential | $N-NH_4$ | $N-NO_2$ |
| $N-NO_3$ | N-Tot. | Reactive phosphorus | Tot. Phosphorus | Chlorides |
| Sulfates | Alkalinity | COD | Sodium | Potassium |
| Calcium | Magnesium | SAR | TC | TOC |
| IC | AOX | Tot. Iron | Dissolv.Iron | Tot. Manganese . |
| Dissolved Mn | Tot.Aluminium | Dissolved Aluminium. | Tot. Chrom | Dissolv. Chrom |
| Tot. Zinc | Dissolv. Zinc | Tot.Cadmium | Diss Cadmium | Tot. Lead |
| Dissolv. Lead. | Tot. Nickel | Dissolv. Nickel | Tot. Copper | Dissolv. Copper |
| Tot. Arsenic | Dissolv.Arsenic. | Tot. Boron | Dissolv. Boron | |

Besides chemical and microbiological analyses on the water, the soils were also analysed before and after irrigation, and the investigated parameters are reported in Table 3.

Table 3. Parameters analysed on the soil before and after the irrigation with wastewater

| | | |
|---|---|---|
| Humidity | Acidity | |
| pH ($H_2O$) | Granulometric analysis | $Na^+$ |
| pH (KCl) | Skeleton | $K^+$ |
| $E_h$ (redox potential) | | $Ca^{++}$ |
| Conducibility at 25 °C | | $Mg^{++}$ |
| Organic carbon | Cadmium | |
| Organic substance | Chromium | |
| Water soluble organic carbon | Nickel | $Cl^-$ |
| Kjeldahl nitrogen | Lead | $NO_3^-$ |
| C/N ratio | Copper | $PO_4^{---}$ |
| Total phosphorus | Zinc | $SO_4^{--}$ |
| Total limestone | Iron | |
| Cationic exchange ability | Manganese | Mineralisation index N/O |
| Degree of saturation in bases | | Humification index $B/E_3$ |
| Exchange bases:( Na,K,Ca,Mg) | | AL/AR ratio |
| Sodium | | b-Glucosidase |
| Calcium | | Phosphatase |
| Soluble boron | | Urease |
| | | Ammonia nitrogen |

### 4.1. Main results and next investigations

The research has been completed in November 2001, the main results are reported below.

A change in the hydraulic properties (conductivity and dispersivity) has only been observed in the first layer (first 20 – 25 cm), with a reduction in the soil's conductivity and diffusive properties at saturation, after the irrigation cycles with the wastewater. This behaviour, which was present at all profiles, though in different entities, should be assessed carefully when planning to use the resource, but at the same time the fact that it is confined to the most superficial layer, that is the layer most subjected to tilling, is encouraging and to the advantage of easier and less costly corrective measures.

It has been observed that the soil works as an effective "filter" of microbiological pollutants, with removal levels of 100% also in the presence of high input loads.

As regards chemical pollutants, no particular problems have been observed not even with the much-feared nitrates. Some care on the other hand should be dedicated to the tendency of the soil to accumulate boron, which is phytotoxic at elevated concentrations. In fact in four out of five profiles the boron concentration at the outlet is considerably lower than the input concentration.

No particular phenomena of metal accumulation have been observed.

As pointed out previously, experimental laboratory work will be followed by field experimentation with continuous monitoring for at least 3-4 years on 5 experimental plots that will be located in the areas where the lysimetric columns used in the laboratory have been sampled. It is considered indispensable in fact, also in the light of the encouraging results obtained in the laboratory, to monitor continuously and for a sufficiently representative period the real field situation in the presence of crops and of natural irrigation cycles of rain and evapotranspiration.

## 5. PUBLIC ACCEPTANCE, CONSUMER ATTITUDES

In the case of recycling, besides evaluating the technologies, the standards, the costs, and the management structures, it must also be considered the modalities of application. These must not only be checked on the soils, but also adapted to the context of experience of the social groups and to the culture and history of the user communities. Since we are dealing with recycled water, the problem is that of guaranteeing quality, and obviously not on purely technical grounds, because we do not know the judgement of public opinion and what possible negative reactions to the project may arise.

The risk is that the investments and work may be wasted if the farmers and the consumers were to refuse to use the resource.

To this purpose, an effective management of the resource requires an understanding of the relationship of the project with the environmental, social, economic, and technical components of the local system. The study has been carried out with the cooperation of the Politic Science Department of the University of Cagliari with the aim of taking into account the public perception issues into the water recycling management strategy.

This paragraph reports the main results that emerged from the study.

The issues that emerged in the focus group were formalised in a questionnaire. After processing the data reported on the 120 questionnaires distributed among the irrigation firms of the southern Campidano plane, some important issues emerged.

First of all recycled water as a form of irrigation is widely accepted by the farmers, purified wastewater is believed to be safer than river water. Awareness of the water crisis is probably the reason to be associated with acceptance of the recycled water (Figure 6).

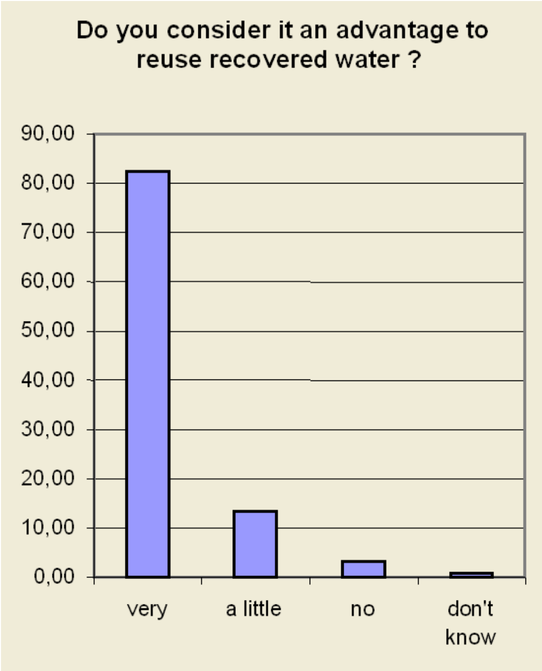


Figure 6. Public acceptance

Furthermore a strong concern about the sale of products, especially vegetables is emerged. The farmers must be able to overcome the resistance through positive concrete evidence from the consumers and the retailers that there will be a market for the products cultivated with the recovered water. This calls for a survey and an adequate information strategy (Figure 7).

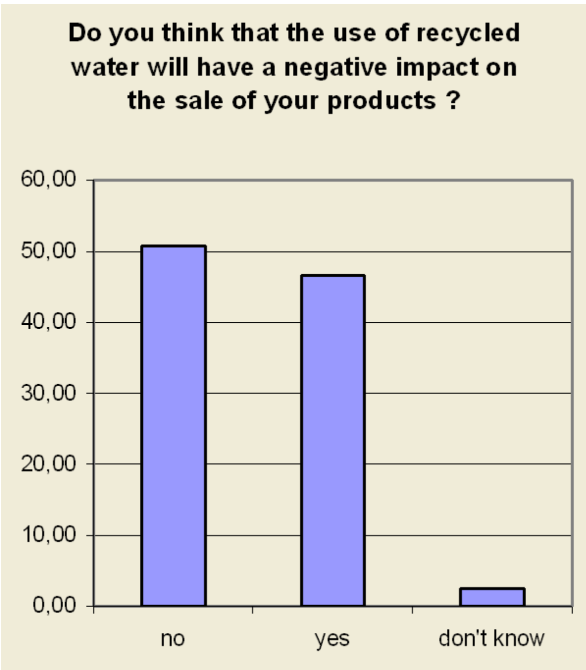


Figure 7. Public acceptance

## 6. CONCLUSION

The main objective of this case study was to analyze water quality from the Is Arenas wastewater treatment plant and to compare it with water quality in existing raw water reservoir. Another important aim of this case study was to determine the effects of irrigation with treated wastewater on the hydraulic properties of soil and to investigate potential soil and groundwater pollution. Results from in situ and laboratory analyses demonstrated the lack of major adverse effects on soil and groundwater. Cost analysis of wastewater reuse for irrigation resulted in price figures equivalent to those from freshwater supply. Public acceptance surveys have pointed out some issues of concern in the use of treated wastewater, regarding mainly impacts on the environment, produce quality and water savings.

As a general consideration, results from the presented case-studies encourage to a larger development of treated wastewater reuse in agriculture, as a sound solution to water scarcity problems and environment protection issues, but, on the other hand, the study has even demonstrated the importance of an adequate information. Even the strictest standards and the most accurate research if kept within the closed circle of researchers, may be destined to fail and on their own they are not sufficient to dispel possible fears in the absence of adequate information.

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