ENVIRONMENT INSTITUTE

ENTE
AUTONOMO
DEL FLUMENDOSA

THE APPLICATION OF ALTERNATIVE TECHNIQUES FOR THE RECOVERY OF WATER FROM EFFLUENTS FOR REUSE

JOINT
RESEARCH
CENTRE
EUROPEAN COMMISSION

2000

EUR 19645 EN

ENVIRONMENT INSTITUTE

ENTE
AUTONOMO
DEL FLUMENDOSA

THE APPLICATION OF ALTERNATIVE TECHNIQUES FOR THE RECOVERY OF WATER FROM EFFLUENTS FOR REUSE

H. Muntau, S. Vacca*, A. Virdis*, P. Botti*, M. Bianchi, V. Lazarova**

Environment Institute, Joint Research Centre, Ispra (Italy)
**Ente Autonomo del Flumendosa, Cagliari (Italy)*
***Lyonnaise des Eaux, Le Pecq-Sur-Seine, (France)*

JOINT
RESEARCH
CENTRE
EUROPEAN COMMISSION

2000

EUR 19645 EN

TABLE OF CONTENTS

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. The actions envisaged consisted essentially in the following:

- reduction of losses during transport and distribution;
- creating separate water distribution networks for municipal and irrigation uses;
- introduce water reuse, especially the effluents from traditional sewage treatment plants.

With regard to the latter, the master water plan drawn up for Sardinia in 1986 estimated that 350 millions m^3 of effluents would be produced each year by the sewage treatment plants currently operating on the island as well as those planned. Of these, the plant at Is Arenas which serves the city of Cagliari and its suburbs, produces every year about 35 millions m^3/year of effluents, which is predicted to rise to 60 millions m^3/year over the next few years. At present the effluents are not reused but are discharged at the sea.

In Sardinia, these effluents represent the major alternative potential water resource, for instance for irrigation supplies, and recycling them could contribute significantly to a more rational use of water resources as a whole. Although there would be a number of alternative uses for these effluents (agricultural, industrial, environmental or for groundwater recharge), their usage in agriculture is the most important in a Mediterranean context in as much as irrigation water accounts for the greater part of demand. In the light of the above, and within the framework of the programme of local government and EU funded actions for coping with the water supply emergency that has arisen over the last ten years, Ente Autonomo del Flumendosa (E.A.F.) in cooperation with the Environment Institute has started and pursued a scheme for reusing the effluent produced by the Is Arenas wastewater treatment plant.

2 REUSING WASTEWATER IN AGRICULTURE

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 shall act as storage basin prior to the reuse of the polished effluents. The collected cleaned effluents shall be 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.

This project shall allow the reclamation and reutilization of the wastewater effluent from the Is Arenas plant for irrigation purposes either with direct or indirect methods. In the next years, about 43 Mm^3/year of Is Arenas effluents will be recycled in irrigation areas of Southern Sardinia. As illustrated in figure 1, the project consists of two main interventions:

- To connect the wastewater treatment plant of Is Arenas with the reservoir (called Simbirizzi) which will be used as a big storage tank (some 20 millions m^3 of capacity) for the water to be reused for irrigation purposes, when the indirect reuse is applied.
- To construct a tertiary treatment line for the effluents from Is Arenas plant with the two aims of **indirect reuse** of the effluent in irrigation, where the process must be capable of reducing the phosphorus (P_{tot} around 2.5 mg/l) to sufficiently low levels for preserving the already precarious trophic state of the Simbirizzi reservoir (P_{tot} around 0.2 mg/l) as well as the bacteria

3 IS ARENAS WASTEWATER TREATMENT PLANT (Primary and Secondary treatment)

The Is Arenas sewage treatment plant serves the city of Cagliari and its suburbs and has a capacity of 35 Mm^3/year which is predicted to rise to 60 Mm^3/year over the next few years.

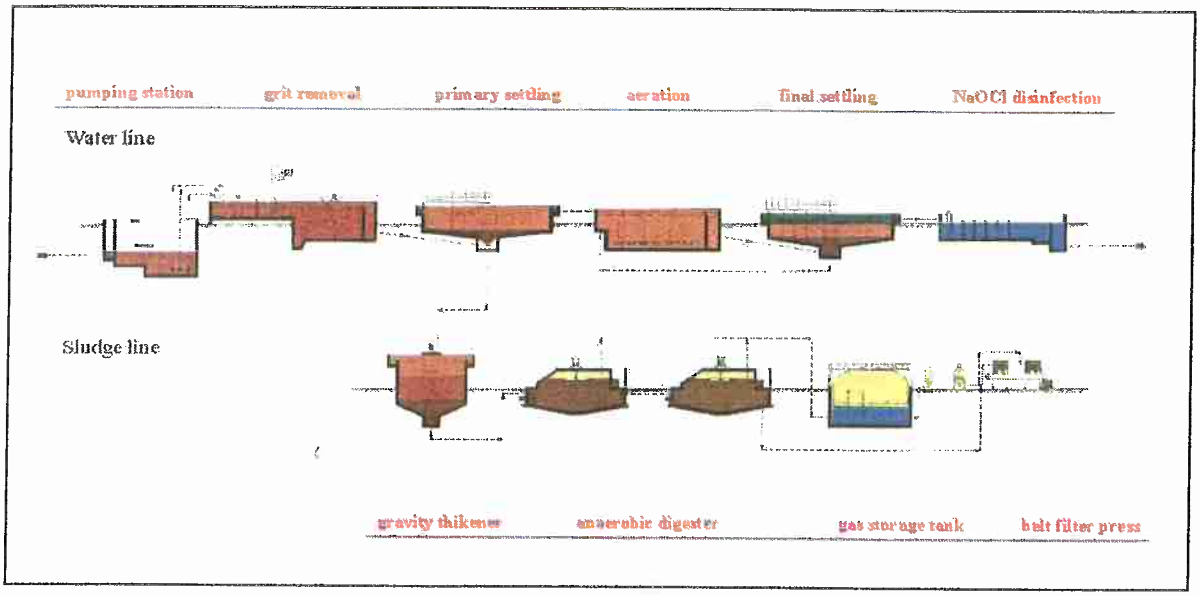


***Figure 2**: The Is Arenas wastewater treatment plant*

Figure 2 reports the scheme of the Is Arenas sewage plant. The process is mainly constituted by a grit removal, a primary settling, a biological process, a secondary settling and, at last a chlorine treatment. At present, the effluents are not reused but are discharged at sea.

4 THE TERTIARY TREATMENT LINE

Figure 3 reports the scheme of the tertiary treatment line at present in construction close to the Is Arenas plant.

In case A the treatment line consists mainly of a flocculation unit, with ferric chloride as a flocculant agent, followed by a filtration unit and a disinfection unit on chlorine dioxide basis.

In case B the treatment line consists mainly by a combined process of filtration, disinfection with UV rays and chlorine dioxide.

The first module of the tertiary treatment line, foreseen in the project, will be concluded at the end of the current year. For the next year the start up of the plant is scheduled as well as the first experimental section concerning the recycling of the water.

The produced chemical sludge coming from the chemical precipitation with ferric chloride will be dewatered and disposed at a controlled sanitary landfill.

The first three aspects will be examined in the following paragraphs, and the latter two later on in this report.

5.1 Water Quality: Exploratory studies on sewage treatment plant effluent quality of Southern Sardinia and multiannual quality monitoring of Is Arenas effluents

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 therefor 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.

In this context we have to bear in mind that the effluent is essentially a diluted multi-component chemical solution and after its application to soil and the subsequent evaporation of water, all dissolved or colloidal components of the effluent, with the exception of small amounts of volatile compounds, shall crystallize and/or adsorb onto soil particles.

While a number of inorganic compounds 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.

Trace metals are transported by the wastewater in sometimes astounding proportions and the larger the city, producing the waste water is, the more complete is the occurence of elements with reference to the periodic table.

Excess iron , not bound by phosphates shall form oxihydrates along with similar manganese compounds, which will act as scavengers for quite a series of not really harmless metals such as As, Se, Ni, Cu; Pb, Tl, Cd and others and after having reached higher concentration levels after some years of effluent application, chelators, such as carboxy acids formed by decomposing organic matter either in the water treatment plant or the soil itself, shall solubilize the metals again, ready for uptake by the crop the formation of organometallic compounds through microbiological action is also highly indicated.

Organic compounds at trace levels (µg/L to pg/L) are found in effluents in such an abundance, that hardly the presence of any compound can be excluded on a *a priori* basis and the presence of non-desired and/or hazardous, though not identified compounds, constitutes a long-term risk for effluent reuse.

All organic matter in effluents, colloidal or dissolved, shall soon after reaching the soil layer, undergo coagulation and adsorption following to organic-matter degradation and pH-drop, and consequently immobilization, thereby reaching extremely high local concentrations. At this stage, the ingredients and boundary conditions being available, all kinds of reaction between organic molecules may occur and the presence of essentially the full periodic table of elements in wastewater of large cities and the element accumulation on relatively restricted (in proportion) soil layers following to extended effluent application, shall produce all sorts of catalytic effects on chemical reactions. Mineral phases present in the effluent-receiving soil show well known catalytic effects as well. Although effects are hard to predict due to the multitude of organic compounds present in effluents and soil, the European Commission considers at present much tighter sewage sludge spreading rules, which include for the first time a large series of organic trace compounds.

On the basis of these considerations, it is highly advisable to extend the table of monitorands as much as feasible in order to reduce the residual risks. Organic trace compounds should be pre-concentrated from larger water samples prior to GC-MS analysis and the spectra carefully stored for later identification of hitherto unknown compounds.

With regard to the effluents of Is Arenas, which are the subject of the present study (all results, methods and related statistics are collected in Final Contract Report, Vol 2, October 1999), the results can be summarized as follows (table.1):

- Total organic carbon concentrations, with few exceptions in winter time, are fairly constant over time (Fig. 4), while the examined single compounds show large scattering. Volatile halogenated compounds, such as chloroform, bromoform, bromodichloromethane, dibromochloromethane, dibromomethane and tetrachloroethylene occur sometimes at high concentrations (Fig.12-15), up to total VOX concentrations of 1040 µg/L. Up to nine different PAH's were detected, though at low concentrations in the order of up to 0.30 µg/L.
- Benzidine was found up to 3.0 µg/l and also 3,3'-dichlorobenzidine. Phenol and a number of substituted phenols such as 2,4-dichlorophenol, 4-chloro-3-methyl-phenol and pentachlorophenol were present at concentrations up to 0.4 µg/L.
- 4-Nitro-phenol appeared once (1.34 µg/L). Besides a number of aliphatic hydrocarbons from C10 upwards, quite a number of pesticide residues are present, as well as several substituted phthalates (Fig.15).
- Amongst the metals, zinc (Fig. 16) reaches concentrations of up to 250 µg/L; other metals appear according to quite irregular patterns. Barium and aluminium reach concentrations close to critical limits (Fig. 19 and 23), while arsenic appeared in the effluents after a certain date (from a single point source?) and taking into account its cancerogenic potential, its origin shall be investigated (Fig. 21).
- There is a periodical occurence of chromium and nickel (Fig. 18), both elements obviously being correlated, probably due to their origin from common sources.
- Most critical, in view of the reuse of the Is Arenas effluents, are the concentrations of simple salts (Fig. 11), sodium chloride first of all. The periodical appearance of high conductivity values (Fig. 5), accompanied by high concentrations of sulphate (Fig. 6), 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 shall take the appropriate counter measures.

In the greater framework of the long-term strategy of the Regional Government Sardinia, which considers reuse of effluents from wastewater treatment plants on the full Sardinian scale, the quality of effluents from an additional number of 34 wastewater treatment plants was assessed and the largest eight of them were given an eight month exploratory monitoring. The effluent quality was in many cases promising and in some cases such as to allow even direct reuse after some corrective measures. The results are available from EAF. (EI Final Contract Report, Vol. 2 and 3, October 1999).

Table 1: Multiannual monitoring of the Is Arenas effluents. List of monitorands (continuation)

Parameter	Unit	Data	Number of determinations	Min	Max	Mean	Median	RSD %
Bis(2-chloroethyl)ether	[µg/l]	41	0	-	-	-	-	-
Bis(2-chloroisopropyl)ether	[µg/l]	41	1	0.01	0.01	0.01	-	-
Bis(2-ethylhexyl)phtalate	[µg/l]	25	21	0.19	1.32	0.56	0.49	57.70
4-Bromophenylphenylether	[µg/l]	41	1	0.09	0.09	0.09	-	-
Butylbenzylphtalate	[µg/l]	36	6	0.08	0.45	0.26	0.26	51.55
4-Chlorophenylphenylether	[µg/l]	41	1	0.12	0.12	0.12	-	-
Diethylphftalate	[µg/l]	25	2	0.55	0.66	0.61	0.61	12.86
Dimethylphtalate	[µg/l]	34	4	0.05	2.35	0.64	0.08	179.10
Di-n-butylphtalate	[µg/l]	34	28	0.07	2.67	0.52	0.28	129.51
Di-n-octylphtalate	[µg/l]	36	4	0.09	0.54	0.38	0.46	53.28
N-Nitrosodi-n-propylamine	[µg/l]	36	0	-	-	-	-	-
N-Nitrosodiphenylamine	[µg/l]	36	0	-	-	-	-	-
Azobenzene	[µg/l]	36	1	0.03	0.03	0.03	-	-
Carbazole	[µg/l]	36	3	0.01	0.05	0.03	0.03	66.67
2-Chloronaphtalene	[µg/l]	36	1	0.02	0.02	0.02	-	-
1,2-Dichlorobenzene	[µg/l]	36	2	0.02	0.02	0.02	-	-
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	-	-
2,6-Dinitrotoluene	[µg/l]	36	2	1.74	1.83	1.79	1.79	3.57
Hexachlorobenzene	[µg/l]	36	0	-	-	-	-	-
Hexachlorobuadiene	[µg/l]	36	0	-	-	-	-	-
Hexachlorocyclopentadiene	[µg/l]	36	0	-	-	-	-	-
Hexachlorethane	[µg/l]	36	0	-	-	-	-	-
Isophorone	[µg/l]	36	1	0.05	0.05	0.05	-	-
Nitrobenzene	[µg/l]	36	0	-	-	-	-	-
1,2,3-Trichlorobenzene	[µg/l]	36	0	-	-	-	-	-
Aldrin	[µg/l]	36	1	0.4	0.4	0.4	-	-
Alpha-BHC	[µg/l]	36	1	0.32	0.32	0.32	-	-
Beta-BHC	[µg/l]	36	0	-	-	-	-	-
Gamma-BHC	[µg/l]	36	1	0.43	0.43	0.43	-	-
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	-	-
4,4-DDE	[µg/l]	36	1	0.09	0.09	0.09	-	-
4,4-DDT	[µg/l]	34	1	0.26	0.26	0.26	-	-
Dieldrine	[µg/l]	36	2	0.12	0.22	0.17	0.17	41.59
Endosulfan1	[µg/l]	36	0	-	-	-	-	
Endosulfan2	[µg/l]	36	1	7.61	7.61	7.61	-	-
Endosulfan sulfate	[µg/l]	36	0	-	-	-	-	
Endrin	[µg/l]	25	0	-	-	-	-	
Endrin aldehyde	[µg/l]	25	0	-	-	-	-	-
Endrine ketone	[µg/l]	36	0	-	-	-	-	-
Heptachlor (isomer B)	[µg/l]	36	0	-	-	-	-	-
Methoxychlor	[µg/l]	36	1	0.11	0.11	0.11	-	-
2-(PCB)	[µg/l]	36	0	-	-	-	-	-
2,3-(PCB)	[µg/l]	36	1	0.06	0.06	0.06	-	-
2,4,5-(PCB)	[µg/l]	25	0	-	-	-	-	-
2,2',4,4'-(PCB)	[µg/l]	25	0	-	-	-	-	-
2,2',3',4,6-(PCB)	[µg/l]	25	0	-	-	-	-	-
2,2',4,4',5,6'-(PCB)	[µg/l]	25	0	-	-	-	-	-
2,2',3,3',4,4',6-(PCB)	[µg/l]	25	0	-	-	-	-	-
2,2',3,3',4,5',6,6'-(PCB)	[µg/l]	25	0	-	-	-	-	-
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	-	-
2-Methylphenol	[µg/l]	39	3	0.02	0.04	0.03	0.02	43.30
2,4,5-Trichlorophenol	[µg/l]	39	0	-	-	-	-	-
Phenol	[µg/l]	39	0	-	-	-	-	-
Benzoic acid	[µg/l]	34	1	0.16	0.16	0.16	-	-
2-Chlorophenol	[µg/l]	39	0	-	-	-	-	-
2,4-Dimethylphenol	[µg/l]	30	0	-	-	-	-	-
2,4-Dichlorophenol	[µg/l]	39	2	0.02	0.02	0.02	0.02	0.00
4-Chloro-3-methylphenol	[µg/l]	39	3	0.02	0.39	0.15	0.04	138.72
2-Methyl-4,6-dinitrophenol	[µg/l]	39	0	-	-	-	-	-
Pentachlorophenol	[µg/l]	39	1	0.28	0.28	0.28	-	-
2-Nitrophenol	[µg/l]	19	0	-	-	-	-	-
4-Nitrophenol	[µg/l]	39	1	1.34	1.34	1.34	-	-
2,4-Dinitrophenol	[µg/l]	39	0	-	-	-	-	-

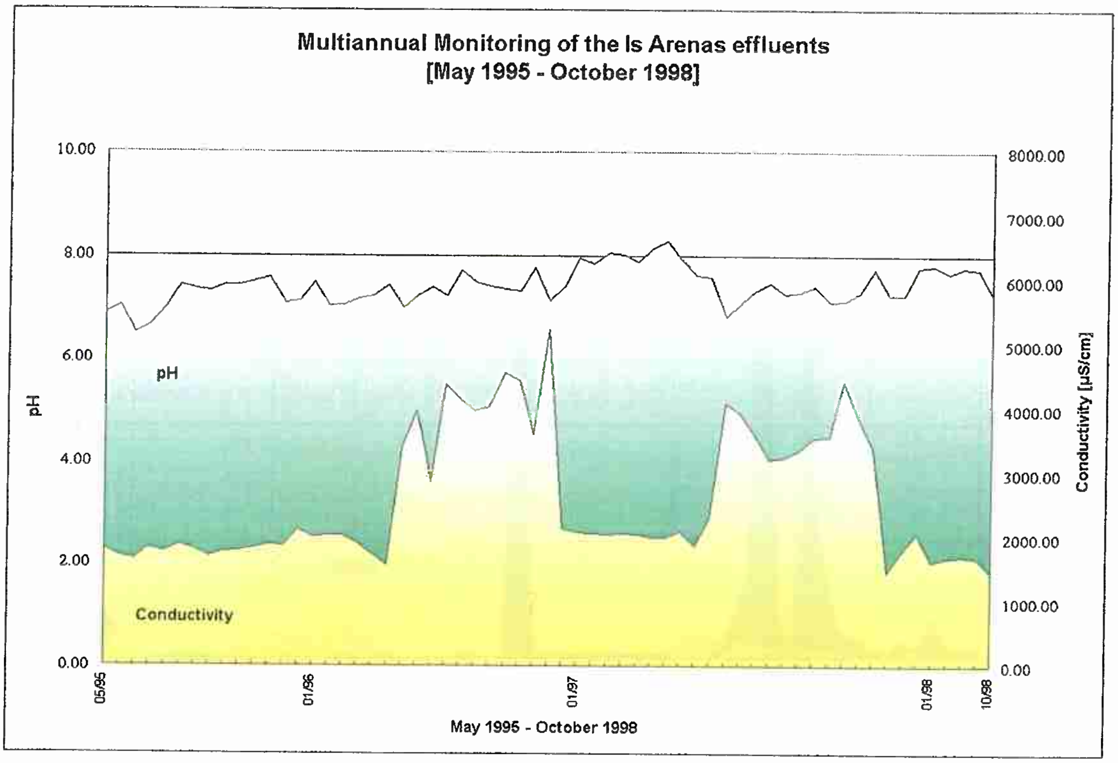


Figure 5: pH and conductivity of Is Arenas effluents

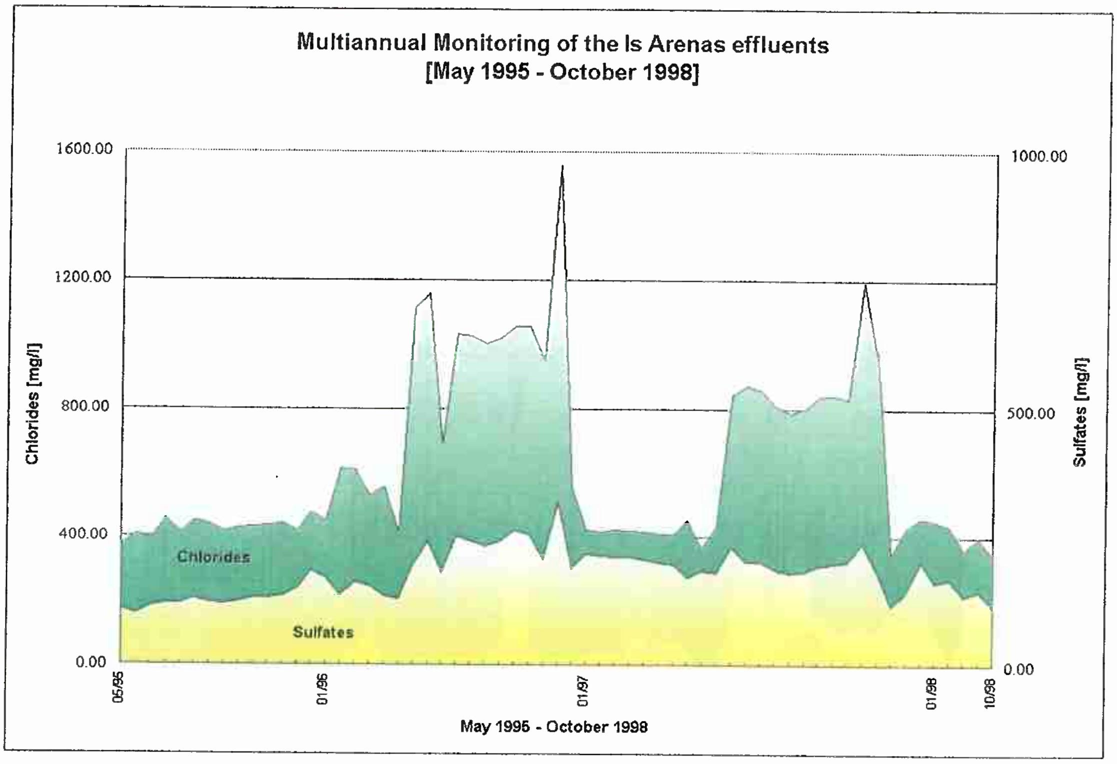


Figure 6: Chlorides and sulphates in Is Arenas effluents

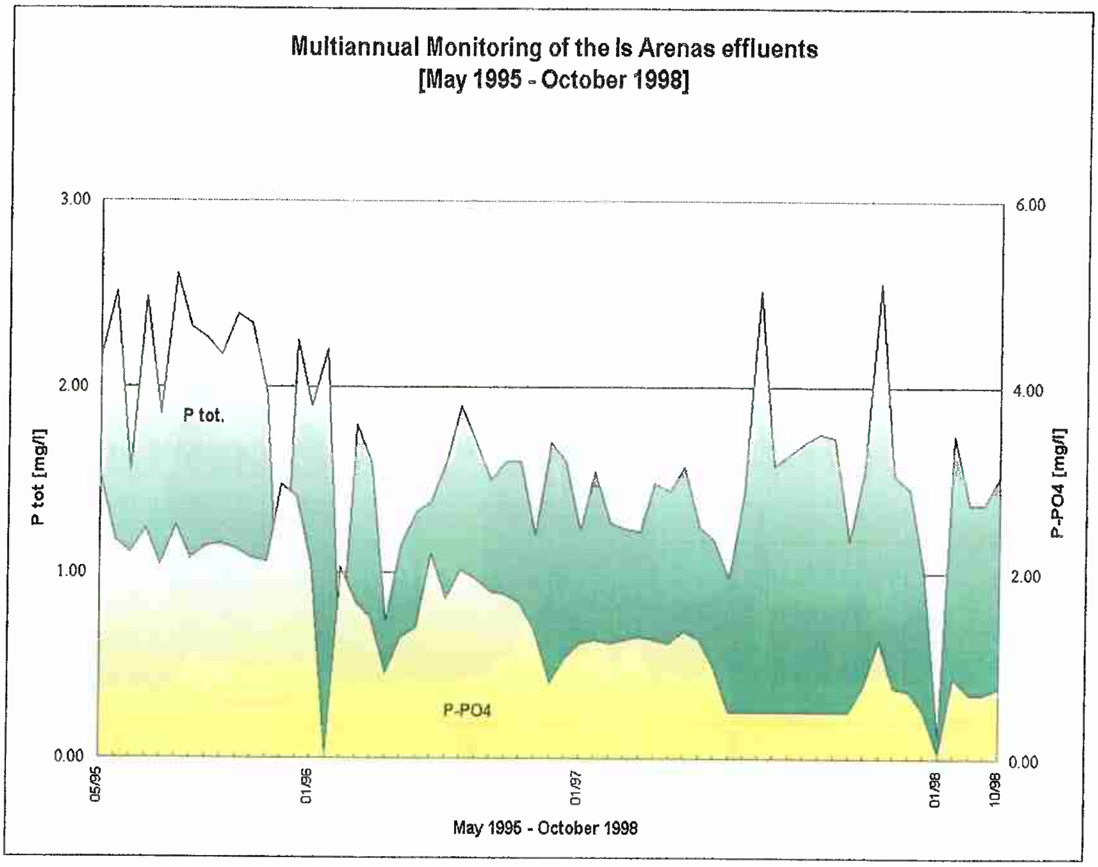


Figure 9: *Ptot and P-PO$_4$ in Is Arenas effluents*

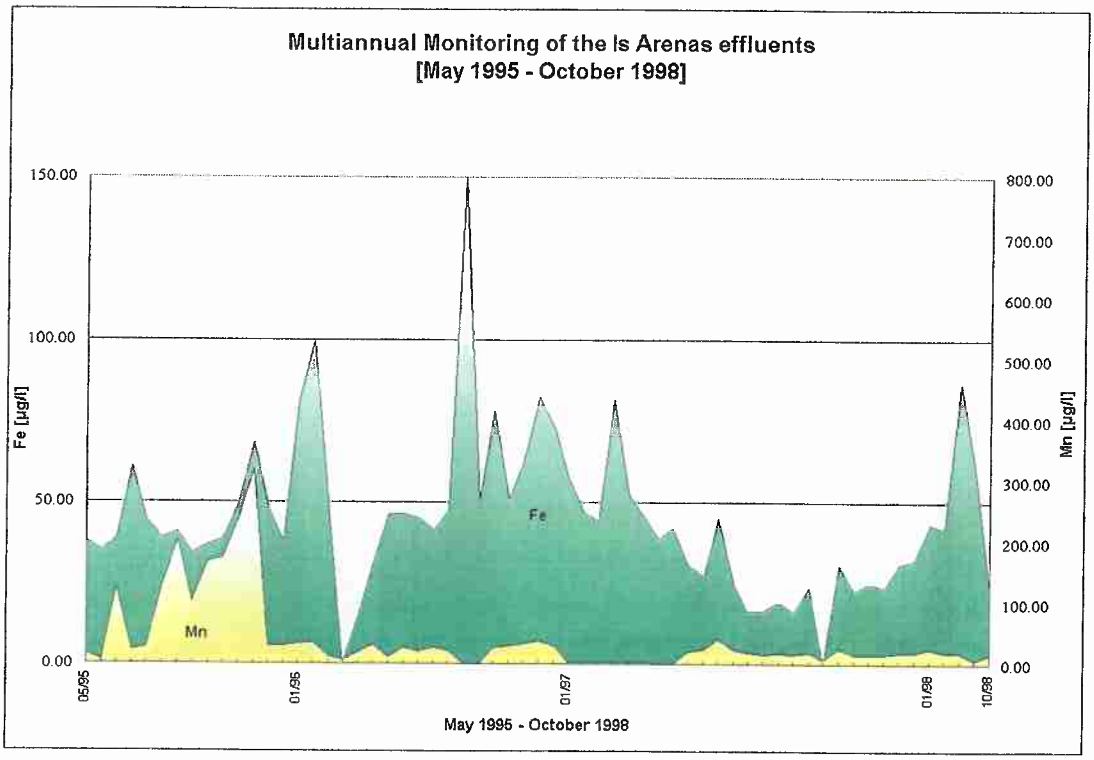


Figure 10: *Fe and Mn in Is Arenas effluents*

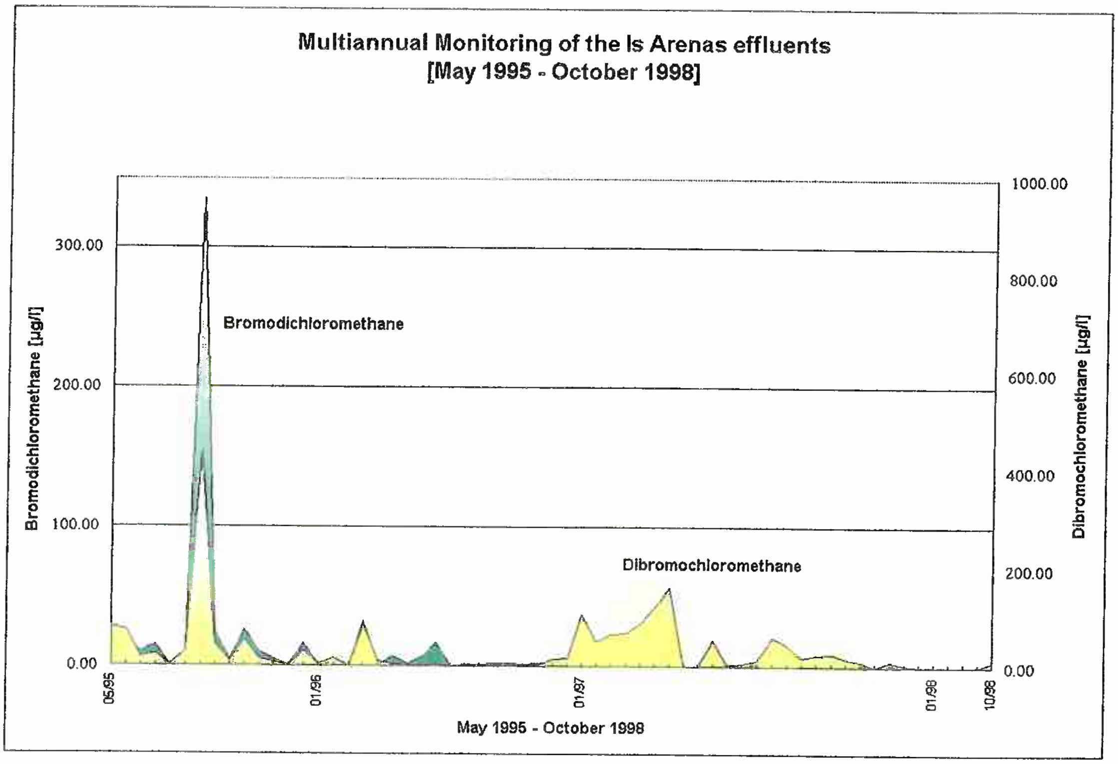


Figure 13: Bromodichloromethane and dibromochloromethane in Is Arenas effluents

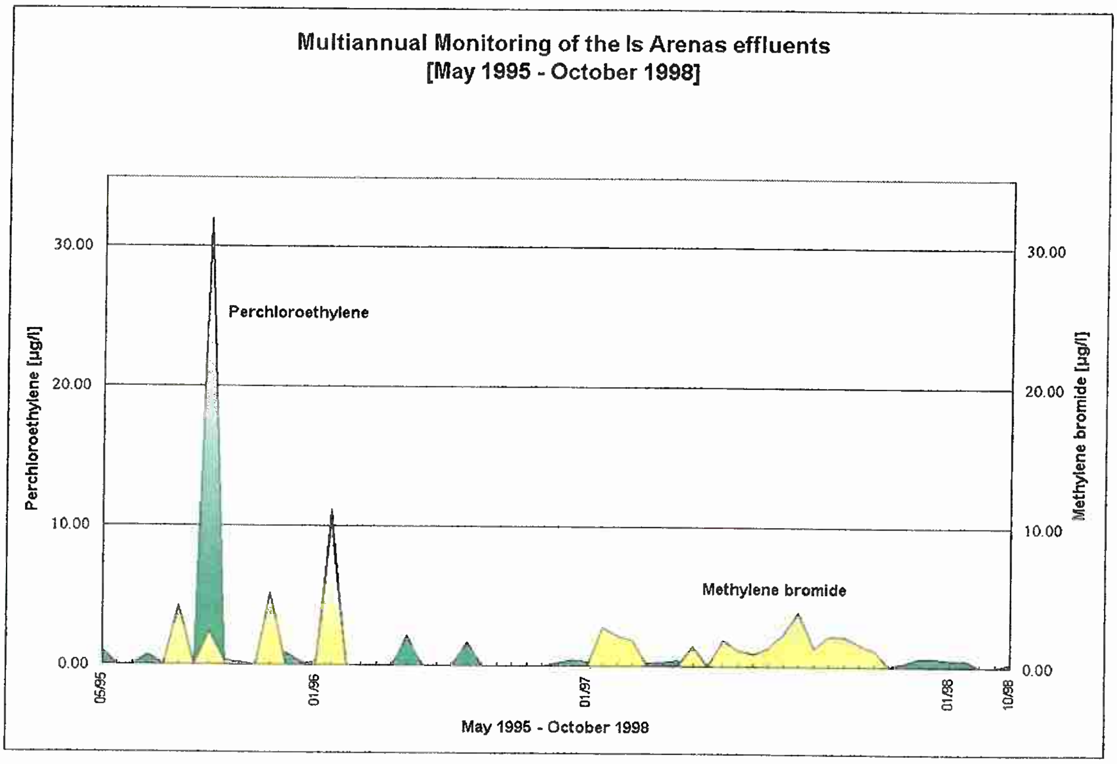


Figure 14: Perchloroethylene and methylene bromide in Is Arenas effluents

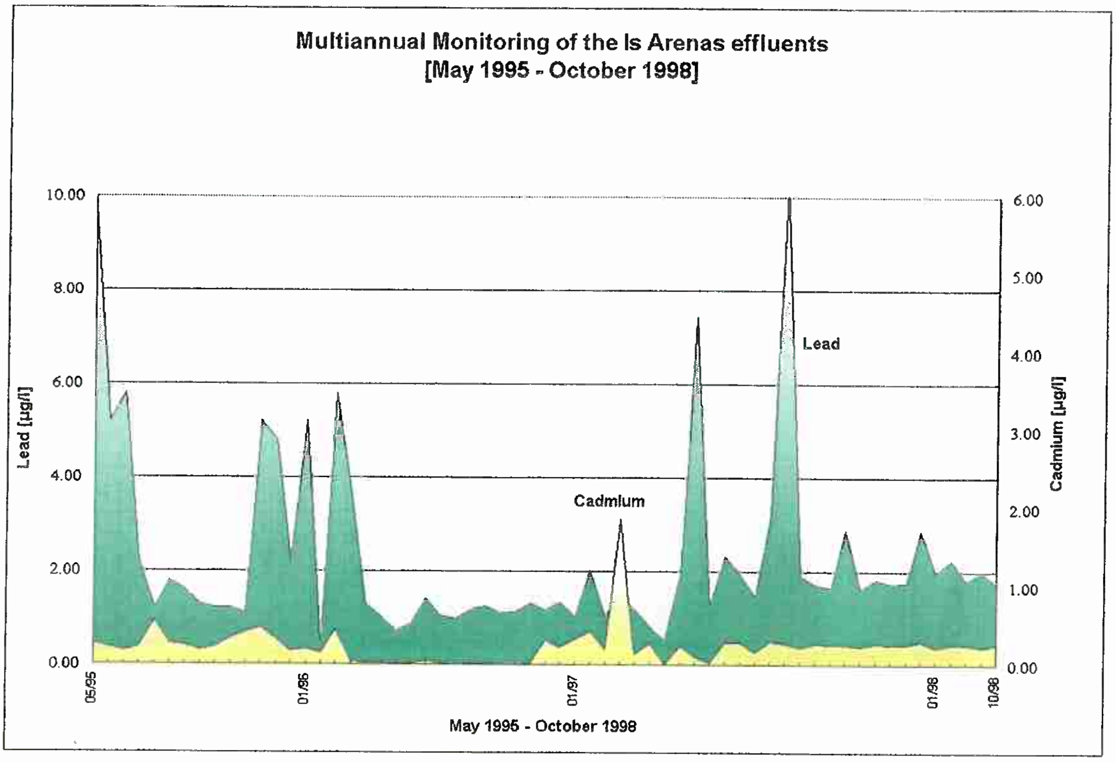


Figure 17: Cadmium and lead in Is Arenas effluents

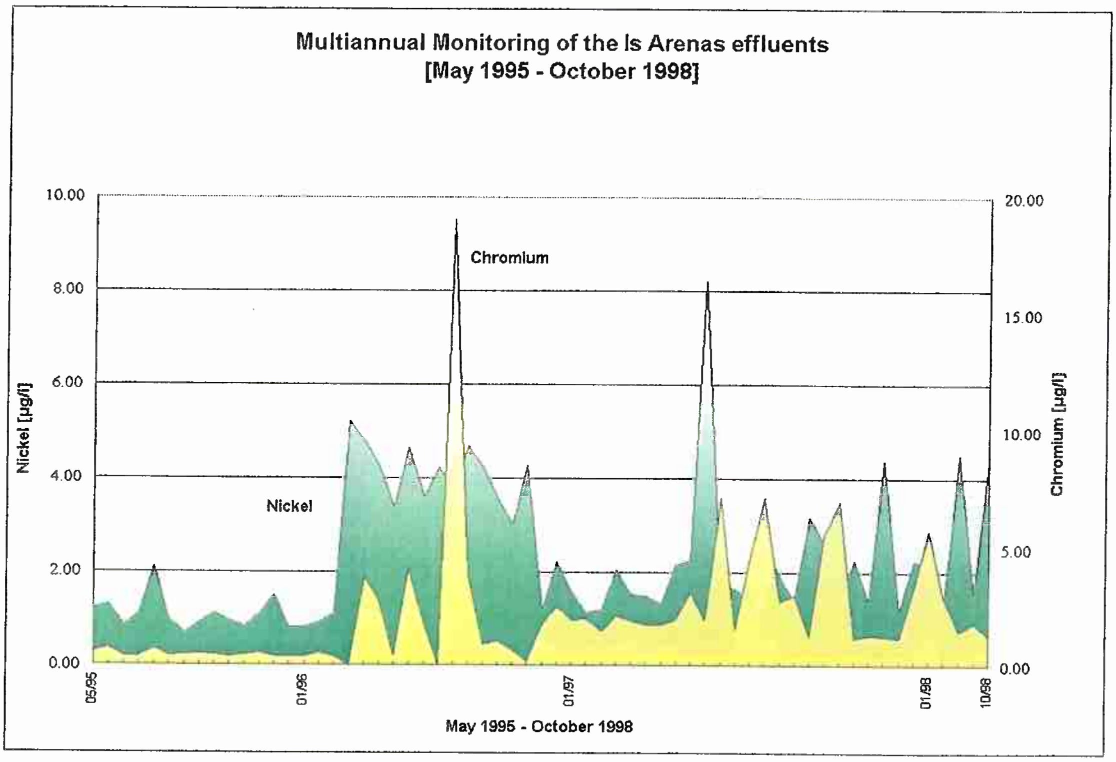


Figure 18: Nickel and chromium in Is Arenas effluents

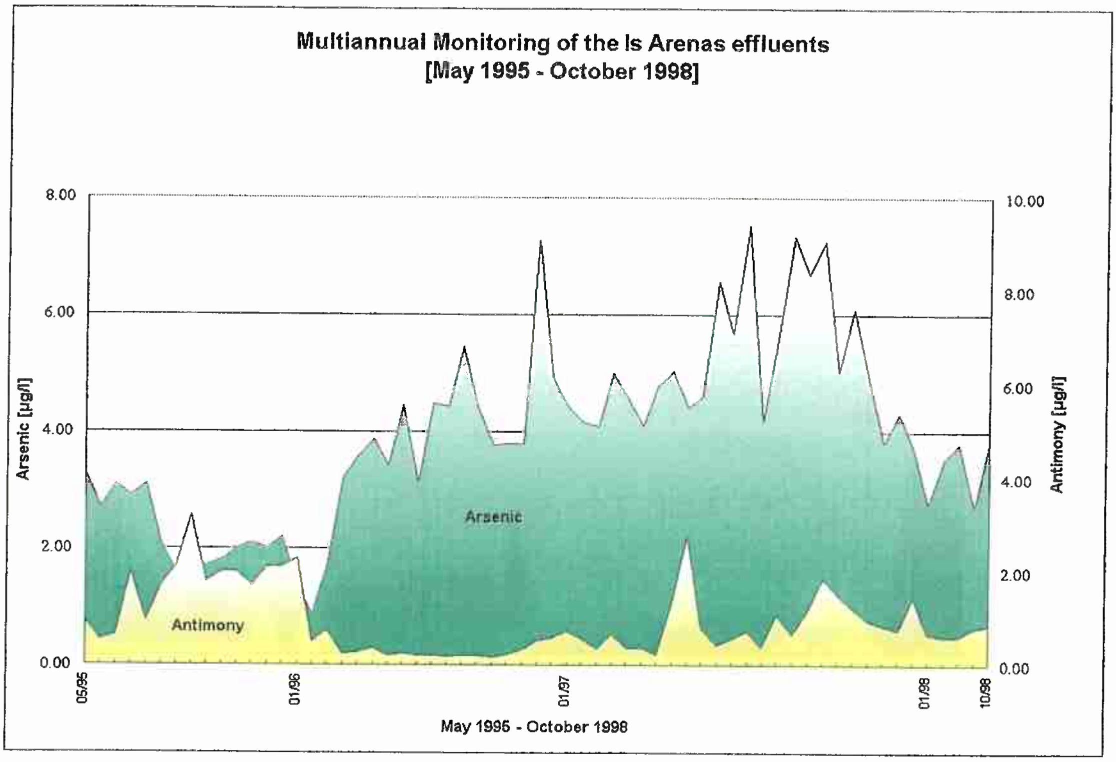


Figure 21: Antimony and arsenic in Is Arenas effluents

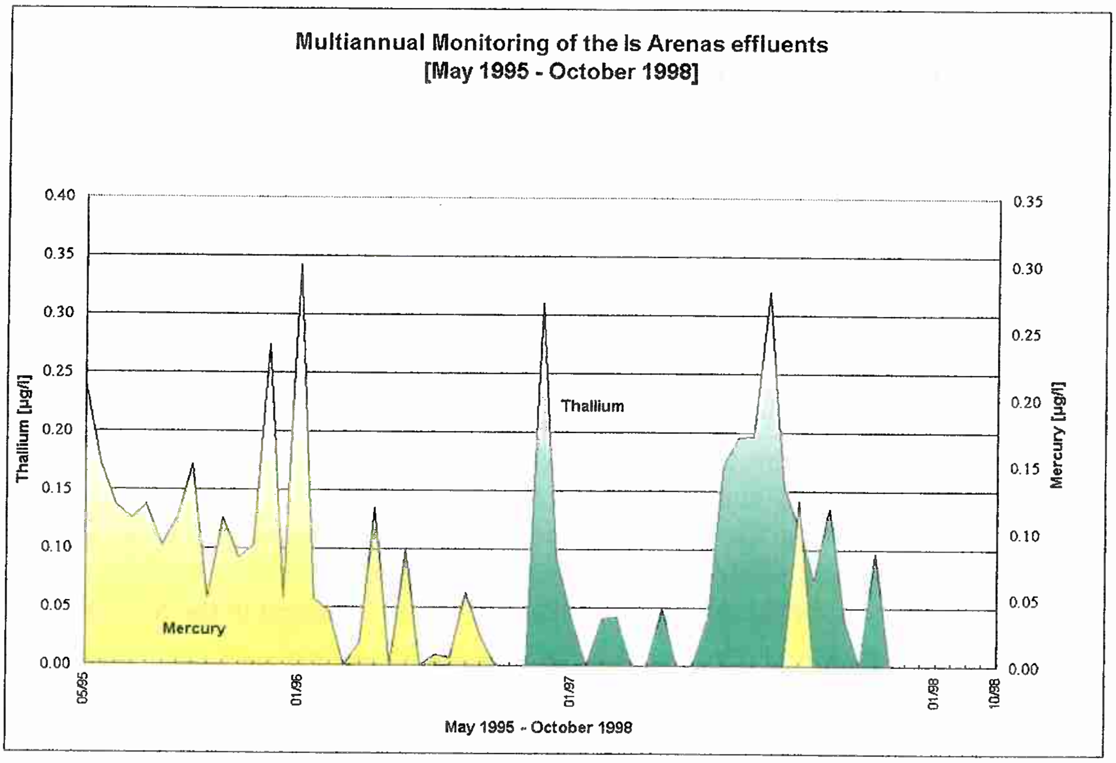


Figure 22: Mercury and thallium in Is Arenas effluents

Line B is for chemical treatment where the waters coming from line A are oxidised by means of ozonation followed by finishing treatment on activated carbon filters.

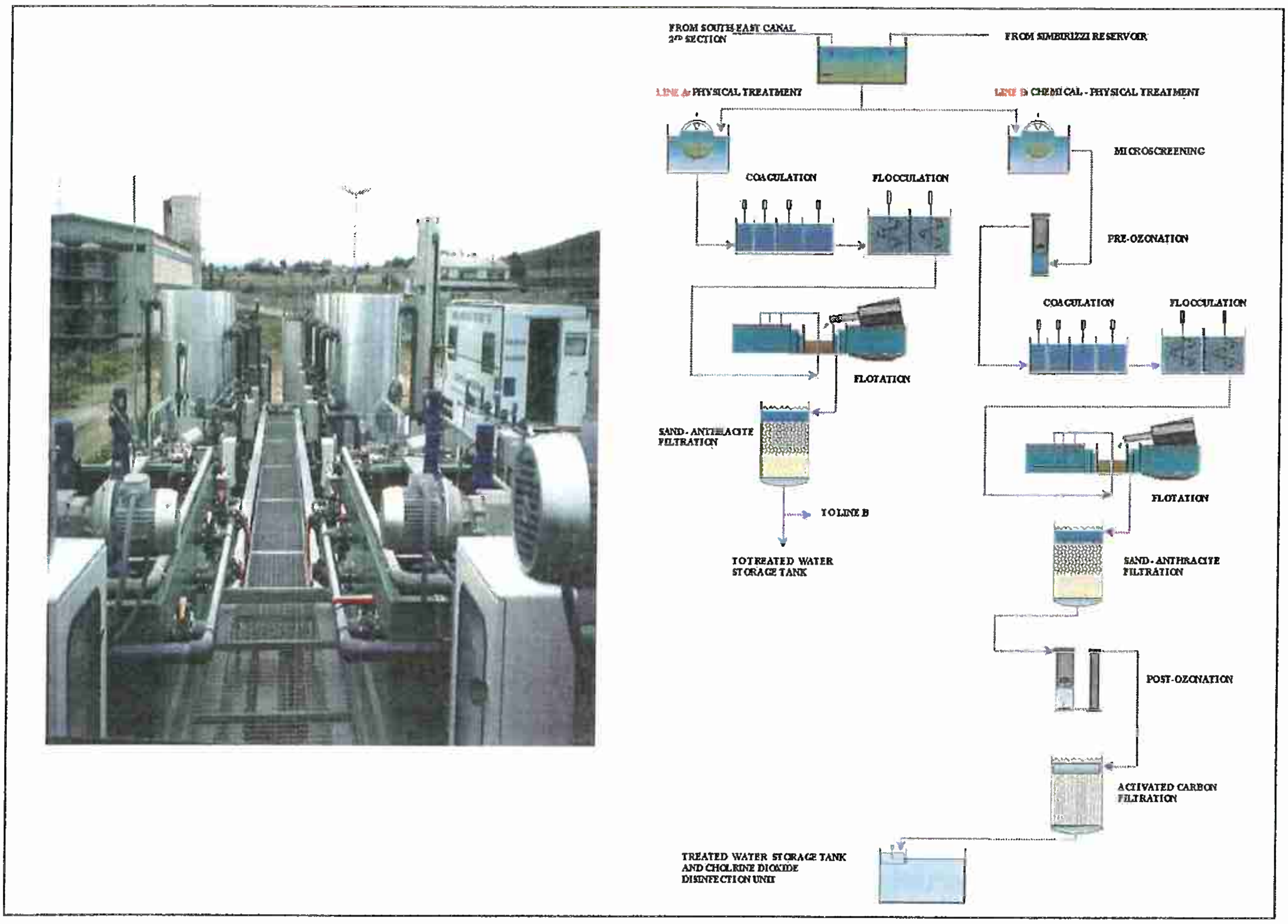


***Figure 24:** The Simbirizzi pilot plant photo and flow sheet*

The process units as depicted in figure 24 are briefly described below:

MICROFILTRATION: Consisting of two microfiltration devices, one on stand-by, which can be fitted with filters of various mesh sizes 5-10-15-20-25-30 μm. Here the efficiency of segregating the algae species present is evaluated as well as any improvements microfiltration may have on the process units downstream.

PRE-OZONATION: Consisting of a cylindrical ozone generator where the ozone, in gaseous form is transferred by means of a porous diffuser into the liquid mass. Here the influence of preozonation on the successive stages is studied.

DESTABILIZATION: Consisting of four tanks of various sizes for obtaining different water residence times (5-10-15-20 s) each fitted with a variable speed agitator so as to evaluate optimum degree of mixing.

AGGREGATION: Consisting of two flocculation tanks of the same size operated independently or in parallel to double the residence time. Each tank is equipped with a helical variable speed agitator for optimising the degree of mixing and maximising floc size.

FLOTATION: Consisting of a dissolved air flotation tank Air is supplied to the tank by means of a system that pressurises part of the treated water. This unit ensures the removal of large proportions of the phytoplankton.

In the first phase of the tests ferric chloride was added in amounts on average of 25 mg/l. For higher proportions, which involved larger suspended solids content, it was also necessary to resort to the flotation stage upstream from the filtration section for solid-liquid separation.

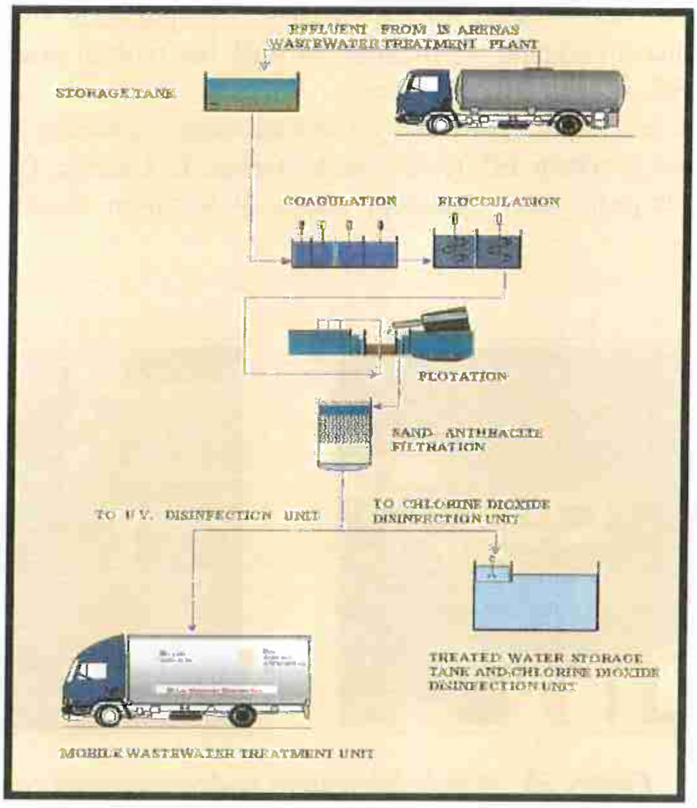


***Figure 25**: De-phosphatization Pilot Plant and Mobile Wastewater treatment unit.*

Lastly the filtered water was disinfected with chlorine dioxide and then stored in a tank for about two hours. The total residual chlorine recorded at the outlet was always below 0.1 ppm.

To assess the efficiency of the pilot plant process, samples were collected from each stage four times a day. Because of the strong variability of the water supplied to the dephosphatization section, it was necessary to take into account the residence time in each process unit.

5.2.3 Application of cross-flow membrane filtration and catalyzed photo-oxidation and the experimental set-up for *in-situ* effluent cleaning studies

In order to extend the water reuse feasibility studies to as many as effluent sources as possible throughout Sardinia and to avoid on the other hand effluent quality changements during transport from the source to the laboratory, it was decided to design and construct a mobile waste water treatment unit, based on a compact combination of cross-flow membrane filtration at micro- and ultra pore size level, with catalyzed photo-oxidation (CFMT-CPO), two advanced wastewater treatment techniques which are since several years under study at the Environment Institute's laboratories at Ispra (Niego, 1995, Tatti, 1995, Bruzzi, 1996, Borio, 1997, Moroni, 1998, Montani, 1998), summarized by Montani *et al.* (2000).

Cross-flow membrane filtration combines a number of advantages compared to to classical "chemical" processes of waste water cleaning. Particles, colloidal matter and macromolecules can be removed stepwise from the water simply by pumping it through a sequence of membranes with decreasing pore sizes, and by applying the backfeeding technique, no wastes are produced. Remaing organic molecules are destroyed by catalyzed photo-oxidation.

In the next future, the mobile unit shall be employed for the de-centralized treatment of small but toxicologically highly significant quantities of wastewater in Sardinia.

5.2.4 Tertiary treatment experiments by means of CFMT-CPO

The experiments described in the following section aimed at the backup of the data obtained on the Is Arenas effluent cleaning studies at the pilot plant and, according to the strategy explained above, to test a number of additional effluent sources in Southern Sardinia such as Decimomannu, Decimoputzu, Uta, Dolianova, Muravera and S.Vito for their reuse potential.

The effluents of Is Arenas, with approximately 30 millions of m^3 the quantitatively best and most promising effluent source of the entire island showed a grey-green colour due to the presence of micro-algae and an unpleasant odour.

The effluents were taken from the treatment plant prior to chlorination. The working conditions of the CFMT-CPO unit were the same for all of the following experiments: Sand filtration, micro-filtration at 5 µm and filtration at ultra-scale (0.2 µm), followed by CPO applying an threefold excess of hydrogen peroxide referred to the initial TOC-value.

Figure 28 shows a typical example. Sample E marks the effluent entering the CFMF-CPO unit, sample F after microfiltration (5 µm), sample G after ultrafiltration (0.2 µm) and sample H after photo-oxidation. The results of a similar treatment scheme applied to water of Dolianova showing a dark brown colour and high concentration of particulate matter, is summarized in figure 28. The residual TOC would be fully compliant with the reuse objectives.

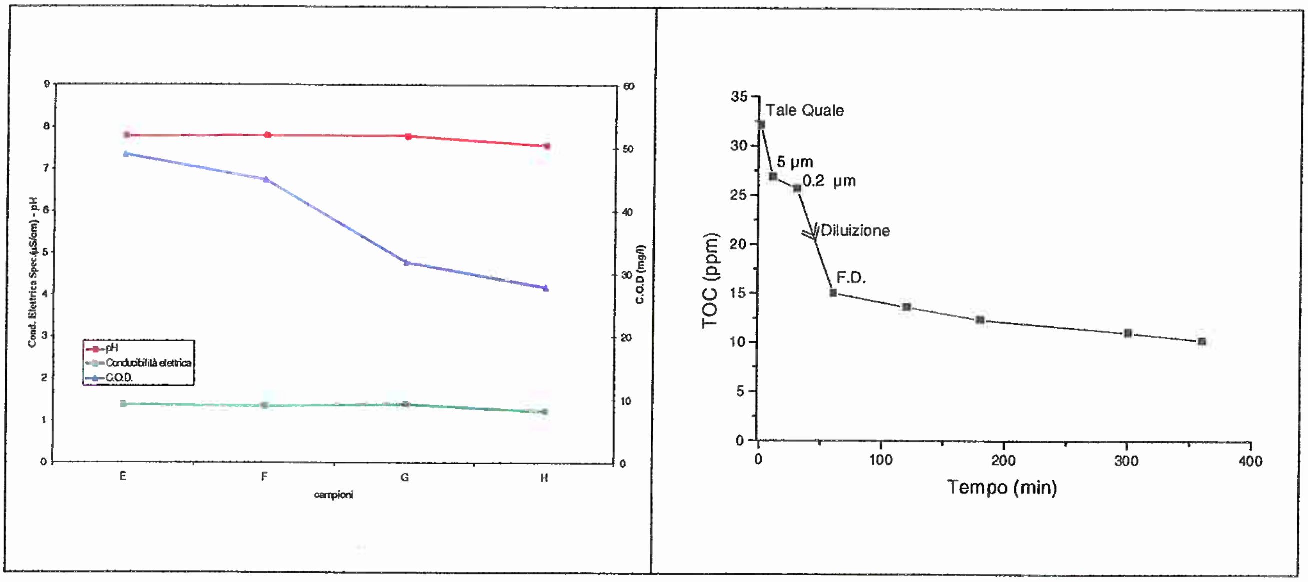


Figure 28: Treatment of effluents from Is Arenas (left) and Dolianova (right)

The reader is referred for more details on the process details and test results on several families of environmentally relevant chemicals with special regard to the water cycle to the work of Niego,1995, Tatti, 1995, Bruzzi, 1996, Moroni, 1998, Borio, 1998 and Montani, 1999.

this very thin biological film actively removes the pollutants by metabolizing the organic substances present in the wastewater, the aquatic macrophytes contribute to the treatment process by providing first of all the oxygen necessary for the oxidation process at root level, a huge surface area of microbial growth, and, last but not least, a pleasant environment.

An extended literature survey on the subject and the construction and application principles has been prepared by Kalajzic et al., 1999. In order to investigate the effects of common industrial chemicals, assumed to be present occasionally even in smaller communities, and to define upper threshold concentration levels for the safe operation of constructed reed beds, the Environment Institute constructed at Ispra a complex testing facility which consists of the following elements:

- A series of modular treatment systems of both vertical and horizontal flow mode, containing sand and gravel as well as broken and classified lava as substrates and three different kinds of submergent aquatic plants (*Phragmites communis, Scirpus lacustris* and *Typha latifolia*).Each module is fed from independent water tanks with aid of peristaltic pumps.All modules can be interconnected, thereby opening a vast variety of combinations of flow modes, different substrates and plants for the differentiated testing of single or multiple chemical compounds (Figure 32). In order to allow quantitative tests and mass balances, the complete facility is set up in greenhouse.
- An outdoor facility composed of a vertical flow system, subdivided by vertical walls into four equal subcompartments for individual feeding, connected to a horizontal flow system; the most often used *Phragmites communis* being the selected plant (Figure 33). Sizes have been selected as to create a real-world water treatment unit which might serve a 10-families condominium or a small hotel, fitness center or similar structure, operating a "grey" water scheme.

Following to the full adaptation of the plants along an entire vegetation period,during 1999 an extended experimental activity was started testing the degradation of common chemicals.Figures 40 and 41 show as an example the comparative degradation of urea exposed to *Phragmites communis* in both the vertical (module 14) and the horizontal (module 9) flow mode.

Test results on surfactants degradation are shown in figures 36 to 38. Process test parameters were both TOC and COD, showing that during degradation stable reaction products are formed. Similar surfactant concentrations were decomposed by *Typha latifolia* at a much lower efficiency.

Figure 39 shows the degradation of dairy waste water, one of the typical mediterranean imaginable application cases, and the graph demonstrates the fast degradation (vertical flow mode) and the absence of any persistent compounds at detectable concentration levels

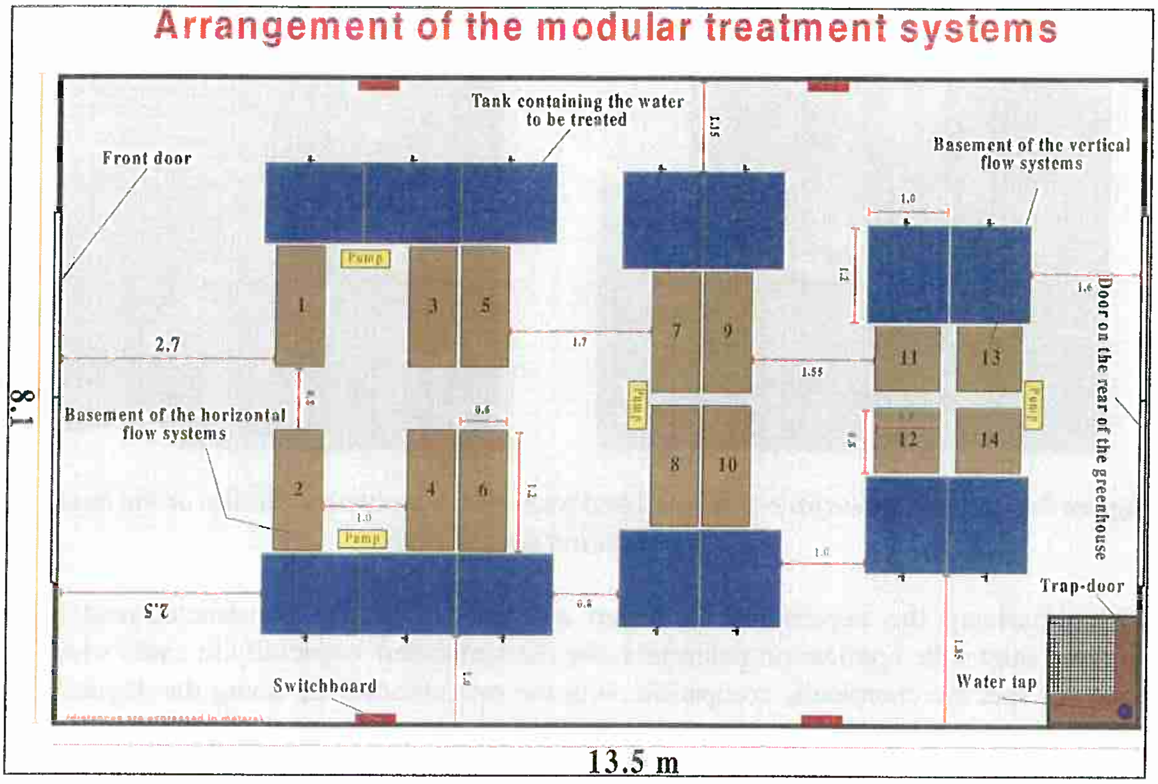


Figure 32: Greenhouse scheme

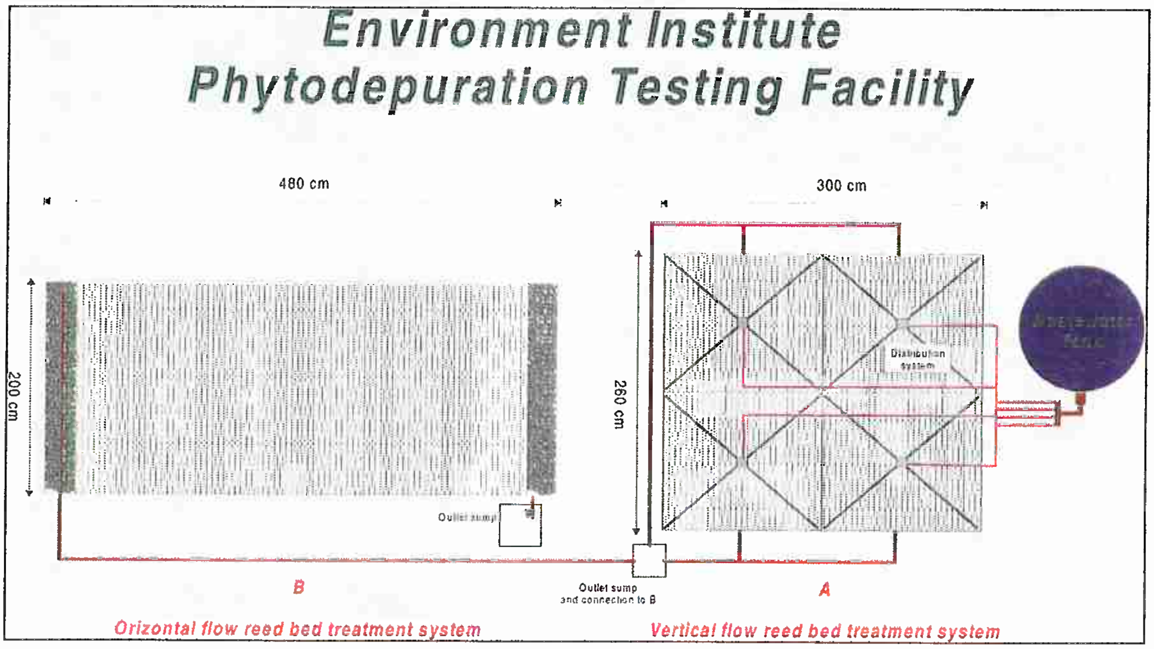


Figure 33: Pilot plant scheme

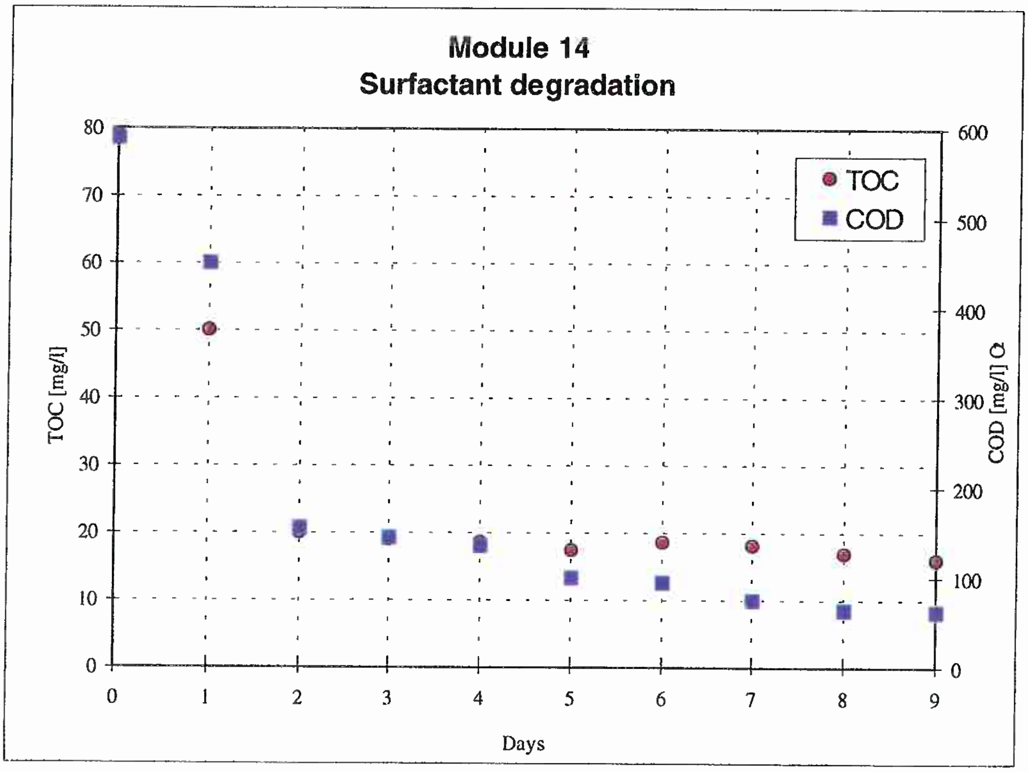


Figure 36: Subsurface-flow reed bed chemical testing - Surfactant

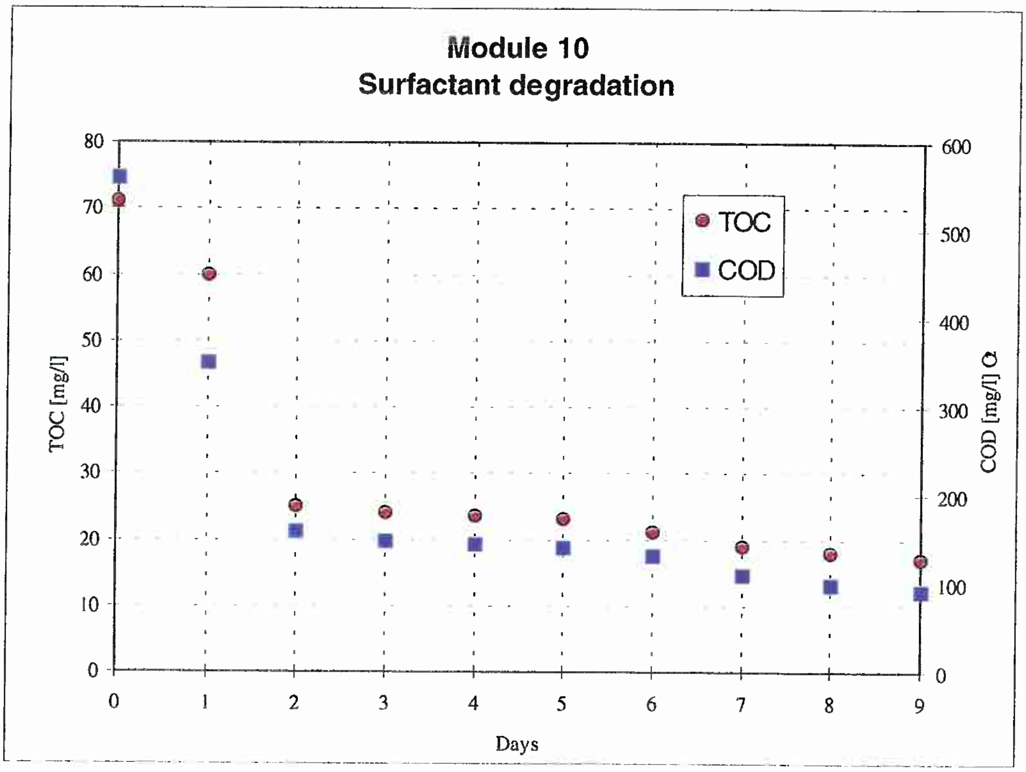


Figure 37: Subsurface-flow reed bed chemical testing - Surfactant

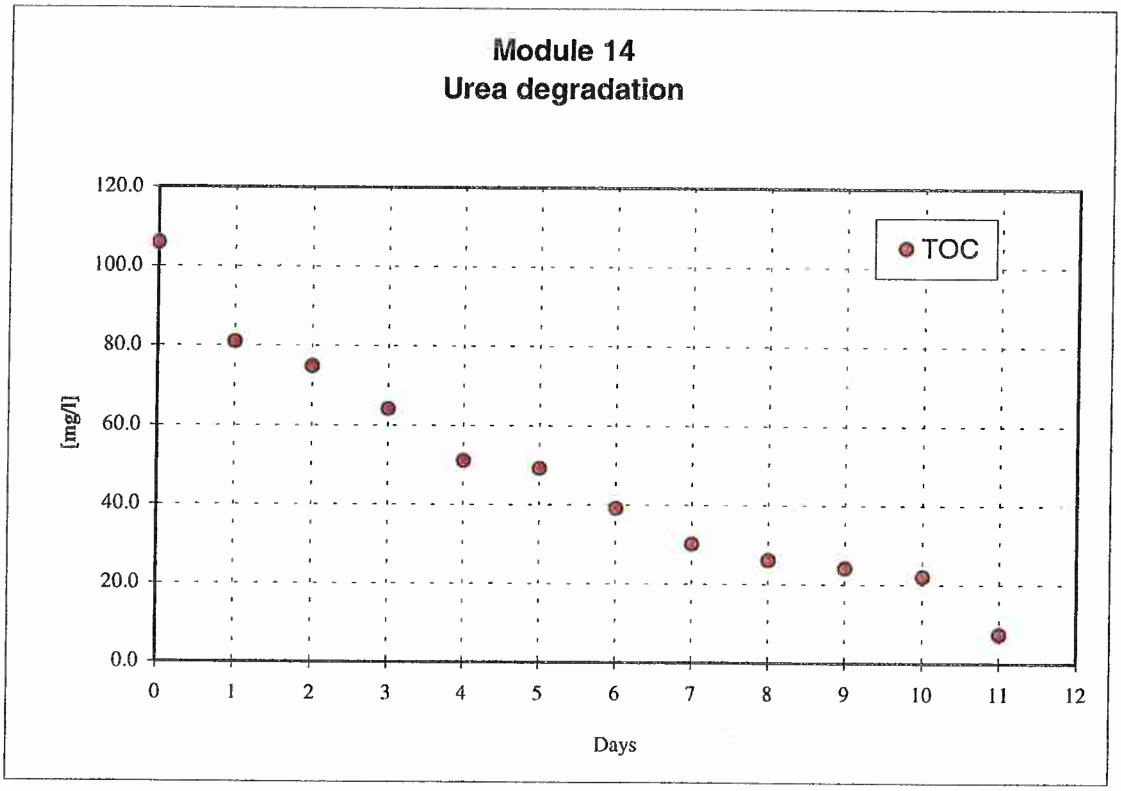


Figure 40: Subsurface-flow reed bed chemical testing: urea

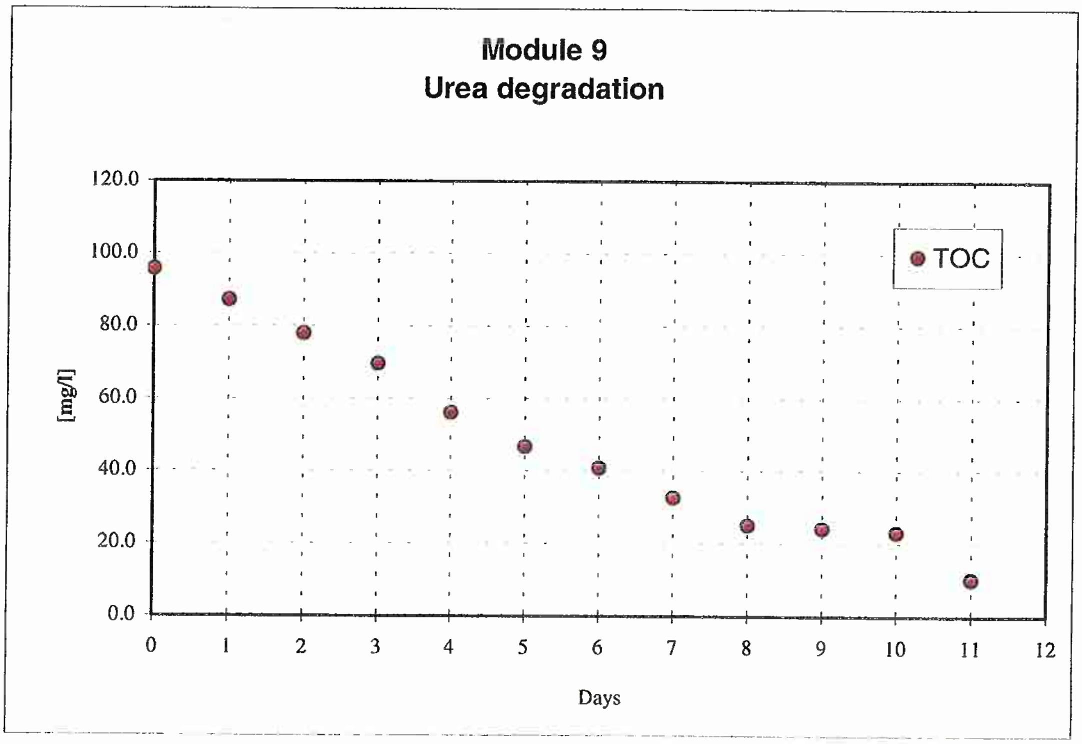
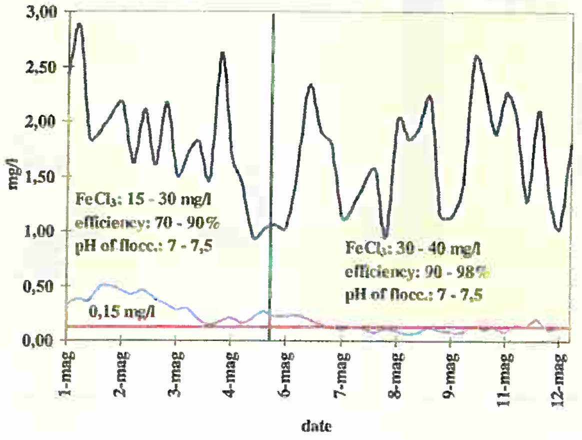


Figure 41: Subsurface-flow reed bed chemical testing: urea

of chlorine dioxide inasmuch as this would call for further chlorination normally by means of reducing salts (for example sulphites) that would increase the salinity of the water.

Furthermore, as UV disinfection is a purely physical process it would not alter the properties of the water. The UV plant should be able to reduce the number of bacteria by three orders of magnitude to obtain a residual content of less than 100 CT per 100 ml.



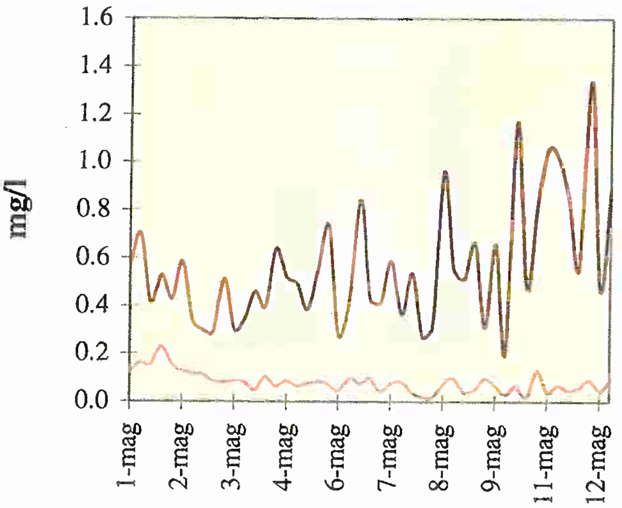
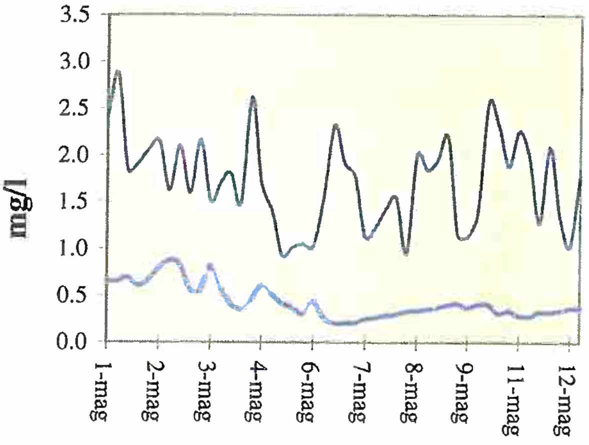


***Figure 42**: Total phosphorus in the raw water and treated water*

***Figure 43**: Total ferrous ion in the raw water and treated water*

During the dephosphatization tests in the pilot plant, bacteria removal efficiency of UV disinfection was assessed in cooperation with. the Environment Institute of the European Commission's Joint Research Centre at Ispra.



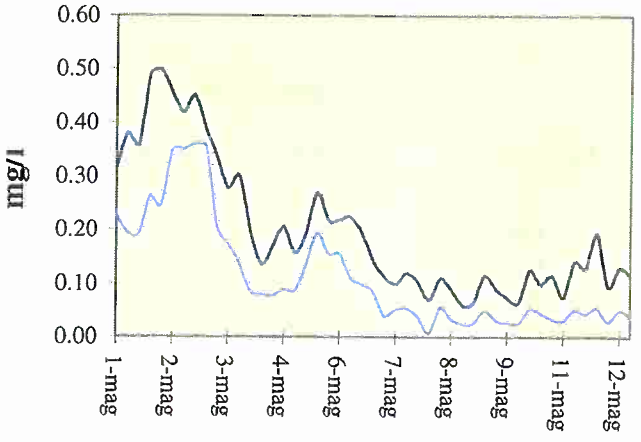


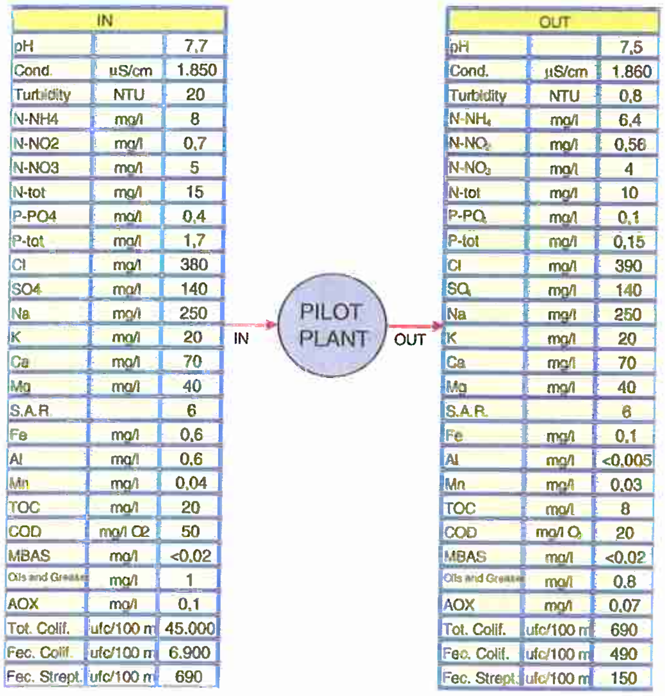
***Figure 44**: Phosphorus distribution in the raw water*

***Figure 45**: Phosphorus distribution in the treated water*

The tests were conducted using the mobile unit for wastewater treatment which houses a compact apparatus that resorts to catalytic photoxidation (which can also work as UV disinfection unit) and membrane filtration techniques. The device consists of five high pressure UV lamps with emission spectrum ranging from 185 to 390 nm.

5.4 Tertiary treatment line efficiency prediction

Figure 48 sums up schematically the overall performance of the pilot plant obtained by comparing the main chemical parameters of the untreated and treated water analysed during the experimental tests.



IN		
pH		7,7
Cond.	µS/cm	1.850
Turbidity	NTU	20
N-NH4	mg/l	8
N-NO2	mg/l	0,7
N-NO3	mg/l	5
N-tot	mg/l	15
P-PO4	mg/l	0,4
P-tot	mg/l	1,7
Cl	mg/l	380
SO4	mg/l	140
Na	mg/l	250
K	mg/l	20
Ca	mg/l	70
Mg	mg/l	40
S.A.R.		6
Fe	mg/l	0,6
Al	mg/l	0,6
Mn	mg/l	0,04
TOC	mg/l	20
COD	mg/l O2	50
MBAS	mg/l	<0,02
Oils and Greases	mg/l	1
AOX	mg/l	0,1
Tot. Colif.	ufc/100 ml	45.000
Fec. Colif.	ufc/100 ml	6.900
Fec. Strept.	ufc/100 ml	690

OUT		
pH		7,5
Cond.	µS/cm	1.860
Turbidity	NTU	0,8
$N-NH_4$	mg/l	6,4
$N-NO_2$	mg/l	0,56
$N-NO_3$	mg/l	4
N-tot	mg/l	10
$P-PO_4$	mg/l	0,1
P-tot	mg/l	0,15
Cl	mg/l	390
SO_4	mg/l	140
Na	mg/l	250
K	mg/l	20
Ca	mg/l	70
Mg	mg/l	40
S.A.R.		6
Fe	mg/l	0,1
Al	mg/l	<0,005
Mn	mg/l	0,03
TOC	mg/l	8
COD	mg/l O_2	20
MBAS	mg/l	<0,02
Oils and Greases	mg/l	0.8
AOX	mg/l	0.07
Tot. Colif.	ufc/100 ml	690
Fec. Colif.	ufc/100 ml	490
Fec. Strept.	ufc/100 ml	150

***Figure 48**: Pilot Plant Global efficiency*

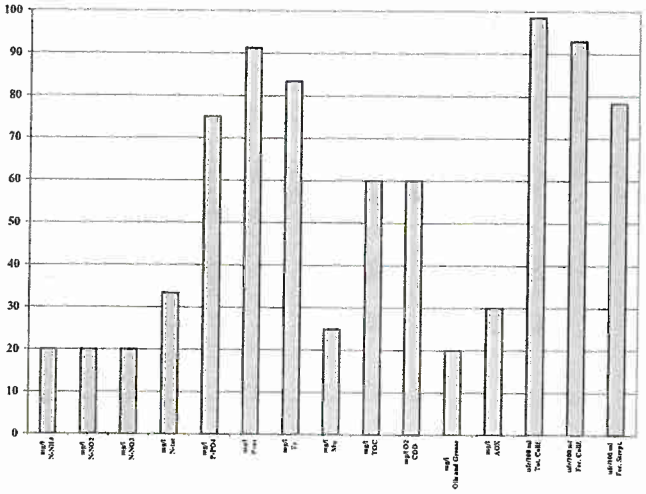


***Figure 49**: Pilot Plant Global efficiency*

Based on the findings of the experimental study carried out in the pilot plant, it was possible to predict the treatment efficiency for the tertiary treatment plant to be built downstream from the Is Arenas sewage disposal plant. The tertiary treatment line is at present in progress of construction and it will be completed in June 2001.

6. THE JOINT CATCHWATER MONITORING PROGRAMME: IS ARENAS WASTEWATER TREATMENT PLANT EFFLUENTS

In the framework of the CATCHWATER project (Workpackage 2), all partners agreed to monitor their effluent sources according to a jointly defined monitorand list at a monthly scale in order to create some basis of comparison.The analytical monitoring program on the Is Arenas plant effluents was started in January 1999 and the obtained results until June 2000 are reported here.

The sampling stations along the treatment line were located at the exit of the secondary sedimentation units just before the disinfection unit and at the exit of the sodium hypochlorite disinfection unit. The samples have been taken twice a month and were analyzed by the EAF chemical and microbiological laboratories. In order to give the reader an idea about the Is Arenas water treatment characteristics and the Cagliari wastewater quality, along with the effluent samples also the entering wastewater has been analyzed on the same dates. The results, together with parallel effluent data, are summarized in table 5 and 6.

The results reported in tables 7 and 8 are related to the effluents taken from the sampling point before the disinfection unit because the effluent of the secondary treatment units will be treated, as

6.1 Analytical methods applied

The analytical methodology applied by EAF is based on official Italian standard methods, as described by IRSA and CNR. The EAF laboratory participates regularly in the interlaboratory exercises organized by the Environment Institute in the AQUACON proficiency testing scheme for water analysis.

Table 4: Analytical methods

Parameters	Methods	Reference
pH	Electrometry	Metodi analitici per le acque, CNR-IRSA (1994)
Cond. (25 °C)	Electrometry	Metodi analitici per le acque, CNR-IRSA (1994)
N-NH_4	Molecular absorption spectrophotometry	CNR-III (1998)
N-NO_2	Molecular absorption spectrophotometry	Metodi analitici per le acque, CNR-IRSA (1994)
N-NO_3, Cl, SO_4, Ca, Mg, Na, K	Ion chromatography	Standard Methods (1995)
N tot, P tot	Molecular absorption spectrophotometry after sample mineralization by K persulphate	Metodi analitici per le acque, CNR-IRSA (1994)
P-PO_4	Molecular absorption spectrophotometry	Metodi analitici per le acque, CNR-IRSA (1994)
Alkalinity	Alkalimetry (mixed indicator: methylene red, bromocresol green)	Metodi analitici per le acque, CNR-IRSA (1994)
COD	Potassium dichromate	Metodi analitici per le acque, CNR-IRSA (1994)
Dissolved Metals	ICP-OES, GFAAS	Metodi analitici per le acque, CNR-IRSA (1994) Standard Methods (1995)
TC, TOC, IC	Catalyzed oxidation and IR detection	Standard Methods (1995)
AOX	Pyrolysis and microcoulometric detection	DIN 38409/14
Total Coliforms	Membrane filtration, Growth Medium: m-Endo Agar-LES	Metodi analitici per le acque, CNR-IRSA (1994)
Fecal Coliforms	Membrane filtration, Growth Medium: m-FC Agar	Metodi analitici per le acque, CNR-IRSA (1994)
Fecal Streptococci	Membrane filtration, Growth Medium: m-Enterococcus Agar	Metodi analitici per le acque, CNR-IRSA (1994)
Escherichia Coli	Membrane filtration, Growth Medium: C-EC-MF	Metodi analitici per le acque, CNR-IRSA (1994)

6.2 Discussion of monitoring results

6.2.1 Chemical parameters

Table 5 summarizes the results obtained from the analysis on the inlet wastewater of Is Arenas plant from May 1999 to May 2000 in terms of basic statistics in order to demonstrate the large variability of the incoming wastewater with regard to those components of the sewage which are of major interest to the reuse of the cleaned effluents in agricultural irrigation, such as conductivity, chloride and sulphates, TOC and COD, AOX and nitrogen species.

A closer analysis of the wastewater quality evolution along the year shows two sharp peaks of TOC and COD (figure 51 and 53) during summer accompanied by corresponding peaks of total phosphorus and total nitrogen (figures 50 and 52).

has been confirmed. In autumn 1999 a sharp conductivity peak can be observed which is matched by corrsponding peaks for sodium, chloride, sulphate, magnesium, calcium and potassium. The period is also characterized by the lowest observed COD values.

6.2.2 Microbiological parameters

Table 6 and figures 69 to 72 show results obtained from the analysis of the treated, but not chlorinated effluent. In the monitoring period, the mean bacterial concentration showed a span of about three and four logarithmic units. To evaluate the bacterial content in the Is Arenas influent, some sewage inlet sampling has been carried out from May 1999 to June 2000. Tthe bacterial removal efficiency obtained is the following:

- Total Coliforms: 7 log units;
- Faecal Coliforms: 6 log units;
- Faecal streptococci: 5 log units;
- Escherichia Coli: 6 log units;

The obtained removal efficiency shows that the Is Arenas secondary treatment line (without the disinfection unit) allows to remove the bacterial content up to about two logarithmic units. Tables 8 summarizes the results obtained during the first phase of the monitoring programme from 11.01.1999 to 3.05.2000. As expected, the bacterial activity along the year is characterized by a dormant low during the cold season, followed by the onset in May which coincides which the beginning of the tourism season (Figure 66 to 69). Escherichia coli has been added to the list of test parameters only lately.

Whether the chemical parameters included in the CATCHWATER agreement alone correctly reflect a suitability for direct or indirect irrigation purposes of the Is Arenas effluents, or any other effluent source, is certainly debatable. The multiannual monitoring for a larger, though not exhaustive list of potentially hazardous elements and organic compounds indicates the necessity to establish a monitoring system of well broadened nature, once the recovery operations are launched. Anyway, the multiannual monitoring progamme as planned and executed to explore the Is Arenas effluent quality and its changements with time, showed that despite of the salinity problem, which is thought to be solved in the next future, the quality of the effluent is such as to expect, all of the necessary care and surveillance provided, that the efforts to recover water for agricultural irrigation purposes from these effluents may be rewarded.

Table 6: Non-chlorinated Effluents (Is Arenas)

Parameter	Unit	Number of results	Mean	Maximum	Minimum	Standard Deviation	Relative Standard Deviation %	Range
pH		30	7.36	7.84	7.07	0.2	2.52	0.77
Conductivity 25 °C	µS/cm	30	2886	6320	1695	942.9	32.7	4625
N-NH4	mg/l	30	2.57	11.3	0.03	2.9	113.2	11.24
N-NO2	mg/l	30	0.22	0.74	0.02	0.2	69.9	0.72
N-NO3	mg/l	30	7.81	19.0	0.72	5.7	73.3	18.3
N-tot	mg/l	30	14.0	23.5	6.2	5.1	36.2	17.3
P-tot	mg/l	30	1.15	2.90	0.05	0.7	59.9	2.9
P-PO4	mg/l	30	0.91	2.44	0.03	0.6	68.2	2.41
Cl	mg/l	30	723	1863	375	316.5	43.8	1488
SO4	mg/l	30	218	365	130	61.8	28.4	235
Alkalinity	meq/l	30	3.75	4.83	3.10	0.5	12.2	1.73
COD	mg/l O2	30	26	65	12	11.7	44.9	53
Na	mg/l	30	430	1059	225	173.5	40.4	834
K	mg/l	30	25	55	5	9.2	36.7	50
Ca	mg/l	30	85	150	58	18.2	21.3	93
Mg	mg/l	30	65	134	44	20.6	31.5	90
B	mg/l	25	0.7	1.1	0.5	0.2	22.5	0.60
SAR		30	8	16	5	2.5	29.9	11
SARa		30	19	38	11	5.9	31.3	27
TC	mg/l	30	51	70	36	8.1	15.9	34
TOC	mg/l	30	15	25	9	3.9	25.8	16
IC	mg/l	30	36	55	18	8.1	22.4	37
AOX	µg/l	29	100	170	38	34.5	34.5	132
Fe	µg/l	24	34	78	13	16.6	48.4	65
Mn	µg/l	24	29	66	10	13.4	46.8	56
Al	µg/l	24	157	798	17	150.9	96.4	781
Cr	µg/l	9	1	2	1	0.3	22.7	0.7
Zn	µg/l	29	30	74	15	13.9	46.5	59
Cd	µg/l	18	1	2	0.5	0.3	29.8	1.50
Pb	µg/l	12	6	10	0.9	2.2	37.1	9.1
Ni	µg/l	1	5	5	5	-	-	-
Cu	µg/l	3	32	50	22	15.9	50.4	27.6
Total coli.	UFC/100ml	26	88421	310000	18000	77031	87	292000
Faecal coli.	UFC/100ml	26	35331	140000	2500	41032	116	137500
Faecal strep.	UFC/100ml	26	10604	40000	1000	10635	100	39000
Escherichia coli	UFC/100ml	18	11531	38000	0	14845	129	38000

Table 7: *CATCHWATER effluent monitoring program results (continued)*

date	***Cr***	***Zn***	***Cd***	***Pb***	***Ni***	***Cu***	***Total Coliforms***	***Fecal Coliforms***	***Fecal Streptococci***	***Esherichia coli***
	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	UFC/100ml	UFC/100ml	UFC/100ml	UFC/100ml
11/01/99	-	-	-	-	-	-	-	-	-	-
27/01/99	1	26	2	6	<5	22	-	-	-	-
08/02/99	1	26	2	6	<5	22	-	-	-	-
24/03/99	<1	32	1	1	<5	50	40000	2500	5500	-
13/04/99	2	15	1	<5	<5	<5	51000	8500	3500	-
03/05/99	1,6	15	1	<5	<5	<5	33500	15500	10000	-
31/05/99	<1	17	<1	5	<5	<5	44250	14000	9500	-
21/06/99	<1	30	1	<5	<5	<5	180000	63000	17500	-
05/07/99	<1	20	1	<5	<5	<5	61500	14000	3000	-
26/07/99	<1	74	<1	<5	<5	<5	23000	18500	6000	-
10/08/99	<1	24	1	<5	<5	<5	75000	68000	22500	-
24/08/99	<1	43	<1	<5	<5	<5	180000	49000	10500	31000
07/09/99	<1	30	1	5	<5	<5	220000	72000	6500	38000
27/09/99	<1	25	1	8	<5	<5	168750	140000	40000	35000
11/10/99	<1	25	2	7	<5	<5	180000	120000	28000	8000
02/11/99	<1	52	1	10	<5	<5	46250	25000	3000	5000
22/11/99	<1	38	<1	<5	<5	<5	32000	7200	2500	4500
01/12/99	<1	35	1	7	<5	<5	20500	9000	3000	3000
21/12/99	<1	33	1	7	<5	<5	40000	12000	1500	4500
04/01/00	<1	39	1	5	<5	<5	73000	22000	10000	10000
26/01/00	<1	30	1	<5	5	<5	-	-	-	-
07/02/00	1	22	1	<5	<5	<5	138000	30000	19000	10000
21/02/00	1	64	<1	<5	<5	<5	18000	3500	2000	2500
07/03/00	1	24	<1	<5	<5	<5	46000	8750	6500	2500
22/03/00	1	30	<1	<5	<5	<5	30000	5000	1000	0
04/04/00	-	-	-	-	-	-	86000	20000	5000	9000
19/04/00	-	-	-	-	-	-	20200	5500	3500	4500
02/05/00	-	-	-	-	-	-	150000	115000	35000	17000

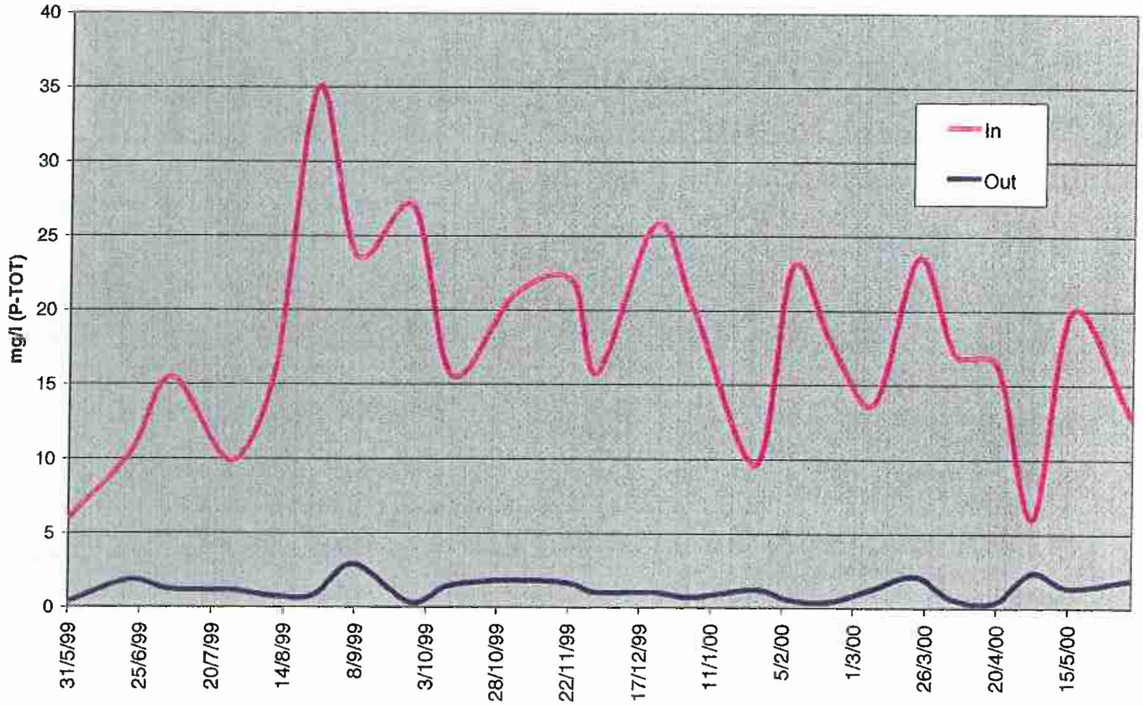


Figure 50: *Total phosphorus in Is Arenas raw water and effluents*

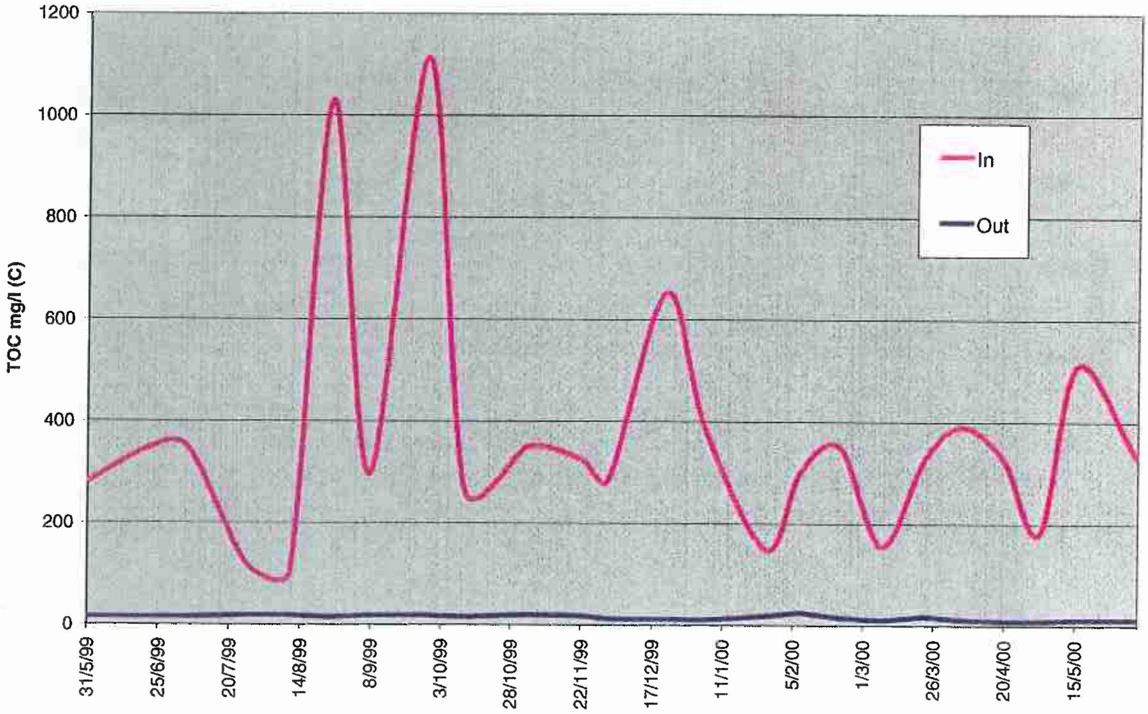


Figure 51: *TOC in Is Arenas raw water and effluents*

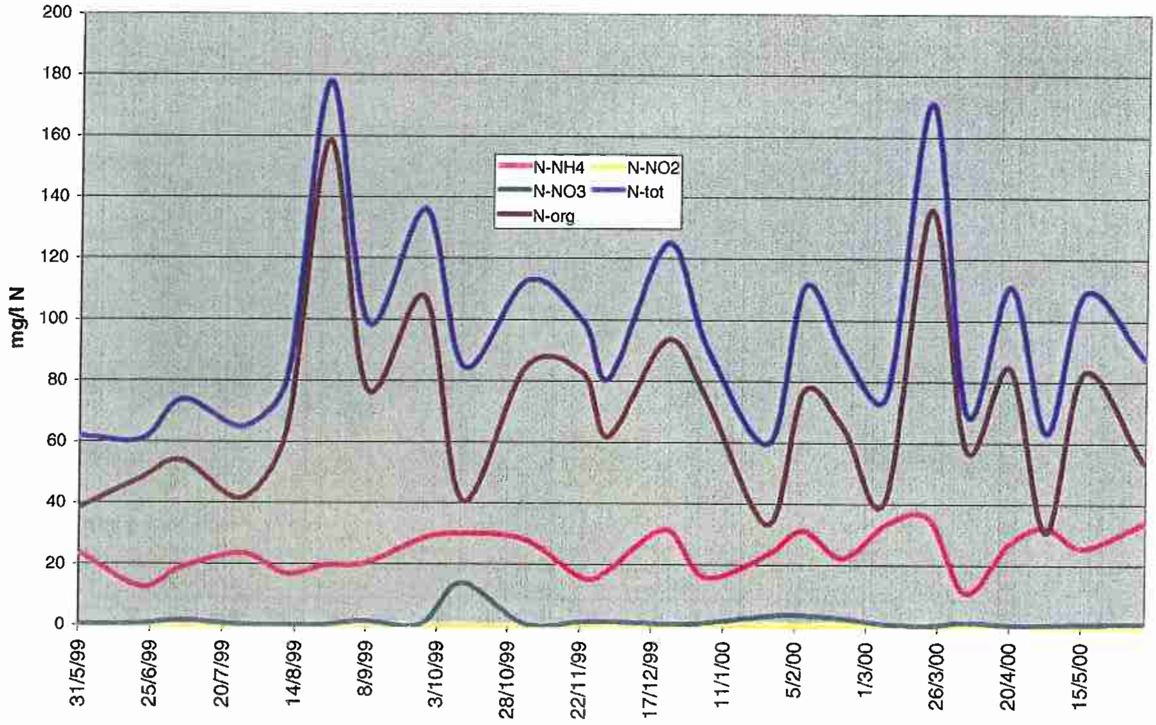


Figure 54: *Nitrogen species in Is Arenas inlet*

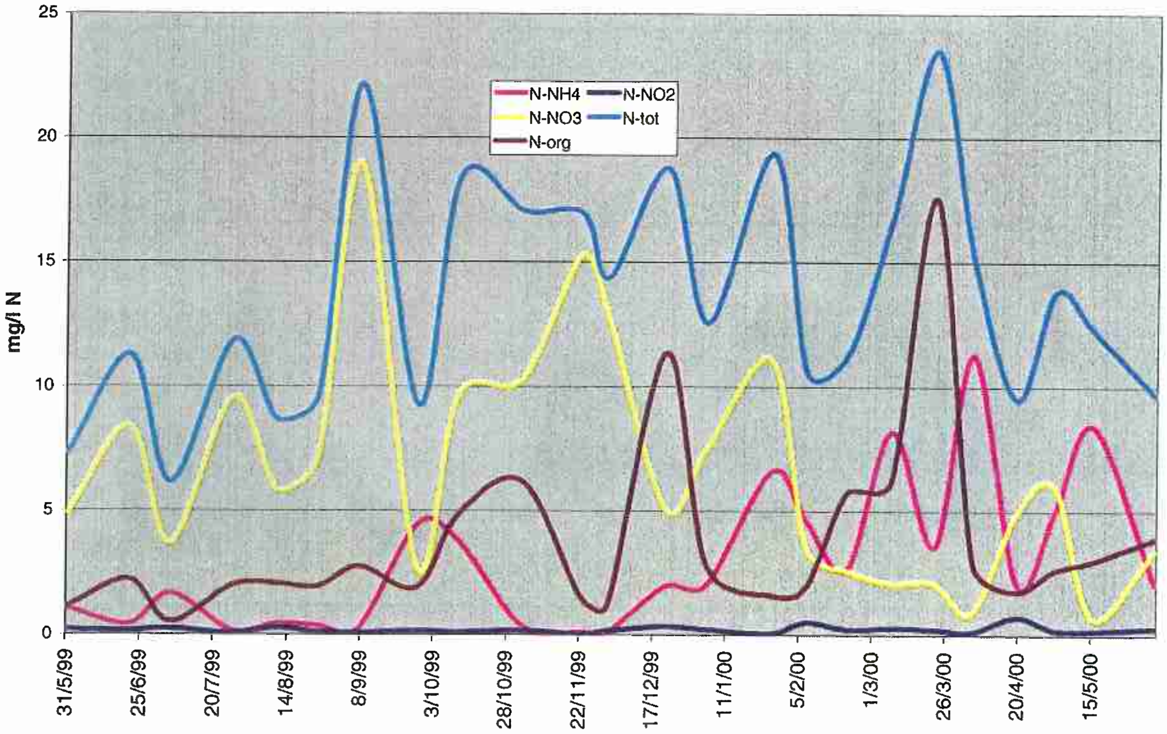


Figure 55: *Nitrogen species in Is Arenas effluents*

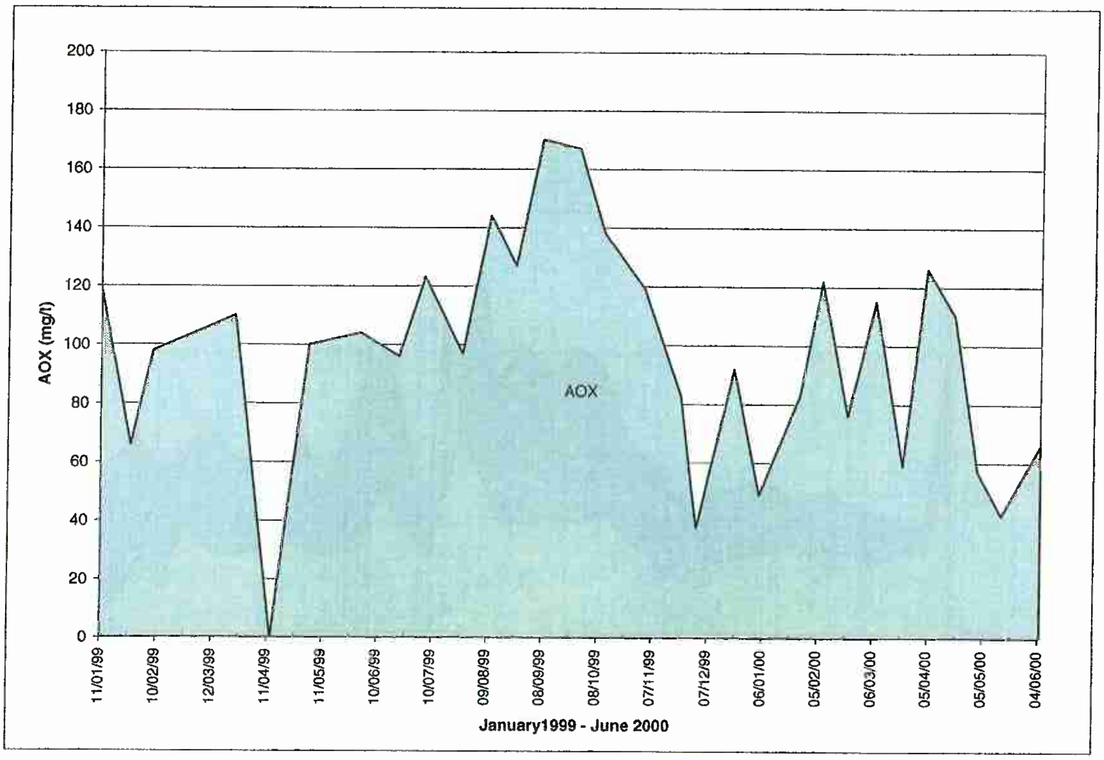


***Figure 57**: AOX of Is Arenas effluents.*

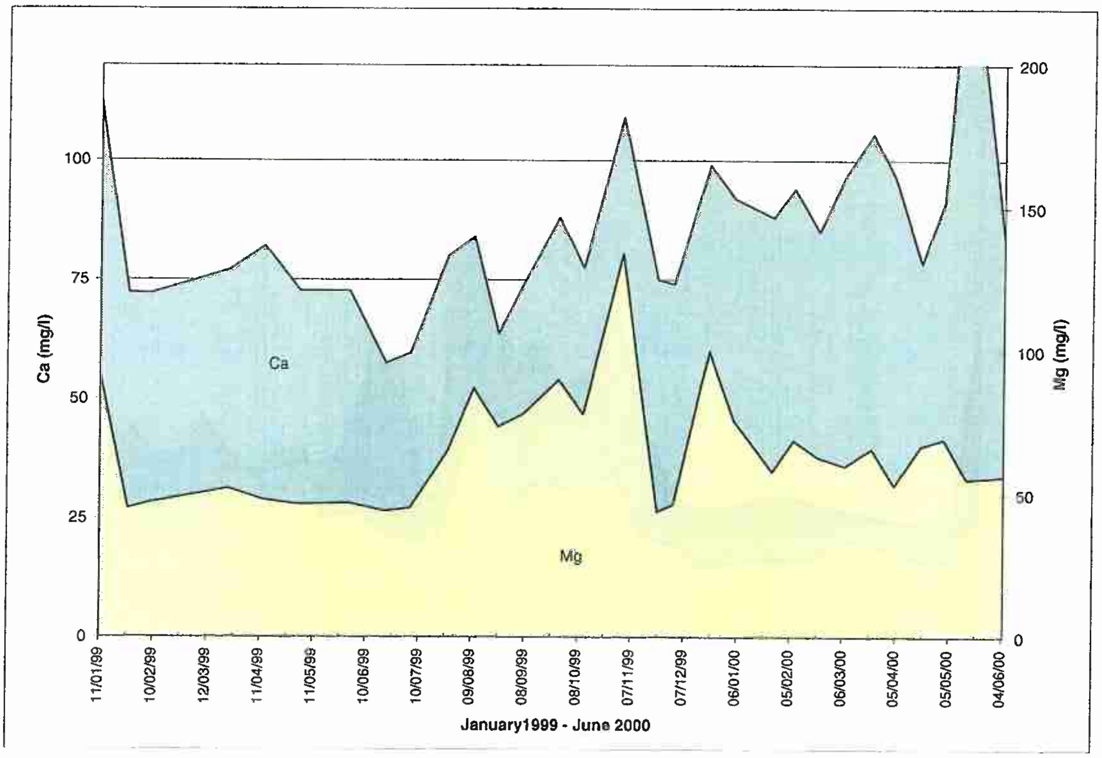


***Figure 58**: Ca and Mg in Is Arenas effluents.*

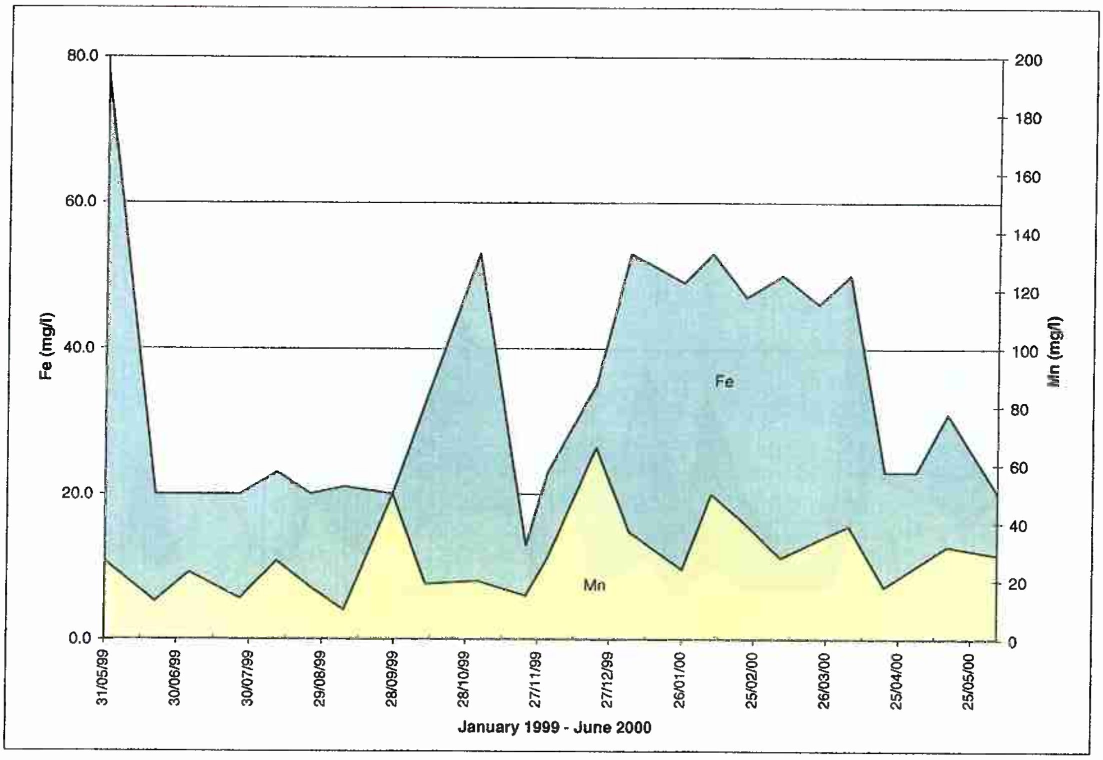


***Figure 61**: Fe and Mn in Is Arenas effluents.*

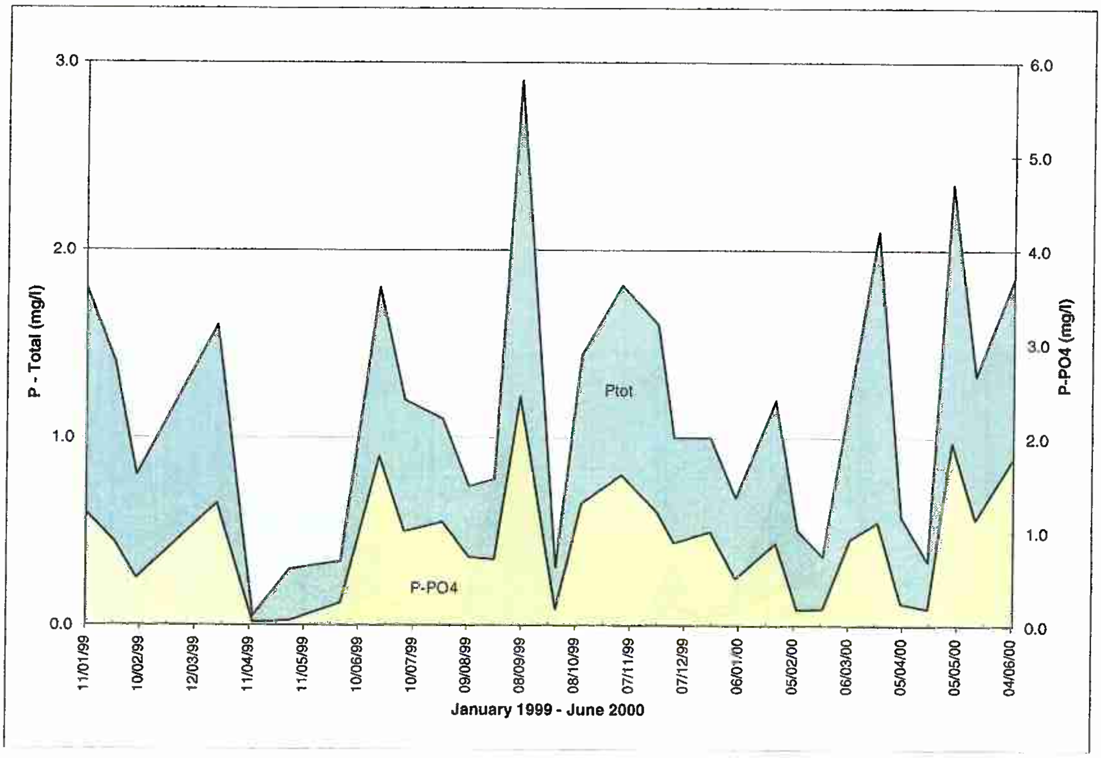


***Figure 62**: Phosphorous species in Is Arenas effluents.*

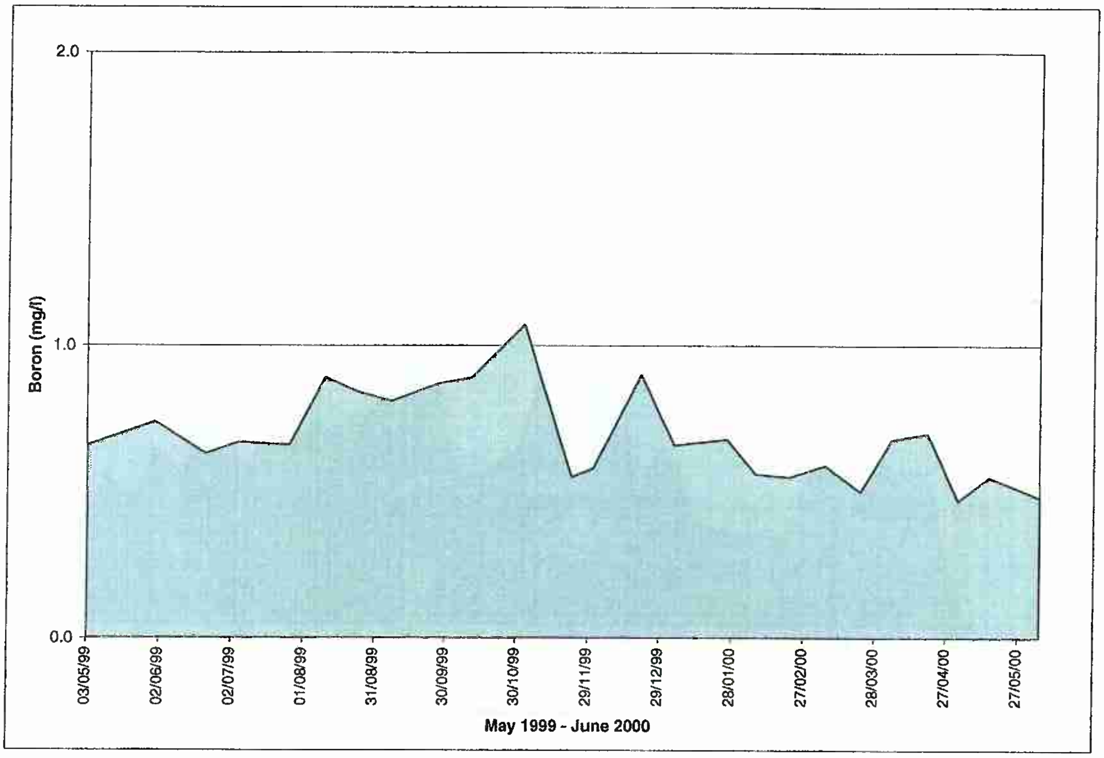


***Figure 65**: B in Is Arenas effluents.*

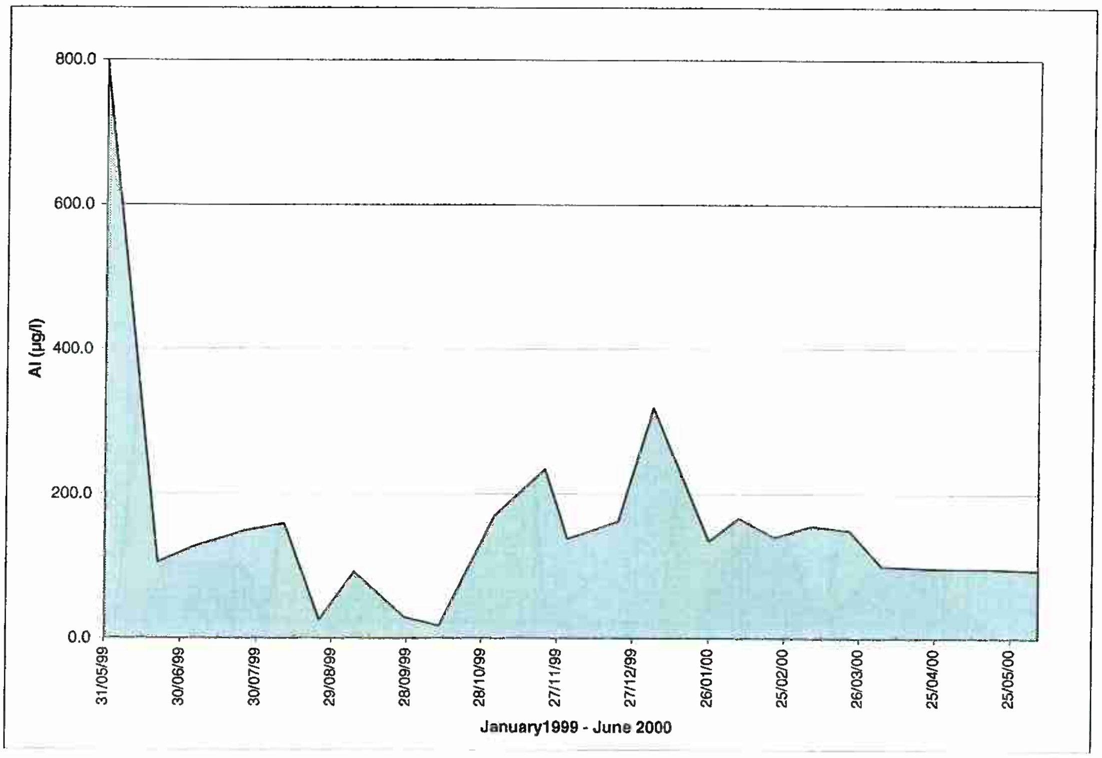


***Figure 66**: Al in Is Arenas effluents.*

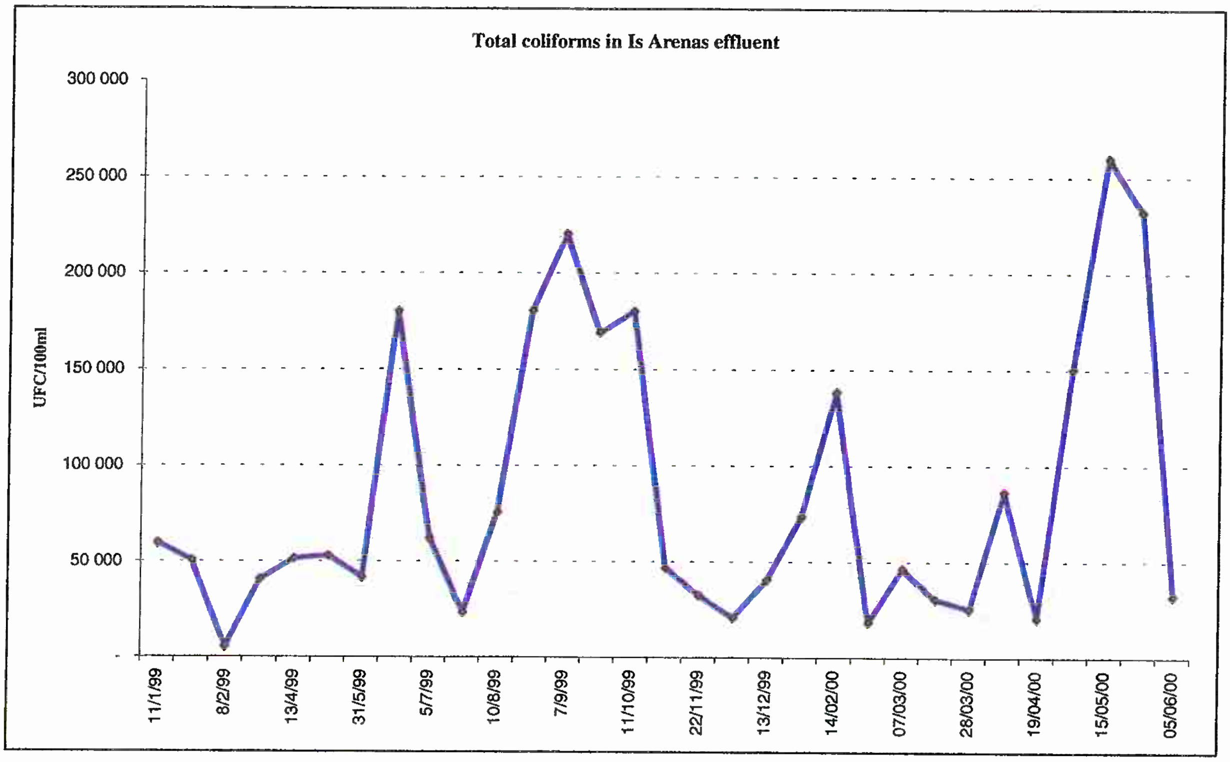


Figure 69*: Total coliforms in Is Arenas effluents.*

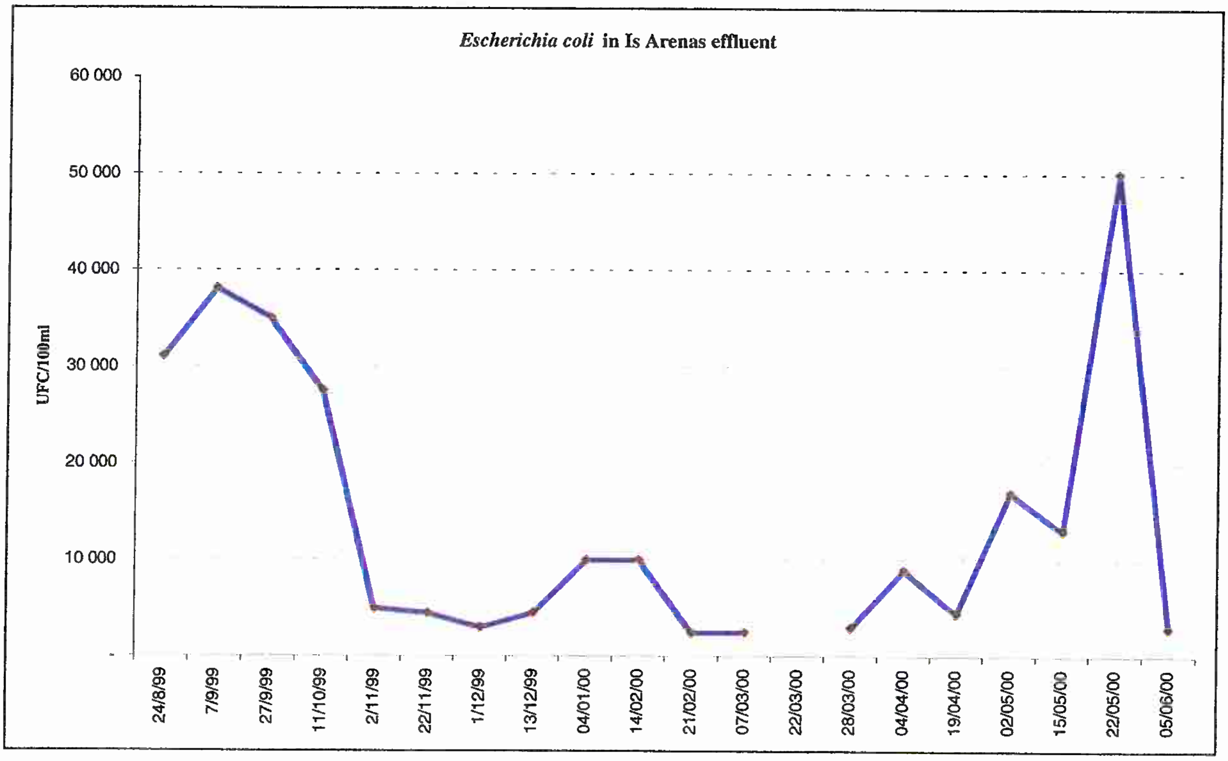


Figure 70*: Escherichia coli in Is Arenas effluents.*

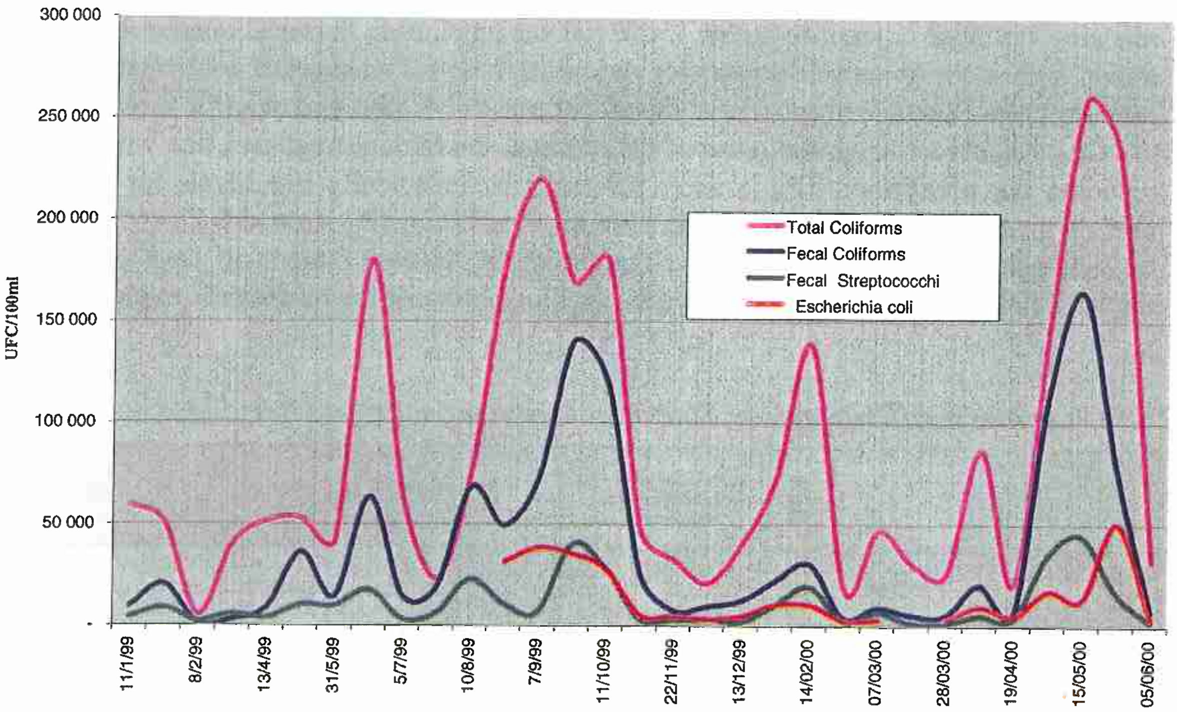


Figure 73: Synopsis of bacterial activity in Is Arenas effluents.

7. SUITABILITY PREDICTION OF TERTIARY TREATMENT LINE EFFLUENTS FOR REUSING IN IRRIGATION

Based upon the chemical, physical and biological analyses of the effluent discharged by the Is Arenas plant, the experimental studies carried out with the dephosphatization pilot plant, and the analysis on the Simbirizzi reservoir, the following conclusions may be drawn:

- The chemical properties (table 9) of the Simbirizzi reservoir water fall, for most of parameters considered, into class I irrigation quality. Due to the high conductivity the reservoir is rated as **class III**. The irrigation quality classes have been illustrated in the interim report n.1. Waters rated as class III can be used periodically for irrigation (e.g. every two or three years), but limited to assisted irrigation of tolerant crops using highly efficient techniques in an environment with low vulnerability. The continuous use of this water for irrigation may lead to phytotoxicity with resulting reduction in yield compared to better quality water;
- The water discharged by the secondary treatment of Is Arenas (table 9) effluent is rated, for most parameters, in the class I of irrigation water quality. Due to the present high salinity content the water falls in the class IV (water that cannot normally be used in agriculture). Nevertheless studies are in progress (see next chapter) to reduce sea water intrusion in the main sewer trunk line of Cagliari thereby allowing to reduce the salinity content and to rate the Is Arenas effluents as **class II**. Waters rated as class II are suitable for continuous irrigation, with limitations on seasonal irrigation volumes, where necessary, and adopting appropriate measures regarding irrigable crops, irrigation technique, soil conditions, and vulnerability of the environment;
- According to the tests conducted on the pilot plant, the water discharged by the tertiary dephosphatization treatment line of the Is Arenas plant, actually in progress of construction, will be rated in the **class II** of irrigation water quality;

8 THE MONITORING PROGRAM ON THE MAIN SEWER TRUNK LINE OF CAGLIARI

From a number of studies it is well known that the reuse of water containing high chloride content (minimum 300 ppm and maximum 2000 ppm) in agricultural irrigation might create damage on both crop quality and soil structure and the related risks must be evaluated case by case. Chloride ions are fundamental for plant growth, nevertheless, high concentrations may cause direct toxicity problems to the crop or even to the soil by changing the chemical and/or mineralogical characteristics and therby the hydraulic properties of the soil. For these reasons the chloride content, and to some extent the sulphate content as well needs to be limited to levels which can be tolerated, but anyhow, should be significantly lower as today encountered in the Is Arenas effluents and hence, first of all the causes of high salinity in the Cagliary sewage need to be identified and in cooperation with the Municipality of Cagliari, a monitoring program applied to the sewer line of Cagliari and its hinterland was established.

8.1 The monitoring area

The Is Arenas wastewater treatment plant shows at present a flow rate capacity of about 1400 l/s (2000 l/s maximum value). The served municipality consists of Cagliari and its hinterland (Pirri, Selargius, Monserrato, Quartucciu, and Quartu S.Elena). The Is Arenas plant owns two sewage inlets, the first one coming from Cagliari city and the second one from the hinterland.

Figure 74 presents the scheme of the main sewer trunk line of Cagliari form the starting point (n.1) to the final point n.6 (Is Arenas plant).

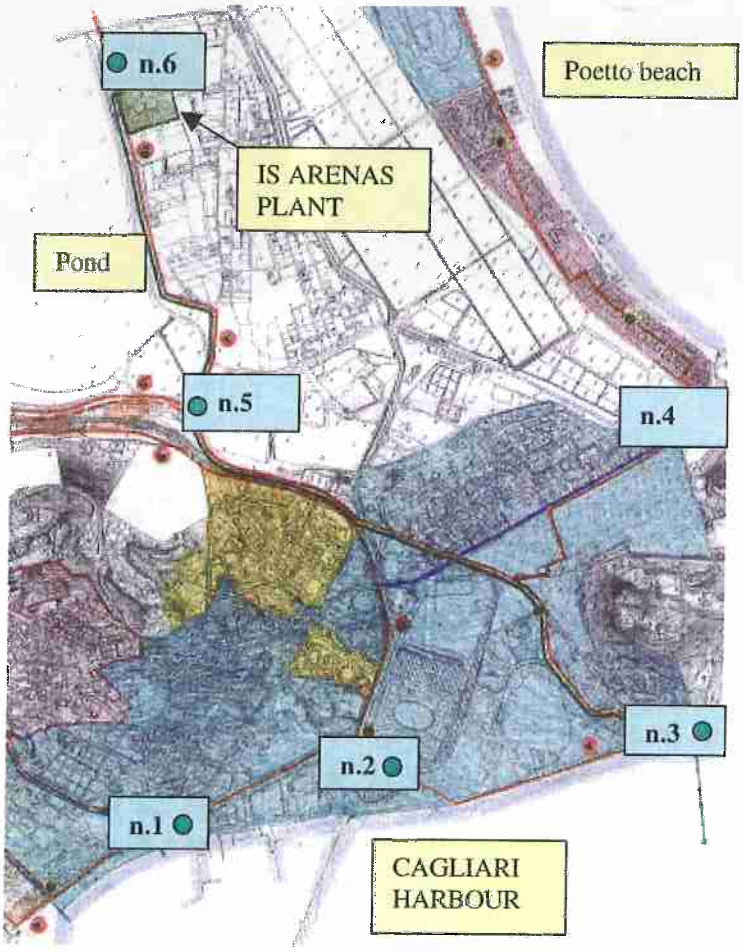


Figure 74: Main sewer trunk line of Cagliari and sampling points.

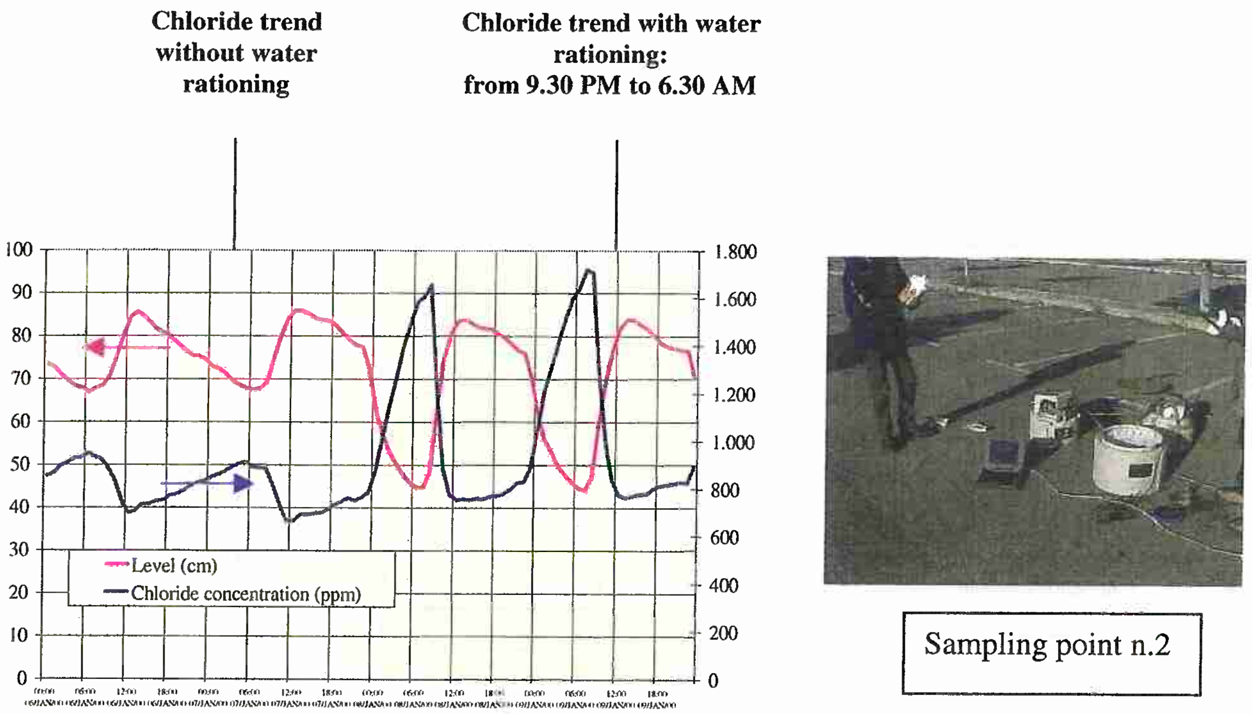


***Figure 76:** Level and chloride concentration at sampling point n.2.*

9 DEPHOSPHATIZATION PLANT MONITORING PROGRAM AND REUSE MANAGEMENT

To evaluate the reliability and to guarantee the proper functioning of the tertiary treatment plant, the effluents will be subjected to rigorous chemical and microbiological analysis summarized in table 10.

The frequency of analysis and the sampling points are also indicated in the table. Taking into account that Italy lives a period of transition concerning the adoption of new irrigation water quality regulations, the indicated parameters might be extended once new parameters are established by the forthcoming law.

Great part of the parameters forseen in drinking water production plants are included in this table, as the foreseen process is constituted by flocculation, filtration and disinfection with chlorine dioxide and UV units. Other parameters are also included for the following reasons:

- Total and dissolved ferric ions because ferric chloride is used to remove phosphate in the effluents;
- Chloride ions because they are present in the effluents with high and variable concentrations (which might compromise their agricultural reuse);
- Escherichia coli and helminth eggs because they might be regulated by the forthcoming Italian law on reusing sewage effluents in irrigation;
- Sodium Absorption Ratio (SAR) because this parameter is hardly variable in the effluents and it is of great importance, along with conductivity, to evaluate the reuse effects on the soils to be irrigated.
- Phosphorous species and forms because these parameters are of great importance to regulate the already precarious trophic state of the Simbirizzi reservoir;

Amongst the applicable models, that of Vollenweider has been used due to the numerous validation exercises available for artificial lakes. This model starts from a number of territorial parameters, such as the phosphorus load of the hydrographic basin, its morphometry (volume, average depth, surface area) and hydrology (water residence time) and enables to calculate some descriptors (phosphorus and chlorophyll), which are determining the trophic state and hence, the quality of the water.

Even considering that the modellistic approach yields results which should be considered with caution taking into account that the model had to be modified and adapted to the specific case, it is expected that following to the removal of phosphorus the trophic status of the lake shall be improved with respect to the present state.

The results given by the model allow to conclude that with a removal of 95% of phosphorous with all probability a mesotrophic situation with respect to total volume and inflow shall be reached Anyway, at a low probability level, even eutrophic conditions might be expected when operating at the maximum allowable level for both total volume and outflow. In any case the water quality shall considerably improve with respect to the present situation.

The management of the new resource should therefore take into consideration the three factors which show the major influence on the trophic state of the lake: **level of phosphorus removal, total reservoir volume** and **inflow volume.**

Level of phosphorus removal: Phosphorus removal should never be lower than 90%, maintaining an average of around 95%. Taking into account a mean value of total phosphorus of 2.5 mg/l in the effluents, de-phosphatization should reach levels of 0.15 mg/l as an average with allowable oscillation towards higher values of not more than 0.05 mg/l at time intervals longer than one month. Such a situation needs to be compensated by a similar period showing 0.05 mg/l less than average. The same holds for any other value. If for example for a period of 15 days, effluents showing a level of 0.25 mg/l have been added to the lake, exceeding the average for 0.1 mg/l, another 15 days with 0.1 mg/l or another 30 days with 0.05 mg/l should be allowed.

Total lake volume: The total lake volume, proportional to the trophic state of the lake, should be kept at the maximum level.

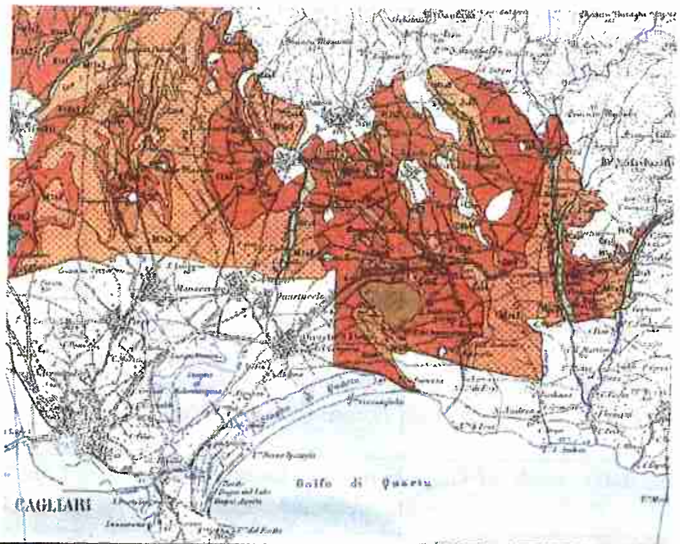
Inflow volume: The inflow volume of water of low phosphorus level should be as high as possible. Should effluents only enter the lake, to all probability even at maximum volume, eutrophic conditions would be reached which can be acceptable at emergency conditions only.

9.2 The reuse-water costs

Taking into account the estimate indicated in the project, the costs of the treated effluents to reuse in irrigation, will be about 114 lire/m^3 (0.06 Euro/m^3). This cost takes into consideration all of the exercise costs (chemicals, electric power, personnel, ordinary maintenance, sludge treatment and its removal and deposition) included the electric power costs to pump the water into the Simbirizzi reservoir or to pump it directly to the individual users (the UV disinfection unit is estimated to work only six months per year) (Figure 76).

One of the major problems in view of a wide-spread application of used water and effluents in particular, for reuse, seems today the public acceptance.

On the basis of their characteristics, morphology and other environmental parameters, the soils have been classified according to their irrigation suitability using the *Land Classification for Irrigation* (U.S. Bureau of Reclamation, 1953), which is divided into six classes of decreasing suitability described in table 11.



Soils derived from marly-sandy sediments of the Miocene	Soils derived from ancient skeletal-sandy alluvia of the Quaternary	Soils derived from recent skeletal-sandy or silty alluvia
Depth: from moderately deep to deep ***Texture***: loam or clay loam Generally very fertile ***Irrigation suitability***: Generally from highly suitable to suitable ***Limitations*** : depth and slope ***Land Classification*** : classes 1 – 2	***Depth*** : generally fairly deep ***Texture:*** sandy loam (surface) and sandy-clay (at depth) Moderately fertile Possible accumulation of carbonates, in places in the form of continuous hardpans ***Limitations*** : stoniness (hampers tilling and reduces permeability of the deep horizons) ***Irrigation suitability***: Generally moderately suitable ***Land Classification*** : classes 2 – 3	***Depth*** : deep ***Texture*** : from sandy to loamy sand or silt or clayey sand Generally very fertile ***Limitations*** : stoniness, low permeability, risk of flooding ***Irrigation suitability***: highly to moderately suitable ***Land Classification*** : class 1

Figure 78: *Map of irrigable soils of southern Sardinia*

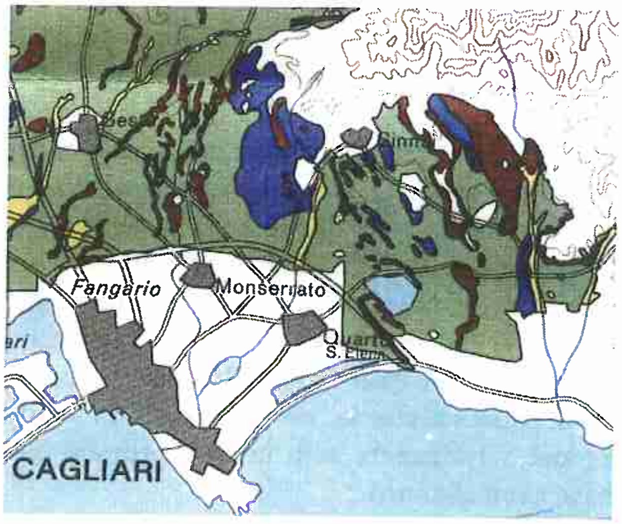


Figure 79: *Map of irrigation suitability of soils (yellow: class 1, green: class 2, blue: class 3, brown: class 4)*

based on the determination of the dielectric constant obtained by measuring the velocity of propagation of an electromagnetic signal into the soil. The signal will be introduced into the lysimeters through a metal coaxial probe imbedded in soils.

***Figure 80:** Soil cylinder extraction*

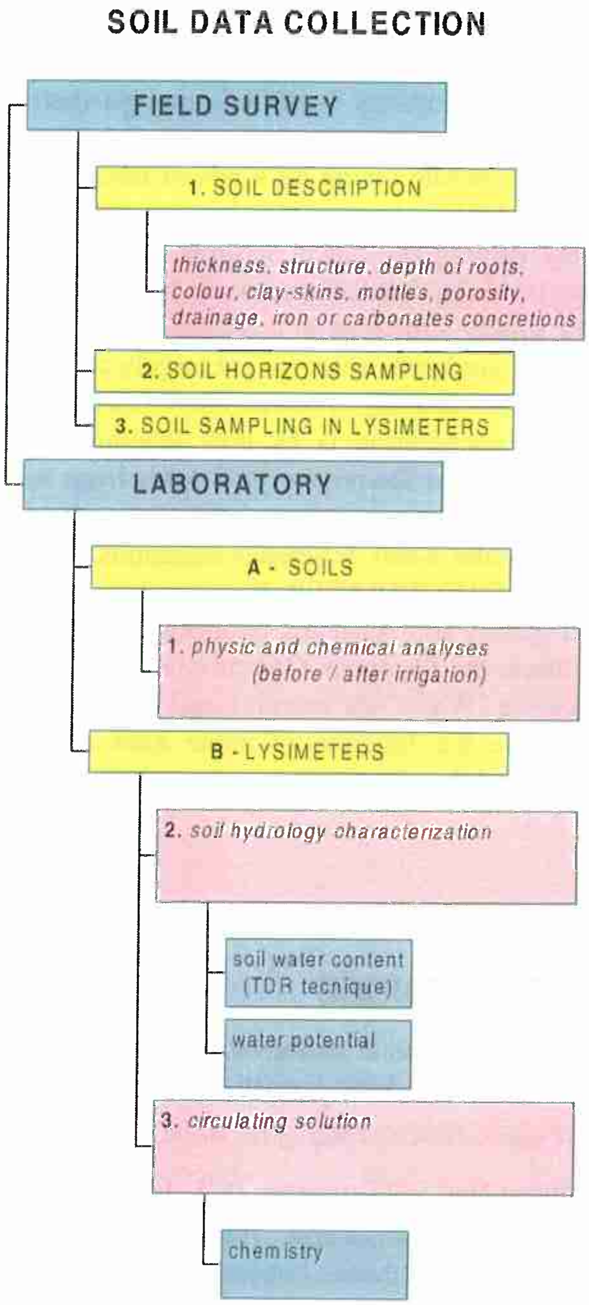


***Figure 81:** Soil studies program*

The soil columns will be instrumented with TDR probes (2 for each horizon), collected to a reflectometer that acts as both the pulse generator of the electromagnetic signal and the sampler of the relative wave forms.

At last the water potential, that means the hydraulic conductivity of soils, will be evaluated using measurements of water flux into a tensiometer, while the circulating solution to be analysed after irrigation will be separated from the soils using extractors located at the base of the columns. The work, described above, and part of the CATCHWATER Workpackage 3, has been started in May 2000 and a substancial report shall be presented in April 2001.

Hidaka H., Zhao J., Pelizzetti E., Serpone N. 1992. *Photodegradation of surfactants. 8. Comparison of photocatalytic processes between anionic sodium dodecylbenzenesulfonate and cationic benzyldodecyldimethylammonium chloride on the TiO_2 surface*. J. Phys. Chem., 96: 2226-2230.

Koster T.P.M., Assink J.W., Slaager J.M., Van der Veen C. 1993. *"Photocatalytic Purification and Treatment of Water and Air"*, D.F. Ollis e Al-Ekabi Eds., Elsevier, Amsterdam, 613

Lepore G.P., Vlsek A., Langford C.H. 1993. *"Photocatalytic Purification and Treatment of Water and Air"*, D.F. Ollis e H. Al-Ekabi Eds., 49 pp.

Niego, D., 1995. *Studio cinetico in impianto pilota della mineralizzazione fotocatalizzata di fenolo e di suoi cloroderivati in soluzione acquosa mediante membrane immobilizzanti biossido di titanio*. Tesi di laurea, Università degli Studi di Milano.

Tatti L.. 1995. *Studio di processi di foto-ossidazione avanzata. Fotomineralizzazione di cloro derivati organici in soluzione acquosa mediante membrane immobilizzanti biossido di titanio*. Tesi di laurea, Università degli Studi di Milano.

Bruzzi P.. 1996. *Fotomineralizzazione di diclorometano in soluzione acquosa, come molecola modello di clorurati alifatici, di reflui agroalimentari e di reflui civili in impianto pilota mediante membrane fotocatalitiche immobilizzanti biossido di titanio*. Tesi di laurea, Università degli Studi di Milano.

Moroni, A., 1998. *Modellizzazione cinetica dei processi di fotomineralizzazione di microinquinanti organici in soluzione acquosa mediante membrane fotocatalitiche immobilizzanti biossido di titanio e studio sperimentale della fotodegradazione di atrazina e suoi intermedi di degradazione in impianti pilota*. Tesi di laurea, Università degli Studi di Milano.

Montani, R. 2000. *Sviluppo ed applicazione di un sistema di fotoossidazione per il trattamento di reflui industriali finalizzato al possibile riuso di acqua in aree caratterizzate da scarse precipitazioni*. Tesi di Laurea, Università degli Studi, Milano-Bicocca.

Montani, R., M. Bianchi e H. Muntau. 2000. *Sviluppo ed applicazione di un sistema di fotoossidazione per il trattamento di reflui finalizzato al loro possibile riuso*. EUR 19525 IT.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

OFFICE FOR OFFICIAL PUBLICATIONS
OF THE EUROPEAN COMMUNITIES
L-2985 Luxembourg