



EUROPEAN  
COMMISSION

Community research

## Water cycle and Soil-related aspects



**water  
technologies :  
results and  
opportunities**

## GLOBAL CHANGE AND ECOSYSTEMS



SIXTH FRAMEWORK  
PROGRAMME

EUROPEAN COMMISSION

**Water Cycle and Soil-related aspects**

**WATER TECHNOLOGIES: RESULTS AND OPPORTUNITIES**

RESEARCH DIRECTORATE-GENERAL  
Global Change and Ecosystems

2004

## LEGAL NOTICE

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which can be made of the following information.

The views expressed in this publication are the sole responsibility of the author and do not necessarily reflect the views of the European Commission.

A great deal of additional information on the European Union is available on the Internet.

It can be addressed through the Europa server (<http://europa.eu.int>)

©European Communities, 2004

Reproduction is authorised provided the source is acknowledged

Printed in Belgium

## INTRODUCTION

European research is delivering more than knowledge; indeed it is providing sustainable solutions to problem owners. The ‘problem solving’ approach combines scientific expertise with industrial involvement to secure reliable and exploitable results with highly marketable potential. However research is not limited to looking at today’s drawbacks. European research projects are anticipating future threats and challenges and are already now delivering strategies and tools for the future.

Since decades Community Research is supporting efforts towards environmental technologies. A wide diversity of activities with relevance to the water sector are promoted and financed by consecutive Framework Programmes.

The completed FP5 (1998-2002) was designed across few thematic programmes subdivided in Key Actions. During this period about EUR 250 million have been dedicated to the research and technological development activities supported by the Key Action “Sustainable Management and Quality of Water”. The main topics for research were:

- Integrated management and sustainable use of water resources at catchment scale
- Ecological quality of freshwater ecosystems and wetlands
- Treatment and purification technologies
- Pollution prevention
- Surveillance, early warning and communication systems
- Regulation of stocks and technologies for arid and semi-arid regions, and generally water deficient regions
- Pre-normative, co-normative research and standardisation

More than 180 RTD contracts have been initiated and many of them are now completed. The intention of this publication is to present briefly results of some technological projects with relevance to the water and soil sector, describing the main achievements, the market potential as well as the exploitation perspectives.

The selection of projects presented here is certainly non exhaustive and definitely not prejudging on the quality and potential impact of other projects. In a limited number of pages addressing a variety of research topics, some examples of completed projects, contributing with technological achievements to areas as waste water, drinking water, industrial water, monitoring and sensor development as well as management and decision making tools, are briefly presented

The **IcoN** project has delivered a new and attractive biological treatment of ammonia-rich effluents at reduced costs. Based on the recently discovered anaerobic ammonium oxidation bacteria, combined with a new sensor and improved control, the system allows nitrogen removal using less energy and oxygen than conventional systems and not requiring any carbon source.

Heavy metals are of concern in waste water streams since decades. Recent achievements obtained by the project **METASEP** have demonstrated the potential of new materials, separation technologies and hybrid processes to advantageously remove toxic metals from industrial waste waters. The project led to the patenting of a combined flotation/membrane process.

After three years of intensive research, validation and demonstration, the **SMAC** consortium is capitalising on a reliable control system for waste water treatment plants combined with innovative concepts as Aeration Tank Settling or biological P removal by intermittent control that can lead to impacting economies in terms of operational costs. In various examples, substantial treatment costs reduction –up to -30%- were demonstrated.

To reduce operational costs is a constant challenge for drinking water distribution. A reliable, safe and economical control system for network management has been developed by the **POWADIMA** consortium and successfully applied in two cases studies with demonstrated economic savings of about 18 and 24 %.

Cyanotoxins are a threat for human health when present in drinking water. The **PHOTOX** project has developed a system combining a photocatalytic process with a reliable monitoring system aiming at safely remove cyanotoxins and bacterial pathogens.

Groundwater is particularly vulnerable to diffuse sources of pollution. Nitrates, persistent organic pollutants and chlorine resistant micro-organisms removal from drinking water is achieved using the electrochemically assisted photocatalytic reactor developed in the **PEBCAT** project.

A new and economical mixing and aeration system initially developed for destratification of water reservoirs in the project **AQUAERATION** is now being evaluated for many other potential uses as fish farming, sewage treatment and other industries.

The **INNOWASH** project has successfully achieved its main objectives and has delivered new sensors and control software for the European textile industry enabling water savings of 50% and more in the washing processes that can be combined with an economic waste water treatment and recycling.

Many industrial sectors are using high pressure water cleaning. Efficient and safe technologies have been investigated during the completed project **WATER SAVING PUMP**. A case study in a slaughterhouse demonstrated that the new high-pressure pump technique combined with new types of nozzles have achieved savings of 20% and 15% in terms of water and energy consumption respectively.

An innovative concept based on immunochemical technology for water monitoring was successfully developed and tested during the project **AWACSS**. The system is able to economically monitor on real-time trace levels of organic micro pollutants in water.

The project **PHYTO-PLANKTON-ON-LINE** has developed a monitoring instrument based on delayed fluorescence, enabling real time monitoring of phytoplankton and of the potential risk of shift to toxic cyanobacteria, due to eutrophication.

Innovative geophysical radar-based techniques have been applied by the **GEOWATERS** consortium to monitor contaminated sediments in rivers, canals lakes and harbours. The new and submersible GeoRadar antenna integrated with advanced data processing and interpretation modules is offering an attractive alternative to conventional site surveys.

The **MULINO**'s main achievement is a stand-alone software and methodology facilitating decision-making mechanisms for integrated water management. The developed and tested tool successfully integrates hydrologic modelling, multi-disciplinary indicators and multi-criteria evaluation procedures satisfying interoperability of data formats.

Communication and information tools and guidelines are essential to support participatory processes and governance of water resources. The **GOUVERNe** project has produced new ICT systems and methodologies to organise and present information, policy scenarios and evaluation indicators enabling improved and responsible water management.

The Commission published in January 2004 the communication “Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union”<sup>1</sup> with the aim *‘to harness their full potential to reduce pressures on our natural resources, improve the quality of life of European citizens and stimulate economic growth’*.

The common challenge of the examples presented here is to pass from the development of a new ‘technology’ to its marketing. This passage is not easy, and maybe only few of the technologies presented here will succeed to reach the marketplace. However, the Environmental Technologies Action Plan is aiming at removing the barriers that make today this process sometimes long and difficult

The water and soil-related environmental technologies have been recognised as key issues needing increased and focused research, demonstration and dissemination. The Commission is committed to support those objectives through a new focus of the current and coming research activities and work programmes. The on-going establishment of a Technology Platform on Water Supply and Sanitation is a major and ambitious step in this direction.

Andrea Tilche

Head of Unit

Water cycle and Soil-related aspects

Additional sources of information:

FP5 Projects information: [http://www.cordis.lu/eesd/src/proj\\_env.htm](http://www.cordis.lu/eesd/src/proj_env.htm)

FP5 Project results: <http://www.forum.europa.eu.int/Public/irc/rtd/eesd/watkeact/home>

FP6 Programme: <http://www.cordis.lu/sustdev/environment/home.html>

---

<sup>1</sup> COM(2004) 38 final <http://europa.eu.int/comm/environment/etap/etap.htm>

# PRESENTATION OF RESEARCH PROJECTS RESULTS

## TABLE OF CONTENTS

1.	ICON: IMPROVED CONTROL AND APPLICATION OF NITROGEN CYCLE BACTERIA FOR AMMONIA REMOVAL .....	8
2.	METASEP: SELECTIVE SEPARATION OF TOXIC METALS FROM SPECIFIC INDUSTRIAL WASTEWATER STREAMS FOR WATER AND METALS RE-USE .....	13
3.	SMAC: SMART CONTROL OF WASTEWATER SYSTEMS .....	19
4.	POWADIMA: POTABLE WATER DISTRIBUTION MANAGEMENT.....	26
5.	PHOTOX: PHOTOCATALYTIC DESTRUCTION OF CYANOTOXINS AND PATHOGENS IN POTABLE WATER .....	31
6.	PEBCAT: PHOTO-ELECTRO-BIO-CATALYTIC TREATMENT OF DRINKING WATER SUPPLIES .....	37
7.	AQUAERATION: IMPROVED RESERVOIR WATER DESTRATIFICATION .....	42
8.	INNOWASH: MINIMIZATION OF WATER CONSUMPTION IN EUROPEAN TEXTILE DYEING AND PRINTING INDUSTRY USING INNOVATIVE WASHING AND WATER RECYCLING TECHNOLOGIES .....	47
9.	WATER SAVING PUMP: NEW WAY OF WATER AND ENERGY SAVING CLEANING TECHNIQUE TO IMPROVE THE HYGIENIC RESULT .....	51
10.	AWACS : AUTOMATED WATER ANALYSER COMPUTER SUPPORTED SYSTEM .....	55
11.	PHYTO-PLANKTON-ON-LINE: INTERACTIVE REGULATION OF PHYTOPLANKTON SUCCESSION BY PHYSICAL FORCING AND INTERNAL PHOSPHORUS LOADING: A COMPARATIVE STUDY IN EUTROPHIC FRESHWATER LAKES FROM DIFFERENT CLIMATIC REGIMES .....	60
12.	GEOWATERS: INTEGRATED GEOPHYSICAL TECHNIQUES FOR SURVEYING AND QUANTIFYING POTENTIALLY POLLUTED SEDIMENTS IN EUROPEAN WATERWAYS .....	63
13.	MULINO: SUPPORTING INTEGRATED DECISION-MAKING FOR SUSTAINABLE MANAGEMENT OF WATER RESOURCES IN EUROPEAN CATCHMENTS.....	68
14.	GOUVERNE: GUIDELINES FOR THE ORGANISATION, USE AND VALIDATION OF INFORMATION SYSTEMS FOR EVALUATING AQUIFER RESOURCES AND NEEDS.....	75

# 1. ICON: IMPROVED CONTROL AND APPLICATION OF NITROGEN CYCLE BACTERIA FOR AMMONIA REMOVAL

Contract: EVK1-CT-2000-00054

Duration: Feb 2001-Jan 2004

URL: <http://www.bt.tudelft.nl/content/icon.html>

## 1.1. Introduction

It is evident that the protection of our water resources is of major importance on a global scale. This is for example reflected in directive 91/271 of the European Community, which “aims to protect the environment from any adverse effects due to discharge of (untreated) urban and industrial waters”. An increasing population and industrialization will increase our water demand, placing even more pressure on water resources. Conventional wastewater treatment plants have not been designed for nitrogen removal, and many plants do not meet the current discharge standards of 10 mg N per liter.

Thus many cost-effective wastewater treatment plants with less input of energy and chemicals are needed to improve the current quality of the effluents. In this way, the quality of water being returned to rivers and other water sources will be significantly improved.

In the icon project, a new combined system is tested and investigated for nitrogen removal based on partial nitrification of ammonia to nitrite, together with anaerobic ammonium oxidation (anammox). Such system has no need for external carbon addition, has hardly any sludge or CO<sub>2</sub> production, and uses less energy and oxygen than conventional systems.

### FISH analysis of SBR 1 biomass after 60 days

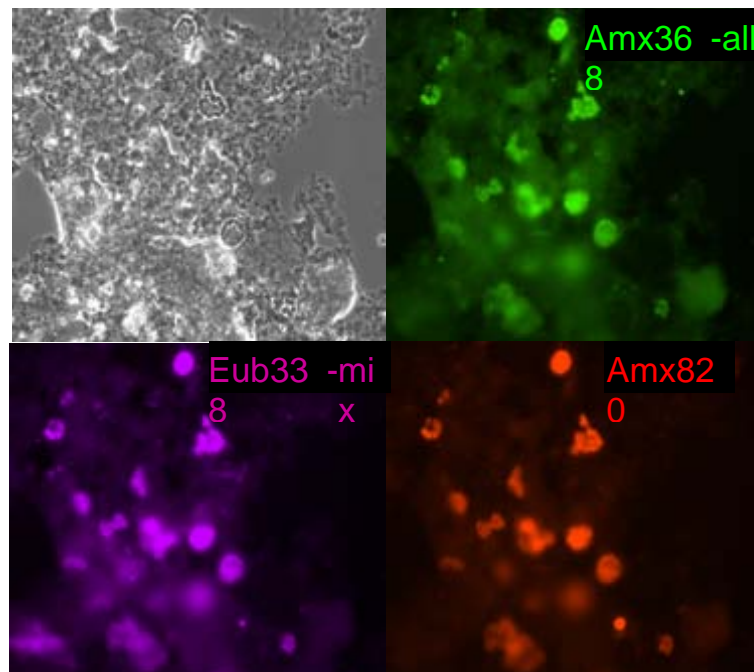


Figure 1. Fluorescence in situ hybridization of anammox biomass enriched from the Dokhaven treatment plant in Rotterdam during the icon EU research project in a sequencing batch reactor (SBR1). Gray, phase contrast of anammox aggregate; Green all anammox bacteria; Purple all bacteria ; Red all fresh water anammox bacteria.



## THE NEW COMBINED SHARON AND ANAMMOX PROCESSES

The introduction of anammox to N-removal would lead to a substantial reduction of operational costs. Wastewater that contains high amounts of ammonium and little organic COD, such as sludge liquor or landfill leachate are prime targets for an anammox application (Jetten et al 2002). The anammox process would replace the conventional denitrification step completely and would also save half of the nitrification aeration costs. Before anammox can be applied, several important questions need to be answered.

1. Firstly, can the anammox community cope with the variable and harsh conditions of wastewater treatment, compared to the optimal laboratory conditions it has been studied in?
2. Secondly how can the process be introduced most efficiently and what source can be used for the start-up of the anammox reactors?
3. Thirdly, how should the nitrification and anammox steps be engineered and designed?
4. Fourthly, what parameters should be monitored during start-up and steady state operation of such systems?

These questions have been the subject of the multi-disciplinary research project icon sponsored by the European Commission.

## New Nitrite Biosensor (UAA/Unisense)

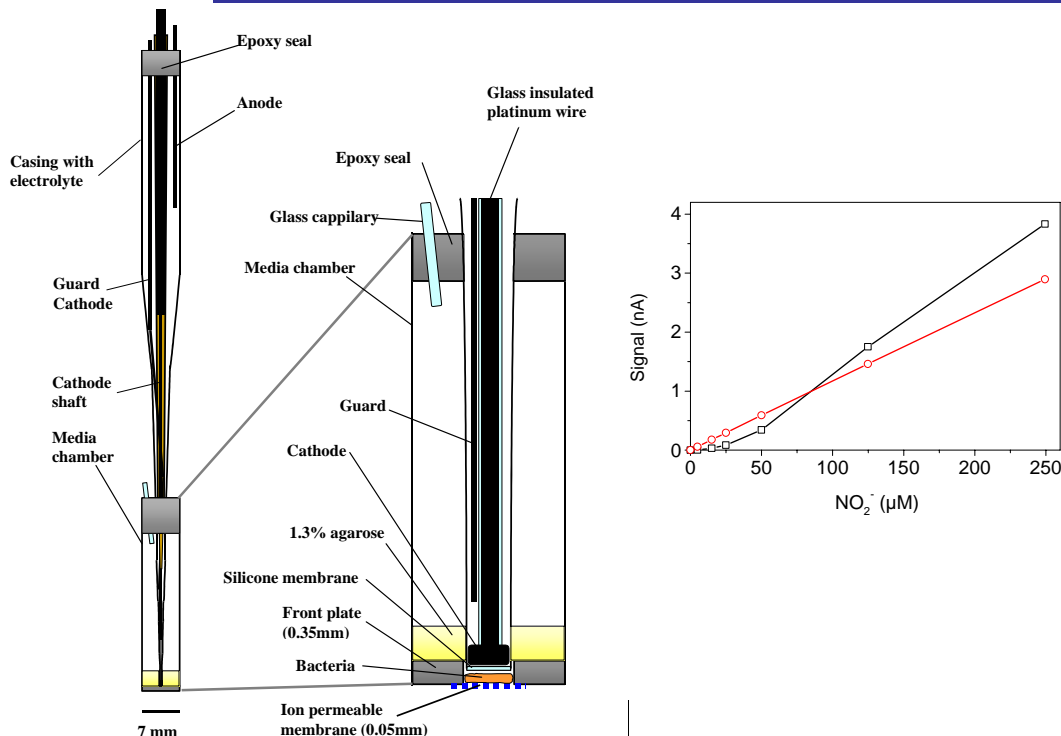


Figure 2. New nitrite biosensor developed during the icon EU project for the on-line monitoring of nitrite in anammox reactor.

## 1.2. Main achievements of the icon consortium

New sensors for on-line monitoring of nitrogenous compounds in wastewater

- Development of new more sensitive N<sub>2</sub>O sensor for commercial application
- A new very sensitive oxygen micro-sensor for laboratory application
- A new and very robust Nitrate and nitrite biosensor for commercial application
- A new ammonia biosensor for research application

Detailed insight in the complex anammox community

- Development of new nitrate reductase probes
- Development of new FISH probes for microscopic evaluation of the anammox biomass
- Discovery of new anammox strains in natural and man-made ecosystems
- Analysis of the flux of nitrogen compounds in the anammox community using <sup>15</sup>N isotope pairing

Preparation of full scale implementation

- Mathematical model of anammox and competing processes
- Performance evaluation of Sharon and anammox reactors using the model
- Development of a control strategy for start up and operation of an anammox reactor
- Strategy for start-up of anammox reactors
- Design of an new anammox pilot plant
- Testing and evaluation of the new anammox pilot plant to design criteria for full scale implementation

## 1.3. Market Potential

The market potential of the Anammox<sup>®</sup> process is tremendous. In principle the Anammox<sup>®</sup> process is suitable for any wastewater containing relative high ammonium concentrations and relative low concentrations organic matter. Wastewater with these characteristics can be produced both in industrial processes as well as in municipal wastewater treatment plants. Compared to conventional nitrification/denitrification the operational costs are reduced by up to 90 %, while CO<sub>2</sub> emission is reduced by 88%. This combination of economic advantage and sustainability makes Anammox<sup>®</sup> a very attractive process for the removal of nitrogen.

Most of the research & development work done by the Universities of Delft and Nijmegen is related to rejection water of sludge digestion plants of municipal wastewater treatment plants. Therefore the market introduction of the Anammox<sup>®</sup> process was initially focused on this application. This resulted in the realization of the demonstration plant at the location Sluisjesdijk/Dokhaven in Rotterdam of the Waterboard Zuid-Hollandse Eilanden en Waarden (ZHEW), as part of this EU 5th Framework Programme project ICON. The market potential for this application is estimated at a total of 50-100 plants in countries like the Netherlands, Belgium, Germany, Denmark, Switzerland and the United Kingdom. Furthermore in countries like Japan and the United States of America interest in the Anammox is growing. In 2002 Paques signed a license agreement with the Japanese company Kurita Water Industries Ltd. for the marketing&sales of the Anammox<sup>®</sup> process in Japan. It is expected that the first full scale Anammox<sup>®</sup> plant will be started up in 2005 in Japan.

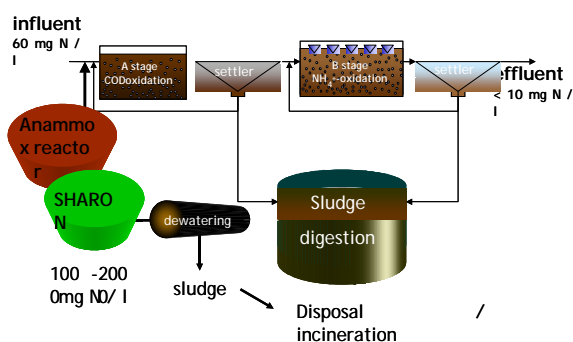
Besides the municipal waste water treatment market, Paques also focused their marketing of the Anammox<sup>®</sup> process on industrial applications. Industries that have been identified as

possible markets for the Anammox<sup>®</sup> process are: food industries, manure processing industries, fertilizer industries, (petro)chemical industries, organic solid waste treatment (landfill, composting, digestion), base metal industry (cokes oven gas).

Figure 3. Schematic representation of the planned implementation of a combined sharon-anammox process for the removal of ammonium from sludge digestion effluent and picture of the demonstration anammox reactor of the icon EU research project at Rotterdam Dokhaven (Courtesy ZHEW and Paques).



### Anammox reactor at WWTP Rotterdam Dokhaven-Sluisjesdijk



Courtesy Paques & ZHEW

#### 1.4. Marketing Strategy

The marketing strategy of Paques for Anammox<sup>®</sup> applications in the industrial market already resulted in two full scale Anammox<sup>®</sup> plants. One plant removes ammonium from waste water originating from a tannery, this plant is started up in the 2<sup>nd</sup> quarter of 2004, while the other Anammox<sup>®</sup> plant, that will be started up in the 4<sup>th</sup> quarter of 2004, will treat effluent from a potato processing industry.

The Anammox<sup>®</sup> process can also play an important role in the treatment of wastewaters containing high concentrations organic matter and ammonium. Combining the Anammox<sup>®</sup> process with anaerobic waste water treatment in which the organic matter is converted in methane gas, results in a sustainable and economical solution for the treatment of these type of effluents.

To ensure an optimal roll out of the Anammox<sup>®</sup> process, Paques will make use of their extensive world wide network of License partners. However, the possibility of extension of the existing network with new partners is not excluded.

### **1.5. Composition of the Icon consortium**

1. TUD, Technical University Delft, the Netherlands  
(Co-ordinator: Prof. Dr. J. Gijs Kuenen, e -mail: j.g.kuenen@tnw.tudelft.nl)
2. PAQ, Paques Biosystems, Balk, the Netherlands (SME)  
    With their assistant contractor ZHEW (end user)
3. USC, University of Santiago de Compostela, Spain
4. UBM, University of Birmingham, United Kingdom
5. UAa, University of Aarhus, Denmark
6. RUG, Ghent University, Belgium
7. Unis, Unisense, Aarhus, Denmark (SME).

## **2. METASEP: SELECTIVE SEPARATION OF TOXIC METALS FROM SPECIFIC INDUSTRIAL WASTEWATER STREAMS FOR WATER AND METALS RE-USE**

Contract: EVK1-CT-2000-00083  
URL: <http://www.eurice.de/METASEP/>

Duration: Mar 2001-Feb 2004

### **2.1. Problems to be solved and state of the art in the removal of toxic metals from industrial wastewater**

Many industrial wastewater streams with high flows contain toxic metal cations or their oxyanions in varying concentrations which must be removed before water reuse or discharge. Some examples of such industries are:

- rinsing water in metal working enterprises containing Cu, Ni, Zn, Sn, Cd, Pd, Ag, Al, Au, Cr, Mo etc.
- rinsing water in the semiconductor industry containing Cu, Sn, Pb, Sb
- wastewater from the copper industry containing As and Se (IV) and Se (VI);
- other types of water, in which the presence of toxic metals causes problems:
  - production of drinking water from ground water contaminated with As;
  - treatment of mine water contaminated with different toxic metals (e.g. U, Ra, As).

When discharged directly into rivers, this wastewater poses a great risk to the aquatic ecosystem, whilst discharge into the sewage system negatively affects bio-sludge activity and leads to contamination of the excess sludge to be disposed of. As a result of the standards specified in the Water Resources Act, which was amended in 1986, industry takes precautions against these risks by treating dangerous components in a partial stream, i.e. before being mixed with other types of wastewater.

The conventional processes to treat this kind of water namely precipitation; precipitation/reduction; ion exchange/sorption bed filtration and the membrane processes: electro dialysis (ED), nanofiltration (NF) and reverse osmosis (RO) as well as process combinations (e.g. chemical precipitation and ion exchange; NF/RO and ion exchange; chemical precipitation and NF/RO and ion exchange etc), have the following disadvantages:

- high use of treatment chemicals;
- the large quantities of sludge produced have to be treated and disposed of;
- inadequate selectivity. Metal re-use can be too complicated and the disposal of the concentrates or sludge may present problems;
- very slow bonding kinetics for the metals and their oxyanions and therefore very large water treatment units and high investment costs are required;
- low capacity of ion exchangers and sorbents;
- the residual metal concentration in the treated water streams can be high and water re-use or discharge is problematic;
- fouling and scaling problems, very low membrane permeability and low water yield (up to 75%) are the main problems encountered with conventional membrane processes (ED, NF and RO). This entails high investment costs and periodical membrane cleaning while high quantities of wastewater are generated;
- treatment processes are periodical and not continuous, followed by a regeneration step in which regeneration chemicals and rinsing water are employed, ultimately generating a new quantity of wastewater;
- treatment of wastewater streams with large volume flow and high concentrations is mostly not cost-effective.

## 2.2. Main achievements of the project “METASEP”

The goal of the METASEP project was to avoid the main disadvantages of conventional processes for the removal of toxic metals from industrial wastewater by developing new technologies, new separation materials and new hybrid processes.

The Metasep technology comprises the following treatment stages:

**First step:** selective bonding of toxic metal cations or oxyanions to suitable, selective bonding agents (BAs)

### **Second step:**

Variant 1: separation of the formed BA-metal complexes by crossflow microfiltration / ultrafiltration (MF/UF) for wastewater with metal concentrations <50 mg/l (Fig. 1).

Variant 2: separation of the formed BA-metal complexes by a hybrid system of submerged MF membranes combined with flotation for wastewater with metal concentrations 50-500 mg/l (Fig. 2).

Variant 3: separation of the BA (produced on-site by electrocoagulation) and the metal complexes by MF for wastewater contaminated with problematic toxic metal anions (Se, As, Sb) (Fig. 3).

**Third step:** recovery, regeneration and recycling of the BAs with simultaneous production of metal concentrates for re-use (Fig. 1 and 2).

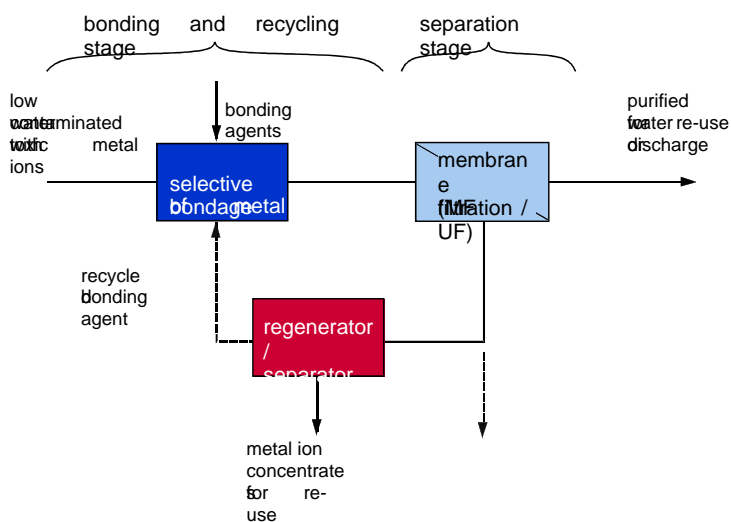


Fig. 1: MF/UF membrane separation of BA/metal complexes for wastewater with metal concentration < 50 mg/l

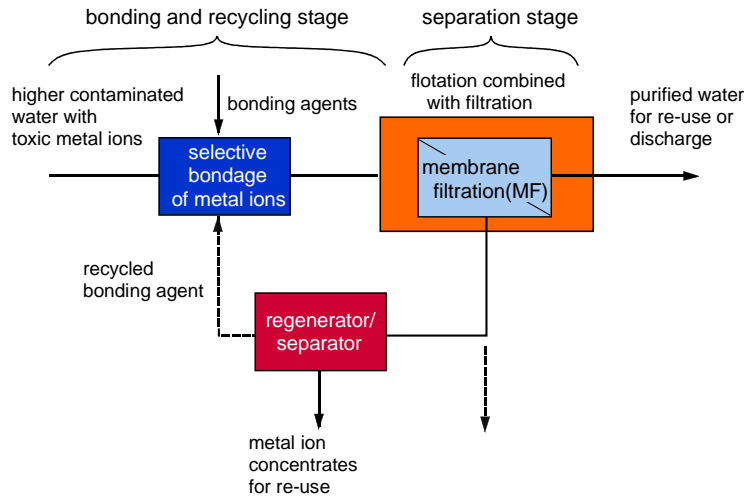


Fig. 2: Hybrid system - Flotation combined with MF/UF membrane separation of the BA/metal complexes for wastewater with metal concentration > 50 mg/l

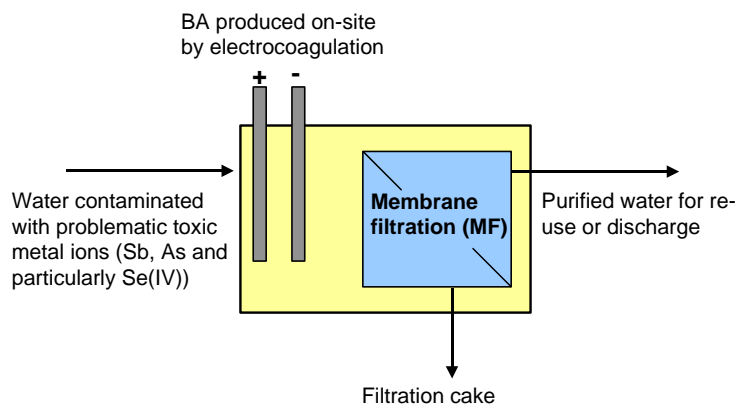


Fig. 3: Hybrid system - BA produced on-site by electrocoagulation combined with MF membrane separation for wastewater contaminated with problematic toxic metal anions (Sb, As and particularly Se(IV))

**The main achievements within the framework of the METASEP project are:**

**A) New technicological variants (Figs. 1, 2 and 3) for the treatment of water and wastewater contaminated with toxic metal**

**B) Selective bonding agents (BA):**

- water soluble: N-acylthiourea modified polymers (~20 kD), Carboxymethyl cellulose (CMC ~10 kD)
- powdered BA: powdered, modified ion exchangers (40-70 $\mu$ m), synthetic zeolites (2 $\mu$ m)
- on-line produced: iron hydroxides by electrocoagulation

**C) Membranes/membrane modules:**

- microfiltration polypropylene (PP) polymer hollow fibres with active layer outside, pore size 0.1 $\mu$ m,
- microfiltration (0.3 $\mu$ m) and ultrafiltration (100 kD cut-off) polyether sulphone (PES) polymer hollow fibres with active layer outside
- microfiltration PES polymer flat-sheet multi-channel membranes, pore size 0.3 $\mu$ m
- transversal flow modules for polymer MF/UF hollow fibre membranes

D) **Hybrid processes:**

- flotation combined with membrane filtration (submerged ceramic or polymer MF flat sheet multi-channel membranes)
- electrocoagulation combined with membrane filtration (submerged ceramic or polymer MF flat sheet multi-channel membranes)

E) **Regeneration of bonding agents:**

- modified electro dialysis (MED) for powdered strong cation exchanger and electro dialysis with bipolar membranes (EDBM) for water-soluble noncharged polymers

The newly developed METASEP technology has several innovative aspects, the most important of which are:

- high bonding selectivity for toxic metals versus other cations and anions;
- fast reaction kinetics resulting in smaller unit design (<10min contact time);
- low residual concentration of toxic metals in the treated streams
- innovative membranes and MF/UF modules resulting in low membrane fouling, higher membrane fluxes and lower specific energy consumption than in conventional modules;
- higher water yield (up to 85 - 99%);
- a continuous process combination using recycled bonding agents;
- high concentration of specific metals in the regenerant. Metal re-use is less complicated;
- an innovative hybrid membrane process;
- an innovative continuous regeneration/recovery step for the bonding agents with MED and EDBM;
- reduced consumption of water, energy and chemicals and reduced production costs.

**2.3. Market potential and marketing strategy of the main achievements of the project “METASEP”**

The market potential and marketing strategy of the developed METASEP technologies and separation materials and processes can be divided into 3 groups:

- a. Companies generating wastewater contaminated with toxic metals
  - mining companies
  - metal-working companies
  - companies in the electroplating industry
  - copper producers
  - automobile industry
  - producers of drinking water from ground water
- b. Companies producing water / wastewater treatment plants
- c. Companies producing separation elements and apparatuses
  - bonding agents
    - modified powdered ion exchangers
    - zeolites
    - water-soluble polymers
  - membranes and modules
    - MF/UF polymer hollow fibre membranes



- MF polymer flat sheet multi-channel membranes
- transversal module
- MED/EDBM – apparatuses for regeneration
- Hybrid apparatuses: flotation/membrane filtration, electrocoagulation/membrane filtration

Please note: The membranes and membrane modules developed in the METASEP project can also be used for treatment of other water streams not contaminated with toxic metals e.g for drinking water production, membrane bioreactors etc.)

#### 2.4. Consortium of the METASEP project and persons to contact

The following tables give an overview of the consortium consisting of 13 partners, 2 subcontractors in 7 countries and the Industrial Advisory Board consisting of 7 partners in 5 countries.

**Table 1: Consortium**

No.	Organisation Name	Country
1	Saarland University, Dept. of Process Technology	D
2	Institute for Environmentally Compatible Process Technology (upt)	D
3	Aristotle University Thessaloniki	EL
4	Technical University Munich	D
5	Bourgas University, Dept. of Water Treatment Technology	BG
6	S-Search B.V. (Separation Research)	NL
7	Institute of Chemical Tech., Power Eng. Dept., Prague	CZ
8	Cebedeau, Belgian Centre for Water Research	B
9	Institute of Mechanics, Sofia	BG
10	General Technologies, Bratislava	SK
11	TNO Institute for Environmental Science	NL
12	Technical University of Brno, Subcontractor Eidos	CZ
13	University of Liège, Subcontractor University of Mining and Geology, Sofia	B, BG

**Table 2: Industrial Advisory Board**

No. Organisation Name	Country	Business Activity
1. ASSAREL-MEDET AD	BG	Copper mine
2. CIRCUIT FOIL LUXEMBOURG	L	Prod. of electrolytic copper sheets for printed circuits
3. EKORA Co. Ltd.	CZ	Decontamination of soil and ground water
4. ELHIM "ISKRA" J.Sc.Co.	BG	Battery company
5. ENTHONE-OMI (Deutschland) GmbH	D	Functional and decorative coatings and electronics
6. INEOS Silicas	UK	Prod. of products based on silica, alumina and zeolite
7. UMICORE s.a.	B and BG	Production of non-ferrous metals

<b>Persons to contact:</b>	<b>Assoc. Professor Dr. Valko Mavrov</b>	<b>Mr. Torsten Erwe</b>
	Dept. of Process Technology, Saarland University, D-66123 Saarbrücken Tel: +49 681 9345 317; Fax: +49 681 9345 380 e-mail: v.mavrov@mx.uni-saarland.de	Dept. of Process Technology, Saarland University, D-66123 Saarbrücken Tel: +49 681 9345 209; Fax: +49 681 9345 380 e-mail: t.erwe@ mx.uni-saarland.de

### 3. SMAC: SMART CONTROL OF WASTEWATER SYSTEMS

Contract: EVK1-CT-2000-00056  
URL: <http://www.smac.dk/>

Duration: Mar 2001-Feb 2004

#### 3.1. Goals

The overall objective of the project is to optimise the wastewater system operation by

- maximising the system capacity and availability dynamically.
- reducing the operating costs by improving the control basis
- minimising the pollutant load to the receiving waters
- increasing the reliability by monitoring the risk linked to uncertainty



To put the system spare capacity into use, an innovative, all-embracing control system with continuous on-line overview of the state of the whole system needs to be developed. This system will integrate control of wastewater collection and treatment.

The control system will incorporate the most disturbing event in the wastewater system, the storm water situation, and also long term performance planning to maintain the nutrient removal processes cost effective with better sustainability.

The individual aims of each of the 5 end-user WWTPs (Wastewater Treatment Plants) were dependent on the existing control structures and plant configurations. Hence, the goals for each plant differed accordingly, but with the central aim in focus.

#### 3.2. Main achievements in project and market potential

- ATS (Aeration Tank Settling) storm water control has increased the hydraulic capacity within existing volumes by 25%.
- Chemical consumption for precipitation has been reduced by 85%.
- Despite the reduced chemical consumption, the Total-P in the effluent was reduced to the lowest level ever, 0.65 mg P/l in the effluent.
- Total-Nitrogen in the effluent has been reduced by approx. 30% to 4 mg N/l in the effluent.
- BOD in the effluent has been reduced by 25%, but it is consider insignificant because of the low values.
- Efficient feed forward NH<sub>3</sub> control of MMBR (Moving Bed Biofilm Reactor) nitrifying process reduced the air and energy consumption for aeration by 40%.

More details of the improvements are mentioned below.

#### 3.3. ATS storm water control for recirculation activated sludge plants (patented process)

*Research group Denmark*

Owner of product: Krüger A/S (a Veolia Water Systems company)

The principle for ATS at a recirculating plant is shown in figure 2.1 below:

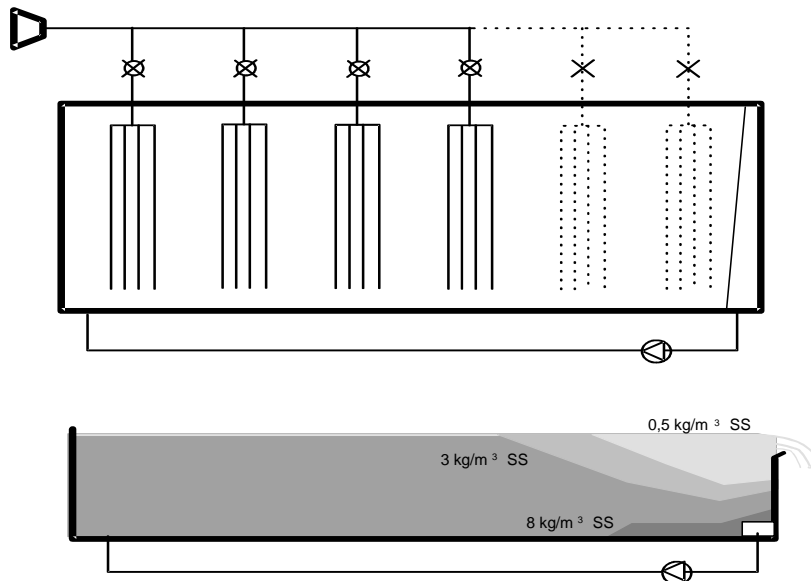


Figure 1: Principles of the patented Aeration Tank Settling (ATS).

In the last part of the aeration tank, the sludge settles periodically by stopping the aeration. When the sludge settles, the water to the clarifier from the top of the tank will carry less sludge, so the clarifier can handle much more water, without experiencing a sludge overload. The ATS control involves careful on-line control of intermittent aeration, internal recirculation rate, returned sludge flow and the limit for max. inflow capacity (the latest not implemented in Helsingør WWTP).

SMAC has demonstrated in full scale **to treat approx. 25 % higher inflow** using ATS for recirculating plants, with the necessary algorithms and programs implemented. Further improvements are expected by future prediction of inflow from sewer pumping stations for initial preparation of the plant before the high flow comes to the plant.

The market potential is huge, as most of the activated sludge BNR-plants worldwide are of the recirculating plant type, and the control method gives more capacity into the existing volume by “intelligent use”.

Krüger will use the project results to improve existing commercial STAR control® system ([www.star.kruger.dk](http://www.star.kruger.dk)) for marketing worldwide through Veolia Water Systems

### 3.4. Biological P removal by intermittent control

*Research group Denmark*

Biological phosphorous (bio-P) removal was introduced in a plant originally not designed for bio-P removal, by intermittent control of a pre-aeration tank.

The major positive effects (please see figure 2) are primarily based on rule based improvements of Bio-P removal, and secondarily on feed forward pre-precipitation control improvements.

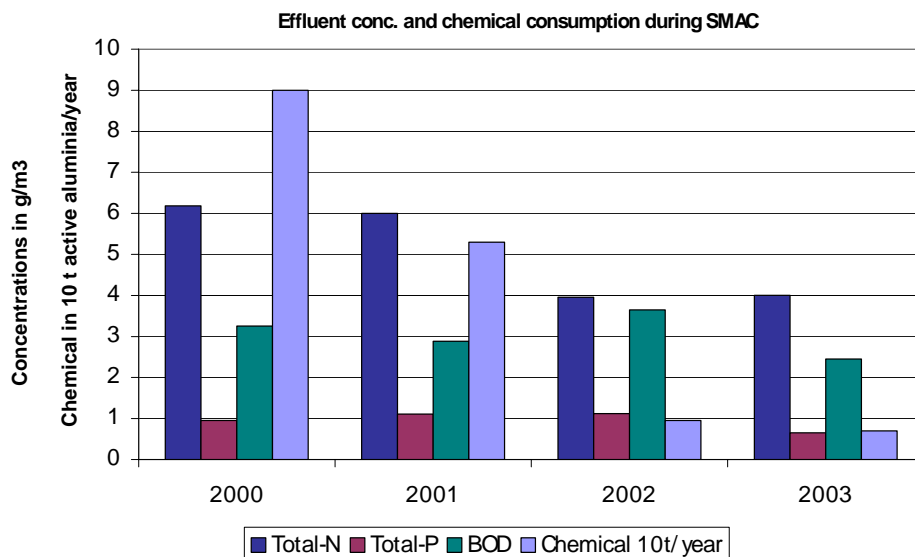


Figure 2: Results of SMAC at Helsingor WWTP, Denmark.

The improvements in the effluent are a result of both increased bio-P control by adapting aeration and hydrolysis time in the Mixed Liqueur Suspended Solids (MLSS), as well as lower suspended solids in the effluent (which contains N, P and BOD).

For the 72,000 PE test plant, the total savings in operating costs amount to 70,000 €/year.

The market potential lies primarily in wastewater treatment plants with surplus capacity, i.e. existing volumes may be exploited for additional purposes (nitrification, denitrification AND bio-P removal)

### 3.5. Control algorithms for ammonia removal by optimal adjustment of DO on MBBR (Moving Bed Biofilm Reactor)

*Research group Slovenia*

Slovenia tested both simple and more advanced MBPC (model based Predictive Control) controls on full scale maintaining the DO and air flow for aeration to meet effluent limits of NH<sub>4</sub>.

Feedforward NH<sub>3</sub> control (figure 3 and 4) showed the greatest improvement, so further complicated control loops were not found relevant in the pilot plant.

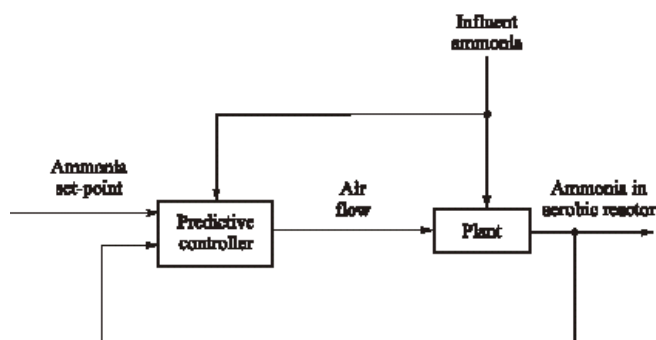


Figure 3: Slovenia. Layout of feedforward NH<sub>3</sub> control controller for optimisation of DO in MBBR.

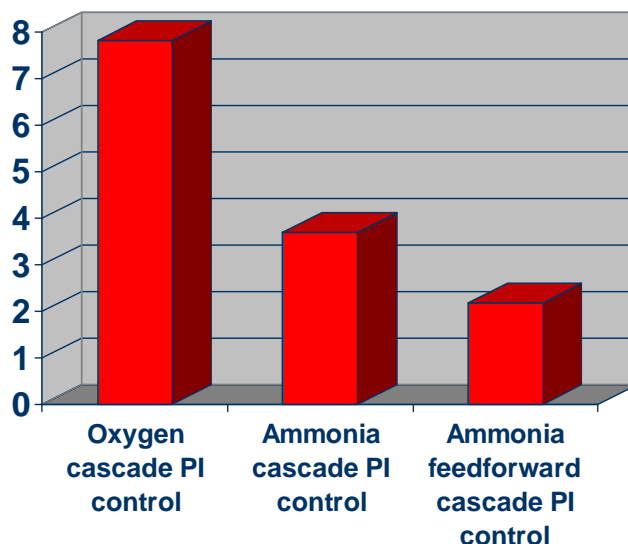


Figure 4: Slovenia. Comparison of different tested controls for optimisation of DO in MBBR.

Despite the best effluent result, the savings in electricity amount to 30,000 €/year for the 200.000 PE plant.

### 3.6. Optimisation of DO at the low level PID controllers using MBPC (Model Based Predictive Controller) techniques

*Research group Scotland*

Scottish partners found that tuning of controllers is possible with the layout in figure 5. The practical documentation was not possible at the test site, so process and economic performance effect has to be proved.

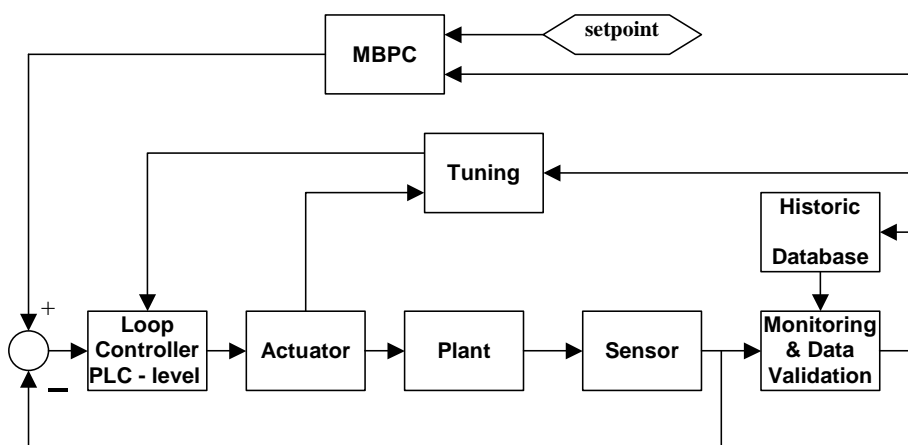


Figure 5: Scotland. Layout of controller for optimisation of DO.

### 3.7. Plant simulator, integrated MPC (Model Predictive Controller) control of sewer and equalisation tanks.

*Research group Poland/England*

Polish test plant installed many new sensors and improved their control capacity with university tools like Matlab directly connected to the SCADA system. A prototype is installed.

The results (Figure 6) showed especially a significant P reduction in the effluent.

A great interest is gained from many WWTPs in Poland in future co-operation with the universities for further development of the system

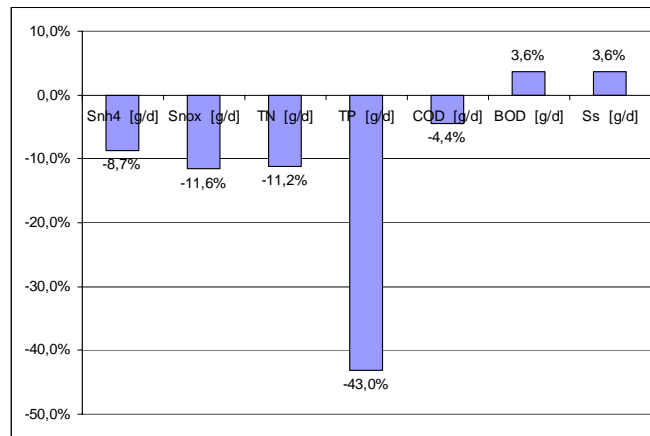
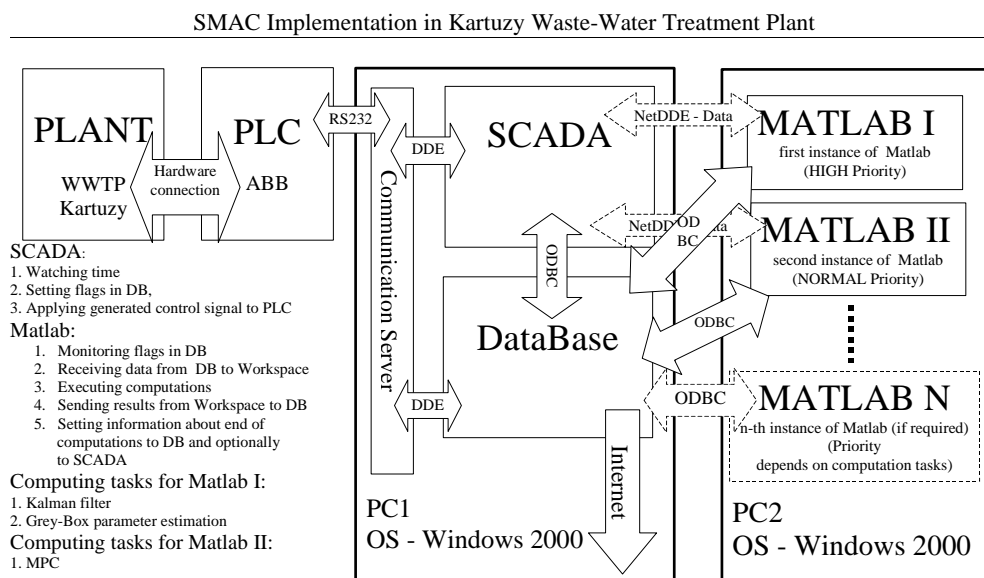


Figure 6: Comparison of effluent discharge using SMAC (simulations) and current plant control at Kartuzy WWTP, Poland.

The layout of the system is shown below

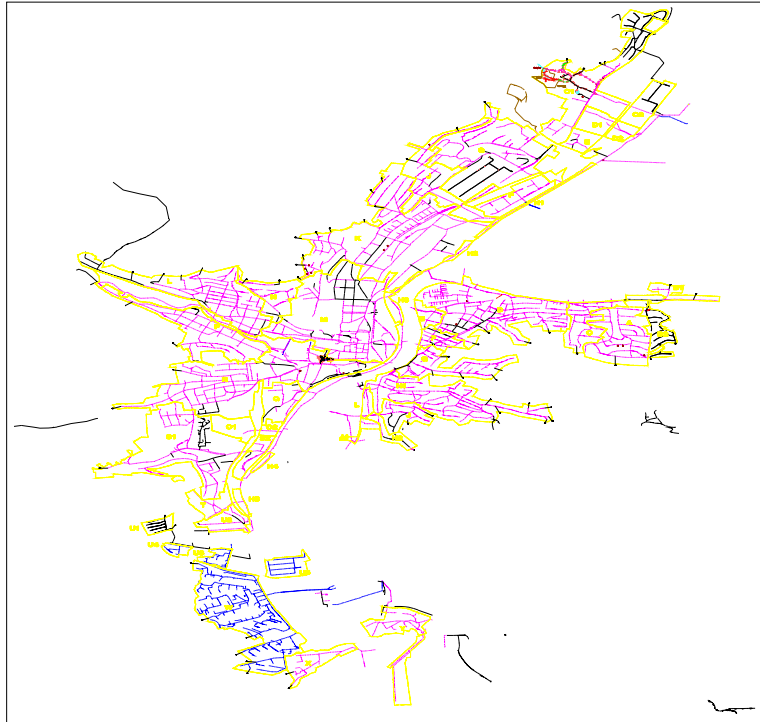


Abbreviations: DDE – Dynamic Data Exchange; NetDDE – Network Dynamic Data Exchange; PLC – Programmable Logic Controller; SCADA – Supervisory Control and Data Acquisition; ODBC – Open Database Connectivity; OS – Operating System; DB – DataBase; WWTP – Waste-Water Treatment Plant

### 3.8. An advisory system with on-line deterministic modelling of sewer & control of in-sewer weirs as well as WWTP

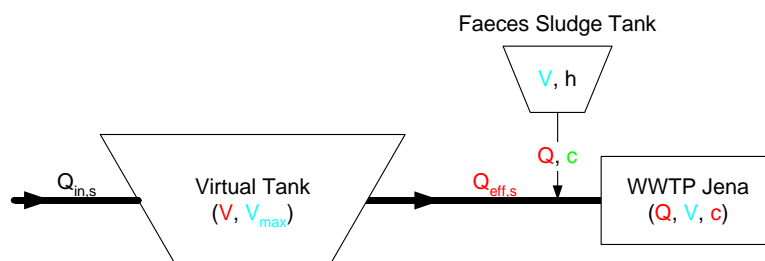
#### *Research group Germany*

The German group documented that to simulate optimal behaviour in the sewer system, it is reasonable to use a strongly simplified overall model to get advises of how to adjust the detailed control.



The sewer system shown above was simplified into the model shown below, where the total sewer system is reduced to one virtual tank. This parsimonic approach is a generic, useful tool when transferring from deterministic complex models or systems into on-line control models.

The market potential is large-scale WWTP in Germany



For the WWTP, the system gives advisory setpoints to the plant operator (e.g. DO-setpoints in aeration tanks).

### 3.9. Contacts

Below is a list of contact persons of the 13 partners of the project.

Contacts are split up into the 5 country sub-committees consisting of university/consulting and the linked end-user.

#### Denmark

Krüger A/S (member of Veolia Water Systems), consulting

Co-ordinator of the SMAC-project. Contact: Henrik A. Rønnow Thomsen, email: [hat@kruger.dk](mailto:hat@kruger.dk)



Danish Technical University, Department of Chemical Engineering. Contact: Prof. Sten Bay Jørgensen, email: [Sbj@kt.dtu.dk](mailto:Sbj@kt.dtu.dk)

End-user: Helsingør Municipality. Contact: Dines E. Thornberg, email: [Det59@helsingor.dk](mailto:Det59@helsingor.dk)

### **Scotland**

University of Strathclyde, Industrial Control Centre. Contact: Reza Katebi, email: [r.katebi@eee.strath.ac.uk](mailto:r.katebi@eee.strath.ac.uk)

End-user: Scottish Water. Contact: Glen Dickson, email: [glen.dickson@scottishwater.co.uk](mailto:glen.dickson@scottishwater.co.uk)

### **Poland/England**

Technical University of Gdansk, Faculty of Electrical and Control Engineering. Contact: Kazimierz Duzinkiewicz, email: [Kduzin@ely.pg.gda.pl](mailto:Kduzin@ely.pg.gda.pl)

University of Birmingham, School of Electronic and Electrical Engineering. Contact: Prof. Mietek Brdys, email: [m.brdys@bham.ac.uk](mailto:m.brdys@bham.ac.uk)

End-user: Water Supply and Sewage Enterprise Kartuzy (KPWIK). Contact: Andrzej Kwidzinski, email: [Kwidza@wp.pl](mailto:Kwidza@wp.pl)

### **Germany**

Fraunhofer Anwendungszentrum Systemtechnik, consulting. Contact: Dr-Ing. Eckhard Arnold, email: [and@ast.iitb.fhg.de](mailto:and@ast.iitb.fhg.de)

Technical University of Ilmenau, Dept. of Automation and Systems Engineering. Contact: Prof. Dr. Ing. Horst Puta, email: [Horst.Puta@systemtechnik.tu-ilmenau.de](mailto:Horst.Puta@systemtechnik.tu-ilmenau.de)

End-user: JenaWasser. Contact: Werner Waschina, email: [abwasser@stadtwerke-jena.de](mailto:abwasser@stadtwerke-jena.de)

### **Slovenia**

Institut "Jozef Stefan", Department of Computer Automation and Control. Contact: Nadja Hvala, email: [nadja.hvala@ijs.si](mailto:nadja.hvala@ijs.si)

End-user: Centralna cistilna naprava Domzale-Kamnik d.o.o., Domzale. Contact: Marjeta Strazar, email: [marjeta.strazar@ccn-domzale.si](mailto:marjeta.strazar@ccn-domzale.si)

## **4. POWADIMA: POTABLE WATER DISTRIBUTION MANAGEMENT**

Contract: EVK1-CT-2000-00084  
URL: <http://www.ncl.ac.uk/powadima/>

Duration: Dec 2000-Feb 2004

### **4.1. Introduction**

At the present time, the operation of water-distribution networks is managed by skilled staff who use their experience and judgement in adjusting the control apparatus such as pumps and valves, to ensure customers' demands are met with the required delivery pressure. Bearing in mind the uncertainties associated with demands, not to mention the limitations of the control techniques currently available, it is perhaps not surprising that the tendency is to err on the side of caution by keeping pressures in the network higher than would be otherwise be necessary. If pressures were kept as low as possible whilst still complying with the statutory operational requirements (continuity of supply, minimum delivery pressure etc.), this would not only minimize pumping costs but also reduce leakage, which is a function of pressure. With the predictive and optimization techniques now available, it is almost certain that an objective control system could identify a better overall solution than would be achieved by human judgement alone, even for a simple network. Additional savings would accrue from the reduction in leakage and the ability to defer capital expenditure necessitated by genuine growth in demands.

### **4.2. Consortium members**

Bearing this in mind, a consortium was formed in January 2000, with the intention of improving the operational control of water-distribution networks. The partners were the University of Newcastle upon Tyne, UK; The Technion – Israel Institute of Technology, Israel; Universidad Politecnica de Valencia, Spain and Universita degli Studi di Ferrara, Italy. With funding from the European Commission under the Vth Framework Research Programme, they embarked on the POWADIMA research project.

### **4.3. Research project**

The main objective of the POWADIMA (Potable Water Distribution Management) research project was to establish the feasibility of introducing real-time, near-optimal control for water distribution. To that end, a control system was developed which responds to the frequent changes in demands, taking account of the electricity tariff structure and operational constraints. In meeting the prevailing and forecast demands on the network, the aim was to minimize pumping pressures (hence the acronym POWADIMA) and exploit the tariff structure, thereby reducing operating costs. This is updated at short, regular intervals to account for the highly-variable fluctuations in demands. Since networks are not 100 percent reliable, consideration was also given to contingency measures for pump failures, pipe bursts etc. Subsequently, in order to improve the credibility of the generic control system developed, it was applied to two case studies of different sizes.

### **4.4. Approach adopted**

Although the use of a conventional hydraulic simulation model has its limitations for real-time control because of the computational burden optimization imposes, nevertheless a process-based model is required to predict the physical consequences of different pump/valve settings, since it would be somewhat impractical to experiment with the real network. One possibility for addressing this conundrum that has been adopted in this

research project, is to capture the domain knowledge of the hydraulic simulation model in a far more computationally-efficient form, using an artificial neural network (ANN). This facilitated the use of an optimization technique, which in this case was based on a genetic algorithm (GA). Whereas the ANN-predictor is used to estimate the consequences of different pump and valve settings, the GA-optimizer selects the best combination.

Rather than simply reacting to changes in demands, water-distribution management has been treated as a feed-forward control system in which operational decisions are taken on the expected future demands as well as the present known demands. Therefore, the control system contains a short-term demand-forecasting module, which is capable of predicting the demands on different parts of the network up to an operating horizon, say, 24 hours ahead. In this way, the control system can not only select the best combination of control settings for the current time step but also those for each time step up to the operating horizon, thereby minimizing the overall energy costs by taking account of low-cost periods in the electricity tariff structure. A dynamic version of the GA-ANN control system, referred to as DRAGA-ANN (dynamic, real-time, adaptive GA-ANN), has been developed which automatically adjusts itself at each update of the Supervisory Control and Data Acquisition (SCADA) facilities.

#### **4.5. Perceived advantages**

Besides the crucial advantage of reducing the computational burden so that the control settings can be adjusted every 15 minutes if necessary, the GA-ANN approach introduces a high level of realism. Unlike some analytical techniques, the use of an ANN-predictor builds on a detailed understanding of the physical processes involved. Obviously, the methodology is conditional upon being able to model the real network with a reasonable degree of accuracy using a hydraulic simulation package but from there onwards, no further assumptions are required. The methodology is also rigorous inasmuch that whilst the global optimal cannot be guaranteed, it can be approximated to a degree which makes little or no practical difference. Additionally, the ability to separate the ANN-predictor from the GA-optimizer enables the control system to be updated easily, should the network be modified in any way. All that is required is to re-run the hydraulic simulation model with the revised configuration so that a new ANN can be trained. If additional control apparatus is to be installed, that might also require the GA to be altered slightly.

#### **4.6. Case studies**

Given that the two partners responsible for the case studies were located in Haifa and Valencia, there was obvious merit, as well as convenience, in selecting these cities for that purpose. Rather than using the whole of the Haifa network, only a portion has been considered, originally to give some variation in scale. This amounted to about 20 percent of the total network and is referred to as Haifa A. The Haifa A network, which is supplied from two directions, serves a population of some 60 000. It comprises 125 pipes configured to create 113 nodes, with 13 pumps grouped at 5 pumping stations. Moreover, there are 9 storage tanks and 1 operating valve. Minimum and maximum storage levels have been assigned to each tank, as well as some having prescribed minimum storage levels at a fixed time each morning. The aim was to minimize the pumping costs, subject to meeting the demands and complying with the operational constraints.

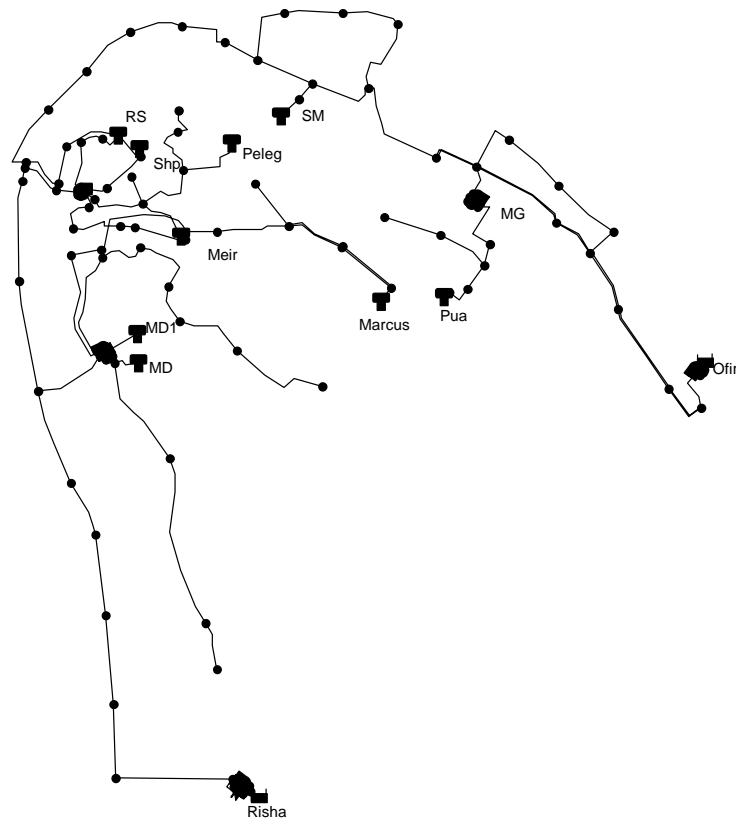


Figure 1 : Haifa A Water-distribution Network

The Valencia network which was used for the second case study, covers the whole city and outlying towns, serving a population of approximately 1 500 000 (Figure 2). Although the network contains some 30 000 pipes, for the purposes of operational control, this has been reduced to a 725-node network. Of the 20 pumps installed, 17 are operational, the other 3 being on standby. These are grouped at 2 pumping stations, one at each of the two treatment plants. The only storage available is located at the two treatment plants, which for the purpose of this exercise, has been regarded to be a composite tank at each. Flows in the network are controlled by hydrostatic pressure and 49 valves, 10 of which are operational. The aim was to minimize the operating costs, including the cost differential between the two treatment plants, subject to meeting the demands and complying with the operational constraints.

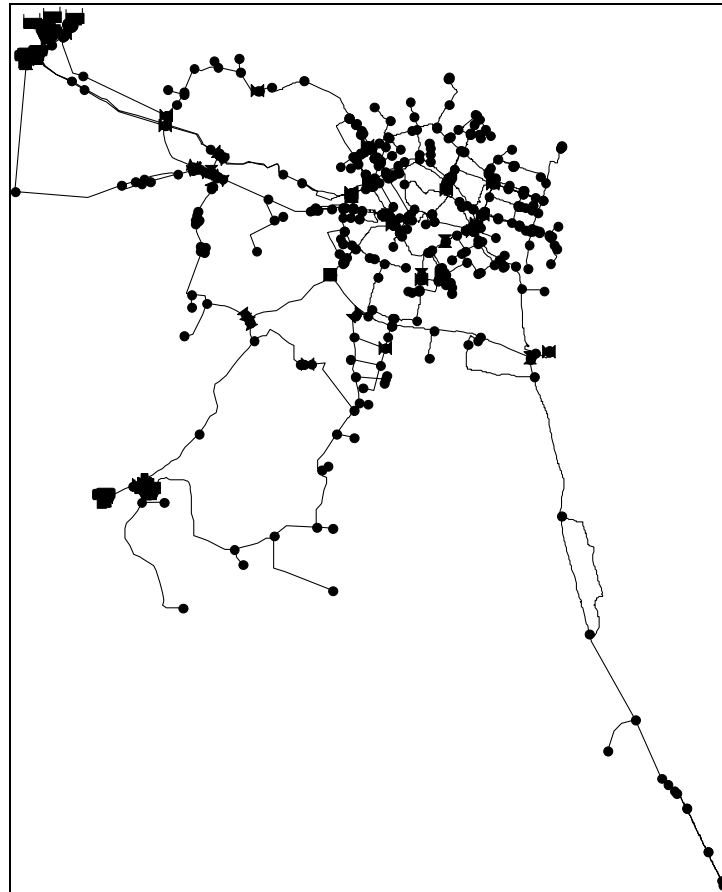


Figure 2 : Valencia Water-distribution Network

#### 4.7. Summary of results

Long-term simulation runs have been carried out to estimate the operating costs that would arise from adopting the control system developed. These have been compared with the present costs of operating each network. In the case of Haifa A, the reduction in operating costs that would accrue amounted to 24.1 percent, whilst that for the Valencia network was 17.6 percent. Additionally, it could be shown that the performance of each network was also significantly improved in terms of delivery pressures, compliance with operating constraints etc.

#### 4.8. Market potential

The control system that has been developed has worldwide application within the water sector, beginning with the more advanced countries of Western Europe, North America and Australasia. The process itself, is generic in the sense that it is applicable to any water-distribution network, or for that matter, any other type of network such as storm-water sewerage. Outside of the water sector, there could be interest from the gas industry to ensure compliance with statutory regulations without the need for excessive pressures in the distribution network. Elsewhere, the chemical industry may be attracted by the possibility of improving control of industrial processes. These and perhaps other sectors could well benefit from the methodology developed in this research project.

#### **4.9. Marketing strategy**

Having established the feasibility of introducing real-time, near-optimal control and the efficacy of doing so, the next phase is to implement the control system in three different countries. To that end, discussions are currently underway with the Haifa Municipality Water and Sewerage Department, Aguas de Valencia and Thames Water, with a view to having three separate prototype systems, which will accelerate the roll-out programme. Thereafter, it will be left to the individual partner, the local water company and their SCADA provider to agree terms for sharing any proceeds arising from sales of the control system to third parties.

#### **4.10. Contact details**

In the first instance, any enquiries relating to the POWADIMA research project should be directed to Prof. D. G. Jamieson who can be contacted at [dgjameson@ukonline.co.uk](mailto:dgjameson@ukonline.co.uk), telephone +44 118 984 5217, fax +44 118 984 1598. Contact details of the other partners can be found on the project website at <http://www.ncl.ac.uk/powadima>.

## 5. PHOTOX: PHOTOCATALYTIC DESTRUCTION OF CYANOTOXINS AND PATHOGENS IN POTABLE WATER

Contract: EVK1-CT-2000-00077

Duration: Dec 2000-Feb 2004

URL: <http://www2.rgu.ac.uk/subj/mes/cee/main/photoxfront.htm>

### 5.1. Introduction.

Water is becoming an increasingly scarce resource throughout the world and furthermore, many of these limited supplies have become nutrient enriched, supporting the growth of toxic cyanobacteria. Cyanobacteria (blue-green algae) produce several types of toxins that can be harmful to humans. The most frequently occurring are the microcystins, a group of at least 70 heptapeptides which share the common structure, cyclo(D-Ala-L-X-erythro-β-D-methyl aspartic acid-L-Y-Adda-D-isoglutamic acid-N-methyl dehydroalanine), where X and Y are variable L amino acids and Adda is a unique 20-carbon amino acid (3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid).

Microcystins are named according to the variable amino acids that they contain. Microcystin-LR (Figure 1), one of the most commonly occurring and frequently studied microcystins, contains leucine (L) and arginine (R) in the variable positions. It has been established that microcystin toxicity is due to their potent and irreversible inhibition of important regulatory enzymes (protein phosphatase 1 and 2A) which can cause both acute and chronic effects. Of great concern is the tumour promoting activity of microcystins and hence there have been recent moves to minimise exposure through the publication of a Guideline Value ( $1 \mu\text{g l}^{-1}$  in drinking water) by the World Health Organisation. The incidence of cyanobacterial blooms in freshwaters, including drinking water reservoirs, has increased over the past few decades due to the aforementioned rising nutrient levels. One particular concern associated with these toxins is their safe removal from drinking water and it has been shown in a number of studies that conventional water treatment strategies fail to reliably eliminate this potential threat to human health.

Safe drinking water does not only require the elimination of toxic contaminants but also the removal of pathogenic micro organisms. While current treatment systems have a good record for the inactivation of pathogens, it is important to evaluate new technologies for their suitability, hence both the destruction of cyanotoxins and bacterial pathogens have been explored in this project.

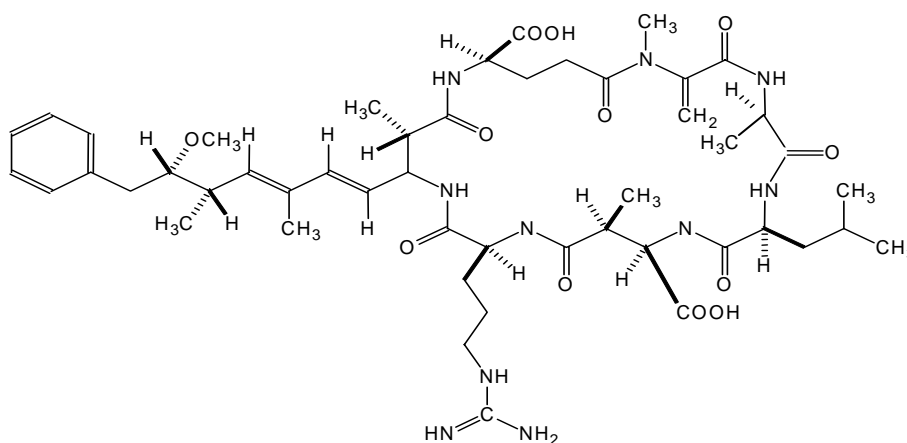


Figure 1. Microcystin-LR.

In recent years interest has focused on the use of titanium dioxide as a photocatalyst for the destruction of polluting materials. Semiconductor materials are flexible reagents for waste treatment. The catalysts are not consumed during the reaction and can carry out oxidations and reductions simultaneously. UV light of longer wavelengths can be used, possibly even sunlight.

In a typical experiment a reaction vessel containing the waste material and the semiconductor is illuminated and the waste is converted to a non-toxic form either by an oxidation or reduction process. The semiconductor and the treated effluent can then be separated by filtration. For example the treatment of a halo-aromatic with such a system would result in the production of carbon dioxide, water and the halide ion. The overall process for the photo-oxidation of waste materials (P), sensitised by semiconductors is shown in scheme 1.



The mechanism for the destruction is considered to be as follows. Hydroxyl radicals are generated via oxidation at the valence band. These radicals then oxidise the polluting material. Oxygen accepts an electron from the conductance band generating the superoxide radical anion. Some workers have suggested that the species being oxidised can transfer an electron directly to the valence band.

## 5.2. The Project.

The aim of this project was to develop a photocatalytic reactor with on-line monitoring for the treatment of drinking water. This included studies on the properties of  $TiO_2$ , and a detailed investigation into the photocatalytic destruction of cyanotoxins (RGU, ISFH, HUI). The development of pilot plant for treating drinking water contaminated with cyanotoxins and pathogens has been evaluated (ISFH, ecoTRANSfair) and elements of a biosensor for the on-line detection of cyanotoxins have been produced and assessed (RGU).

The main objectives of the PHOTOX project were:

1. Examination of the destruction of different classes of pathogenic micro-organisms and cyanotoxins.
2. Characterisation of the mechanism of destruction and the production of reaction intermediates particularly with respect to their toxicology.
3. Investigation of the destruction of micro-organisms and cyanotoxins in abstracted waters and at environmentally relevant concentrations.
4. Development of new catalysts and detailed examination of their properties.
5. Development of antibody-based biosensor for on-line monitoring of cyanotoxins.
6. Development and construction of a suitable reactor and optimise catalyst performance.
7. Evaluation of the efficiency of photocatalytic destruction in scaled-up pilot plant in water treatment plant.

Comprehensive study on the dependence of hydroxyl radical yield on the substrate concentration, pH, oxygen concentration, and light intensity, using different  $TiO_2$  preparations was carried out. The quantum yields of formaldehyde and carbon dioxide,



obtained with the aid of an integrating sphere in aqueous solutions of methanol, formic acid and formate systems, respectively, were determined. The limiting yield of  $\cdot\text{OH}_{\text{ads}}$ , at high scavenger concentrations, was found to be nearly independent, of the scavenger nature or pH within a wide range. Oxygen induces 15-20 folds increase in product yield, compared to air free systems, although the result is not sensitive to oxygen concentration.

The detailed mechanism of the above systems has been elucidated on the basis of known properties of the transient intermediates. The results of the study enable comparison of the quantum yield in  $\text{TiO}_2$  layers and suspensions. A rigorous treatment of the effect of absorbed photon density on the quantum yield enables the derivation of a constant,  $K_d$ , which is a measure of the efficiency of surface water oxidation to hydroxyl radicals. Unlike earlier works, where only reactant depletion and product formation rates have been reported (almost always without regarding for the absorbed light density), the parameter is a property of the  $\text{TiO}_2$ , and is not affected by the experimental conditions (wavelength, light intensity, layer thickness).

Comparison of  $K_d$  using different types of  $\text{TiO}_2$  shows that in contrast to commonly assumed, preparation methods and sizes of aged titanium dioxide nano-particles have only a relatively small effect on the basic photocatalytic efficiency.

Comparison of  $K_d$  values for a number of different titania shows clearly that the basic yield of hydroxyl radicals depends relatively little on particle size, pH, media and shape (powder, suspension, sol). This enables selection of appropriate photocatalytic titania on the basis of the nature of the substrates. Since the reaction rate usually increases with surface area, small nanocrystallites have a practical advantage for detoxification of small molecules, although the light absorption as well as yield of hydroxyl radicals is not affected. Coating the titania nano-particles with Pt metal increases the yield of oxidation. Our mechanistic studies imply that the platinum acts as an electrons sink, inducing charge separation, rather than enhancing the reduction rate of oxygen.

Mechanistic studies of microcystin model compounds show that the effect of sorbic alcohol ( $\text{CH}_3\text{CH}=\text{CHCH}=\text{CHCH}_2\text{OH}$ ) on decreasing the aromatic hydroxylation and increasing the peroxide yields in solutions containing 2-phenylethanol ( $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{OH}$ ) at pH 3 is considerably higher than expected on the basis of  $\cdot\text{OH}$  scavenging only. The mechanistic work on microcystin model systems explains the results of Liu, Lawton, and Robertson (*J. Environ. Sci. Technol.* 2003) who studied the intermediates of microcystin photocatalytic detoxification and observed no products that could be attributed to hydroxylation of the aromatic ring.

Degradation experiments have been carried out using the amino acids that are components of microcystin-LR. In each case the influence of several parameters was studied carefully. The results obtained for L-Leucine can be regarded as typical for the entire series of amino acids studied. It was found that the fastest overall degradation of L-Leucine occurs at pH 11 while its degradation at acid pH-values is considerably slower. It is furthermore interesting to note that the fastest mineralisation was achieved with a photocatalyst that is a pure rutile material. This is in clear contradiction with the common notion that anatase titania will usually be more active than its rutile form.

Using a standard protocol the optimum photocatalyst and reaction conditions were successfully determined also leading to an appreciation of the impact of potentially variable system parameters. We found that out of the five powder catalysts tested Degussa P25, the catalyst used throughout preliminary work, performed significantly better. However, the use of a powder catalyst does present problems due to the removal of the powder from the drinking water. While this is not insurmountable it will add to the cost of treatment hence

granular catalysts were also evaluated and these were found to effectively remove microcystin-LR but at a predicted slower rate.

In the study of factors that can be used to enhance the photocatalytic destruction we found that hydrogen peroxide was a suitable additive which enhanced the photocatalytic destruction of microcystin. A full evaluation was made of the resultant by-products produced in the presence of H<sub>2</sub>O<sub>2</sub>. While H<sub>2</sub>O<sub>2</sub> did significantly enhance degradation the feasibility of incorporating a dosing/monitoring system must be closely evaluated along with the safety implications.

Through the study of a number of microcystins and reaction conditions we are now able to describe how cyanotoxins interact with the TiO<sub>2</sub> photocatalyst. This work demonstrated how the dark adsorption of the pollutant to the catalyst (i.e. attraction to the catalyst surface) is important in achieving high destruction rates, although even when this is minimal destruction still occurs albeit at a greatly reduced rate.

Using appropriate bioassays we have clearly demonstrated that both the acute and chronic toxicity associated with microcystins has been eliminated through suitable photocatalytic treatment. Furthermore, we have also successfully evaluated the efficiency of microbial treatment using TiO<sub>2</sub> photocatalysis and three model bacterial pathogens. It has long been established that UV light alone can be used to kill bacteria in potable water, however some bacteria can repair the damage caused by UV light but when they are cultured on agar plates they are found to produce characteristic small colony variants (SCVs). Our studies demonstrated that the potential advantage of using TiO<sub>2</sub> photocatalysis is that it eliminates SCVs produced during UV treatment alone.

Several photocatalyst fixation techniques have been developed and compared with a standard method that utilises a commercially available titanium dioxide powder (Degussa P25) suspended in water to coat the surface of glass panes using a sedimentation technique followed by heat treatment at 100°C. Two new fixation techniques have been developed and compared with the above described sedimentation technique, i.e., a spraying and a sol-gel method. The spraying technique yielded very even photocatalyst coatings that exhibited almost identical activities when compared with panes prepared by the standard sedimentation technique. However, while the stability of the coatings obtained using the sedimentation and the spraying technique, respectively, still needs to be improved considerably, the titanium dioxide layers obtained with the sol-gel method were found to be mechanically very stable. Unfortunately, the wettability of the latter panes was found to be too poor to be employed in practical water treatment reactors. The direct coating of TiO<sub>2</sub> onto Polymethylmethacrylate (PMMA) following these dip- or spray-coating techniques was not successful. The layers are not stable and can be very easily washed off by soaking the panes in water. Therefore, the PMMA sheets were initially coated with a SiO<sub>2</sub> layer prepared from an acidified ethanolic solution of tetraethoxysilane under controlled hydrolysis at room temperature. Subsequently, the previously described spray technique was employed to coat the pane with commercially available titania. This preparation procedure results in the formation of rather stable coatings the activity of which was found to be even superior to that of glass panes coated by the same spray technique.

### **5.3. Main achievements:**

Following the previously developed concept of the so-called double skin sheet reactor (DSSR) that utilizes readily available industrial products (PMMA double skin sheets,

manufactured by Röhm GmbH, Darmstadt, Germany) to construct reactor plates with a meandering water flow a new type of reactor was designed, constructed and tested. This so-called Aerated Cascade Photoreactor (ACP) employs a constant flow of pressurized air to stabilize the catalyst/water suspension even at very low flow rates. Thus it should be possible to adjust the flow rate of the water to ensure its treatment within one single pass through the reactor sheet. To test the ACP reactor concept a small continuous solar pilot plant was designed and constructed employing a UV sensor to measure the intensity of the UV-A light impinging on the reactor surface. The volume flow of the water entering the reactor is automatically adjusted following the amount of UV light available by simply changing the pumping velocity. A simple sedimentor is used to separate the treated water from the photocatalyst that is recirculated into the reactor while the clear water is transferred into a tank. Tests of this pilot plant employing a model pollutant showed that it is indeed possible to achieve constant water quality at the reactor exit independent of the incident light intensity due to this regulation of the pumping speed.

Finally, one possible design of a pilot plant employing artificial illumination for the degradation of microcystin LR in water was developed, constructed and tested. In particular, this pilot plant consists of a tubular packed bed reactor surrounded by an array of tubular UV(A) lamps. This reactor can be operated in continuous or in batch mode, respectively. At the reactor outlet samples can be taken online and measured by TOC analysis. This pilot plant reactor has been designed to be used with newly developed large particle photocatalysts. The long-term mechanical stability of these photocatalytically active, porous spherical and cylindrical ceramics has been investigated by pumping water through a photocatalyst bed and measuring the weight of the photocatalyst at the beginning and at the end (after drying) of a run. Single lots of the photocatalysts tested showed a significant decrease in weight due to rubbing-down and decay of the photocatalysts. The photocatalytic efficiency of these materials for the degradation of microcystin-LR was also studied evincing that two of the newly prepared ceramic particles are rather efficient catalysts for the photocatalytic degradation of microcystin-LR successfully tested at the Robert-Gordon-University in Aberdeen.

While the evaluation of the technologies to eliminate of cyanotoxins in drinking water is crucial it is also essential that we can reliably monitor their removal. Within this project we evaluated the use of an antibody based detection system. Antibody fragments were produced using recombinant DNA technology to provide antibody fragment capable of detecting a range of microcystins and nodularin. The integration of these antibodies into a suitable sensor system has been evaluated with promising results.

This project has been extremely successful with both a significant number of publications and presentations to the international scientific community. We have clearly demonstrated the potential of this technology as a new potable water treatment system particularly well suited to the removal of cyanotoxins which may persist after conventional water treatment. This has been combined with both the evaluation of the removal of pathogens and the development of an antibody-based sensor for monitoring microcystin levels in treated water. Along with the technological advances, we have developed European wide expertise in advanced water treatment technology and enhanced collaborative links between partners.

#### 5.4. Contacts:

Linda A. Lawton<sup>a</sup>, Peter K.J. Robertson<sup>a</sup>, Detlef Bahnemann<sup>b</sup>, Joseph Rabani<sup>c</sup> and Ralf Dillert<sup>d</sup>.

*a The Robert Gordon University, Schoolhill, Aberdeen, AB10 1FR.*

*b Institut fuer Technische Chemie, Universitaet Hannover, Callinstrasse 3, D-30167 Hannover, GERMANY*

*c Department of Physical Chemistry, The Hebrew University of Jerusalem, Jerusalem 91904 ISRAEL*

*d ecoTRANSfair Gesellschaft fuer Umwelt und Gesundheit mbH, Rebenring 33, D-38106 Braunschweig, GERMANY*

## **6. PEBCAT: PHOTO-ELECTRO-BIO-CATALYTIC TREATMENT OF DRINKING WATER SUPPLIES**

Contract: EVK1-CT-2000-00069

Duration: Feb 2001-Apr 2004

URL: <http://www.engj.ulst.ac.uk/nibec/photocatalysis/pebcats.htm>

### **6.1. Problems to be solved**

The demand for wholesome clean drinking water supplies within Europe is increasing and, therefore, there is a need for novel treatment and purification technologies which, may be used to clean water not normally treatable by conventional means. A major percentage of drinking water in Europe is derived from groundwater resources. Groundwater is particularly vulnerable to diffuse sources of pollution, especially agricultural practices and the fallout of atmospheric pollution arising mainly from industry. Increased chemical and bacterial concentrations in excess of EC limits set in the Drinking Water Directive have been recorded in isolated wells for many years. Of particular concern is the contamination of groundwater with nitrates originating from agricultural fertilisers. Elevated levels of nitrates and nitrites in drinking water supplies may cause methaemoglobinaemia in infants (blue baby syndrome) and may also lead to the production of carcinogenic N-nitroso compounds in the human gut. There is also increasing concern about groundwater contamination with low level organic pollutants such as pesticides and herbicides. Where surface water and groundwater systems are linked there is the possibility of microbial contamination. The problem of groundwater contamination by *Cryptosporidium* was highlighted recently in the Bouchier report (*Cryptosporidium* in water supplies, 3rd report of the group of experts, UK, 1998).

The Commission has identified that there is a need to protect and conserve our groundwater resources. This development of a novel technology which, may be used to treat contaminated water to drinking water quality will help alleviate the demand on clean groundwater resources and therefore aid in their conservation and protection.

### **6.2. Scientific objectives and approach**

The main objective of the project was to develop a photo-electro-bio-catalytic (PEBCAT) reactor for the treatment of drinking water supplies contaminated with nitrates, persistent organic pollutants and chlorine resistant micro-organisms.

The consortium brought together into a fully integrated programme of fundamental research, academic expertise in photocatalysis, electrochemistry, electro-bio-catalysis, biotechnology, and chemical engineering, together with industrial expertise in water treatment engineering and technical-economic evaluation, manufacturing, and drinking water quality control.

The development of the PEBCAT reactor was pursued following two main approaches in parallel; 1. The development of photo-electrochemical cell utilising nano-crystalline TiO<sub>2</sub> for the photocatalytic oxidation of persistent organic pollutants and killing of micro-organisms. And 2. The development of an electro-bio-catalytic reactor (EBCAT) based on immobilised denitrifying bacteria for the removal of nitrates from water. The ultimate aim was then to combine the two reactors into one photo-electro-bio-catalytic reactor (PEBCAT) for the simultaneous treatment of water supplies contaminated with nitrates, persistent organic pollutants such as pesticides, and chlorine resistant micro-organisms.

The linking of photocatalysis to electro-bio-catalysis in an electrochemical device, for the treatment of water, appears as a completely novel idea.

### 6.3. Main Results

#### 6.3.1. Photoelectrochemical reactor for the electrochemically assisted photocatalytic treatment of drinking water.

A pilot scale photo-electrochemical cell (PEC) has been designed and constructed and is currently under test (Photo 1).



Photo 1. showing constructed pilot scale PEC

The reactor incorporates a UV transparent photoanode (225 mm x 290 mm) coated with nanocrystalline photocatalyst. Previous laboratory scale studies showed that the application of an external electrical bias to the photoanode resulted in a significant increase in the rate of degradation of certain model pollutants and the rate of inactivation of microorganisms including chlorine resistant spores of *Clostridium perfringens*. Furthermore, it has been shown that photocatalysis is effective for the inactivation of chlorine resistant *Cryptosporidium* oocysts which if ingested can cause severe diarrhoea (figure 1).

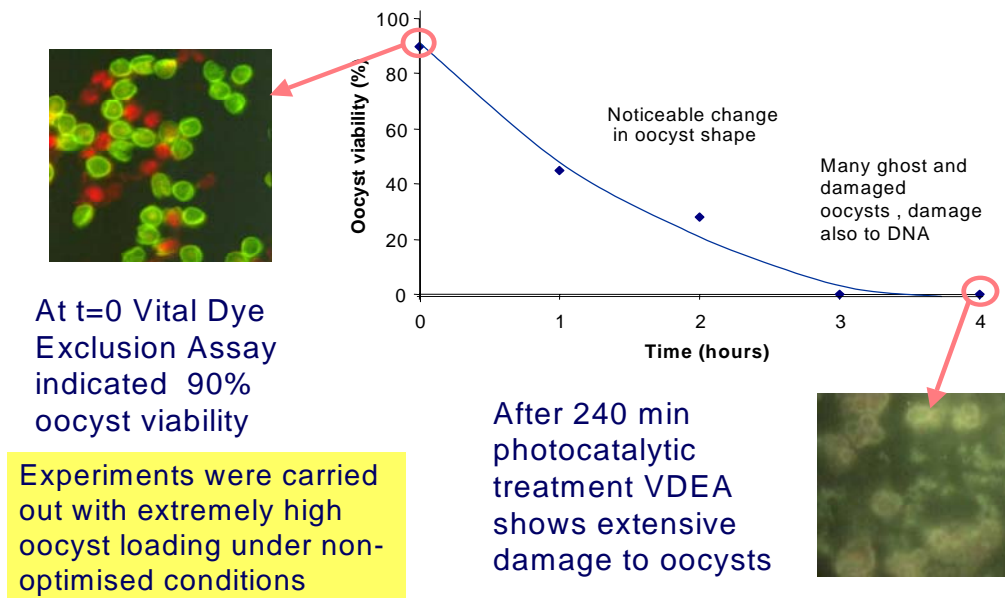


Figure 1. Showing photocatalytic inactivation of *Cryptosporidium parvum* oocysts followed by vital dye exclusion assay..

The electrochemically assisted photocatalysis is a promising technology for the purification of water contaminated with persistent organic pollutants and/or chlorine resistant pathogenic microorganisms. A cost base analysis is being prepared to determine the economics of the process in relation to other technologies available.

### 6.3.2. Electro-Bio-Catalytic removal of nitrate

The second important aspect of the PEBCAT project was to research and develop a bio-cathode that could utilise denitrifying bacteria for the removal of nitrates and nitrites from water. This research was very much “blue skies” in the sense that one must make electrical connection to immobilised bacteria via immobilised electrochemical mediators. Initially aerobic denitrifying bacteria were isolated and tested for their denitrifying capability in the presence of a carbon source.

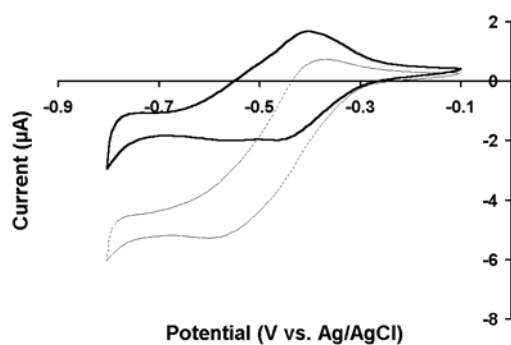


Figure 2 a. Cyclic voltammetry of a new NR modified electrode in de-oxygenated 0.1 M of Tris solution (pH 7.5) in the absence (A) and presence (B) of 5 mM  $\text{KNO}_3$ ; scan rate 5  $\text{mV}\cdot\text{s}^{-1}$ .

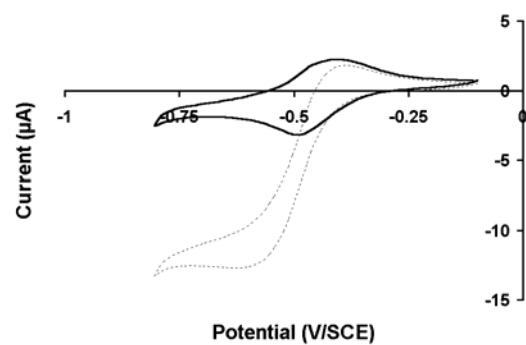


Figure 2. b. Cyclic voltammetry of a ccNiR modified electrode from a de-oxygenated solution of 0.05 M of Tris pH 7.5 containing 0.1 M of KCl at a scan rate of 20  $\text{mV}\cdot\text{s}^{-1}$ . A) Without  $\text{NaNO}_2$ . B) With 5 mM of  $\text{NaNO}_2$

Then various strategies were investigated towards producing bio-cathode materials with immobilised bacteria. The final problem was to mediate electron transfer from the cathode

material to the immobilised bacteria using mediator molecules. In order that the mediator would not be lost another requirement was to immobilise the mediator. Attempts to electrically link denitrifying enzymes to an electrode were successful (figure 2). Furthermore, electrochemical mediation to the enzyme was possible using immobilised mediators. Electrochemical connection to immobilised bacteria was also successful with denitrification occurring in the absence of a carbon source (figure 3).

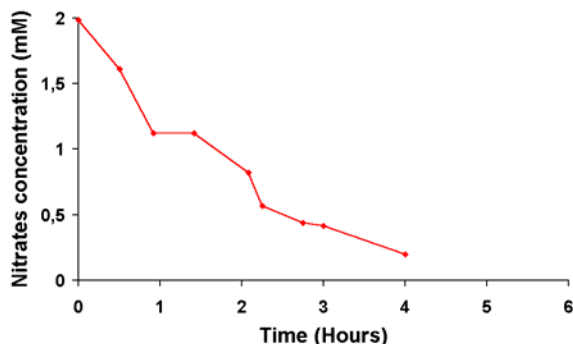


Figure 3. Removal of nitrate using immobilised bacteria which are supplied with electrons from an electrode using free mediator (no carbon source required).

The final stage was to electrically link the bacteria to the cathode using immobilised mediator. Unfortunately that was not possible in the time frame of the PEBCAT project.

### 6.3.3. Biosensors for nitrate and nitrite detection

Another important goal of the PEBCAT project was the development of biosensor technology for the detection of nitrates and nitrites in water. The research carried out towards the production of the EBCAT reactor is most relevant to the development of biosensors, either using bacteria or enzymes. Other work had focussed on the development of optodes utilising bacteria which had been modified to generate light pulses in the presence of nitrates.

## 6.4. Conclusions

The PEBCAT project has generated significant intellectual property that can be commercially exploited. A technical and economic feasibility study centred on the results and technology developed is in preparation. In addition, a Technology Implementation Plan will be drawn up to identify how the results of the PEBCAT project will be exploited.

There are two clear results which will be addressed in terms of further exploitation i.e. the Photoelectrochemical reactor for the electrochemically assisted photocatalytic purification of water, and the electrochemical biosensor technology for the detection of nitrates.

## 6.5. Contact and partnership

For further information on the PEBCAT project contact

Dr Tony Byrne – University of Ulster (UK) at [j.byrne@ulster.ac.uk](mailto:j.byrne@ulster.ac.uk)



<b>Partner</b>	<b>Country</b>
University of Ulster	UK
University Joseph Fourier Grenoble 1.	F
Ben Gurion University	IL
Groningen University	NL
Texam Ltd.	UK
Drinking Water Inspectorate	UK

## **7. AQUAERATION: IMPROVED RESERVOIR WATER DESTRATIFICATION**

Contract: EVK1-CT-2000-30007

Duration: Mar 2001-Apr 2003

### **7.1. The problem**

Thermal Stratification causes a number of water quality problems in reservoirs. The presence of a layer of warm water overlying colder and denser water inhibits vertical mixing, particularly the downward transfer of dissolved oxygen from the usually well oxygenated surface waters. The bottom waters become deoxygenated, with the possibility of the release of metals from the bed sediment, and the warm, well lit surface layer is conducive to the growth of large populations of phytoplankton. If stratification can be controlled by artificial mixing, the dissolved oxygen can be maintained at an acceptable level throughout the water column and algal growth is reduced as the phytoplankton are continually mixed through the water depth reducing the time spent in the photic(well-lit) zone where growth is possible.

Once formed, thermal stratification will, without artificial mixing, remain until meteorological conditions change and the surface water is cooled sufficiently by one or more of evaporative cooling, heat loss to the atmosphere and wind induced mixing to cause the reservoir to overturn. This happens every autumn when the temperature of the surface water falls below that of the bed water, resulting in an unstable density profile and strong vertical exchange.

It is difficult to destroy a stable thermal stratification (density increasing with depth) by artificial means, as dense water displaced vertically upwards will tend to fall back to its original level unless it can be well mixed with less dense surface water.

### **7.2. The project**

To evolve a new economical mixing and aeration system, based on scientific data which proves it can destratify reservoirs and reduce the occurrence of algal blooms. Full scale Site Tests with Production Models have shown that this has been achieved, with the resultant technical data available. The developed 'AQUAERATOR' has been patented.

The Research Project was divided into four main work packages:-

- 1) The characterisation of existing destratification and reservoir operation practices.
- 2) A complex iterative process of design, manufacture, laboratory testing and model development.
- 3) The testing of the final Aquaerator design in full-scale field trials in UK and Spain.
- 4) Analysis of the operational field trials, comparison with mathematical model simulations and reporting.

### **7.3. Main achievements**

The SME Contractors and the RTD Providers were successful in achieving the key objectives of the project. Four different full scale prototype Aquaerators, for mixing bubbles with water to form an effective bubble plume at the bed of a reservoir, were designed, manufactured and tested in a 6m deep tank in the laboratory, a 10m deep reservoir at Foix, near Barcelona and a 20m deep London Reservoir. The performance of the final pre-production Aquaerator was significantly better than the Helixor.

HRW put its main research effort into developing and testing new mathematical theories and numerical models to describe the physical processes in the mixing device, the resulting rising buoyant (air/water) bubble plume, and the effect of a set of plumes in thermal stratification in a London reservoir.



AMG and HRW successfully deployed sets of 3 and 6 pre-production Aquaerators in a Spanish irrigation supply reservoir and a London water supply reservoir, respectively.

An analysis of the field data – and a hind cast prediction using a 3D seasonal model – showed that as few as six Aquaerators reduced the peak and average potential energy of thermal stratification ( $J/m^2$ ) by about

40% in the London reservoir, compared to conditions without Aquaerators.

The three widely spaced Aquaerators in the very heavily polluted Foix reservoir, which is located in a popular nature park, were unable to improve significantly the anaerobic conditions in the near bed layers because of the excessive sediment oxygen demand. The concentration of sulphur in the hypolimnion was reduced to nil in the vicinity of the Aquaerators and there was anecdotal evidence that the smell and level of fish kills were reduced significantly by the bubble plumes.

#### **7.4. Market potential**

Meetings with potential Customers show that Future Sales will be worldwide and not limited to Potable Water Reservoirs, but at least six separate Industries, namely:

The Water Industry

Fish Farming Industry

Sewage Industry

Electrical Generating Industry

Food Industry Effluent

Frozen Lakes and Rivers

#### **7.5. Marketing strategies**

As a small SME it is important to use our modest resources to start Marketing in the UK and Spain to maintain financial viability. It would be preferable to expand faster in order to maximise the benefits of the Patent, thus investigate sources of Venture Capital and Scottish Grants.

##### *7.5.1. WATER INDUSTRY*

BRISTOL WATER LTD – Our first contract was confirmed with an installation of a five Aquaerator System completed at Blagdon Reservoir near Bristol, which ran successfully during the hot summer of 2003. This resulted in a further contract for ten Aquaerators at the three Barrow Reservoirs, with installation of the initial 3 in Barrow 1 during April 2004.

ANGLIAN WATER SERVICES LTD – A pre Aquaerator Contract Survey is being negotiated for both Rutland and Grafham Reservoirs. The former is the largest man made Reservoir in Europe, for which we designed and installed an aeration system in 1995. The existing Grafham destratification system is ineffective and damaged, thus we have submitted a Consultancy Report to obtain budgetary funding for a new Aquaeration System.

THAMES WATER PLC – Their Wraysbury Reservoir was used for the full scale Production Model Trials for the EU Project run by H R Wallingford. On conclusion Thames decided that Wraysbury is unlikely to stratify as long as they do not stop pumping from the R Thames. However their Process Scientist reported to the Management that an Aquaerator System is ideally suited to Queen Mother Reservoir and we await developments after their algal investigations.

AGENCIA CATALUNYA DE L'AGUA – Foix Reservoir, near Barcelona was used for the tropical EU full scale Trials run by the University of Barcelona and proved to be a real test, as it is one of Spain's most polluted reservoirs. It has huge Algal Biomass and BOD problems, with an extremely high SOD caused by nutrients from untreated sewage. The field trials were concluded early as the reservoir turned over in September 2002. ACA agreed to fund further Trials in 2003, but instead of a 900m line of three Aquaerators, they have been formed into a 100m by 175m parallelogram with the introduction of a fourth Aquaerator. At least all the reservoir's carp have shown their appreciation by swimming close to the Aquaerators, reproducing in larger quantities and staying out of range of the fishermen.

CANAL DE ISABEL 2 – Madrid Reservoir is 100m deep and they have other 10m deep Reservoirs, which are being considered for an Aquaerator System. They want a mobile system to solve the destratification problem and surface mounted to work at various depths dependant on the nutrient levels and available outlet valves. Their problem is *Oscillatoria rubescens* which has gas vacuoles and can be disoriented by aeration.

AMERICA – It is intended to contact and possibly visit mid year the Marine Department of the University of Wisconsin in Madison to obtain advice on the potential of the Great Lakes.

GERMANY – We learnt from the German Water Institute, which covers 70 Reservoirs, including Holland and Luxembourg, that they use a Wahnbach Reservoir Aeration System, as many need to supply colder hypolimnion water for Industrial use. However our Brochures will be available to the Technical Directors of some German Reservoirs during their next Conference 28/29th April.

FRANCE - The result of a British Embassy Market Research Project indicates that there are only four big firms which obtain major Water Industry Contracts. These are Vivendi, Lyonnaise des Eaux, Saur and Electricite de France, thus we have asked Business West to attempt to make the initial contact, probably with Vivendi.

#### *7.5.2. FISH FARMING INDUSTRY*

Not originally considered as an AQUAERATION Market, but visits in 2003 to potential customers have shown that some fish farming problems could be solved plus additional benefits.

At both Blagdon Reservoir near Bristol and Foix Reservoir, Barcelona it was noticeable that rainbow trout and carp respectively congregate around the Aquaerators. This is possibly due to bringing the cooler bottom water to the surface, with the resultant aeration improving DO levels and readily available food. An additional benefit is the Aquaerator's flow can disperse the Algal Biomass and help to give salmon back their natural spawning environment of flowing water.

INSTITUTE OF AQUACULTURE – The University of Stirling Meeting showed considerable potential for Aquaeration, including algal dispersion, assisting destratification, mixing, improved DO levels in the cages, cooling the surface water and raising cleaner bottom water.

MARINE HARVEST – After several meetings with the largest Scottish Salmon Farmer, who in turn are part of the largest Aquaculture Group, Nutreco, in 2003 we installed 2 Aquaerators with specially designed mid water rigs and an electric compressor for easier control in their Lochleven fish farm. This enabled our Sales CD to be filmed and to determine the parameters which need to be tested to show the real value of the Aquaeration System to Fish Farming

SCOTTISH SEA FARMS and AQUASCOTT – Meetings have been arranged with the next two largest Scottish Fish Farmers during March 2004.

EGLWYS NUNYDD RESERVOIR – Our proposed Environmental Management Plan was accepted by Corus Steel, as there is a problem with a huge quantity of Oscillatoria covering this shallow 250acre Reservoir, which is affecting their cooling water filters and killing the fish.

CHILE – Chilean salmon production is four times bigger than Scotland, also they have major DO and mixing problems, causing the fish to eat less and become lethargic. The British Embassy in Santiago are investigating the best way to introduce the Aquaerator to this Market. Discussions are progressing with the Production Manager of Marine Harvest Chile.

CHINA – This is considered to be our biggest Market, but will need to be approached with care due to the distance and language, also the need for a Chinese Partner to market our product.

### *7.5.3. SEWAGE INDUSTRY*

This industry has used aeration to reduce the BOD of raw sewage for many years. A meeting took place with Imperial College to discuss modifying the Aquaerator to suit this Market. A major Water Company has offered its facilities for tests and a well known PLC, already a Major Player in this Industry, is interested in marketing the proven product.

### *7.5.4. ELECTRICITY GENERATING INDUSTRY*

Some European Countries, such as France, Spain and Switzerland, use Lakes and Rivers to generate electricity and our initial Market Survey has shown that hypolimnion water is being used, which can cause damage to metal structures and equipment.

ENDESA GENERACION SA – Initial contact has been made as they use many stratified Reservoirs for generating electricity and encounter many costly maintenance problems

### *7.5.5. FOOD INDUSTRY*

Many of the food industries effluents need aeration to break down fats and generally improve their quality before entering Local Rivers or Drainage Systems.

### *7.5.6. FROZEN LAKES AND RIVERS*

Aquaerators could be used to bring the warmer water to the surface during winter, thus melting the ice, as an Aquaerator at 40m will raise 32tons of water per second and has been scientifically designed to use the minimum amount of energy.

## 7.6. The partnership

The Project Group consisted of the following:

SME's:-	Aquarius Marine Group Ltd	Project Co-ordinator
	Van Reekum Materialen BV	Manufacturer of Prototypes
	Hydrocal International	Technical Input

RTD Providers:-	H R Wallingford Ltd	Research Aspects
	University of Barcelona	Research Aspects

The Project Co-ordinator, Tony Wynes, can be emailed at [tonywynes@AOL.com](mailto:tonywynes@AOL.com) or phoned/faxed at 00 44 1458 834734

## **8. INNOWASH: MINIMIZATION OF WATER CONSUMPTION IN EUROPEAN TEXTILE DYEING AND PRINTING INDUSTRY USING INNOVATIVE WASHING AND WATER RECYCLING TECHNOLOGIES**

Contract: EVK1-CT-2000-00049

Duration: Apr 2001-Mar 2003

### **8.1. Introduction :**

Washing off processes represent a very important and cost intensive step in textile processing and finishing. The whole European textile industry, represented by more than one-hundred printing houses, produce each year approximately 450.000t of reactive printed fabrics. The unfixed dyestuffs, auxiliaries and thickeners must be removed from the goods in order to get high quality products and excellent fastness. Rinsing and washing is mostly performed at too low temperatures and without any controlling. This results in high and unacceptable water consumption and high pollution. In order to get best fastness properties, the goods are usually washed too long and too intensely, which also prevents the economical application of recycling technologies. Mostly a much shorter washing process would be enough, which would save time, water and energy. This also would give the chance for a local, safe and economic acceptable recycling and reuse of process water.

### **8.2. The project:**

The aim of this project is the minimization of water pollution and water consumption in washing processes of reactive dyed and printed cotton fabrics using innovative washing and controlling techniques as well as recycling technologies and especially combinations of them.

The first step was the monitoring and improvement of conventional washing processes. This included the analysis of problematic dyeing and printing recipes of the involved dyeing and printing houses. Generally spoken, the recipes were better than expected and no significant overdosage of chemicals could be observed. But it became obvious that washing of reactive dyed and printed fabrics should be performed without surfactants!.

In order to display inefficient process conditions, the water consumption and water flow as well as temperature in compartments for each phase of washing was measured in industry. This very important investigation provided very new data to the printing and dyeing houses and contributed to the identification of inefficient steps in rinsing and washing. The present water consumption is around 30 l/kg washed good. Process conditions (i.e. water flow, counter current, temperature, number of compartments...) were analysed. It became obvious that the first washing baths worked at too low temperatures (40°C) and no consequent counter current was applied.

Out of this monitoring the first general recommendations to save water and time are:

- Consequent counter current, with no or low freshwater supply at the beginning of the washing process
- Starting with higher temperature (60-80°C) even if washing off of cold pad-batch dyed materials
- Use of less freshwater
- Use of less compartments

Further investigations focused on the correlation between the extent of the removal of hydrolysed dyestuff from the material and the fastness properties. Printed and dyed fabrics were washed at high temperatures and the quantity and removal properties of hydrolysed dyestuff and thickener were determined. On the basis of this data different washing effects

could be realized using a time and temperature depending washing procedure. The wet fastness properties of these goods are presented in fig.1 .

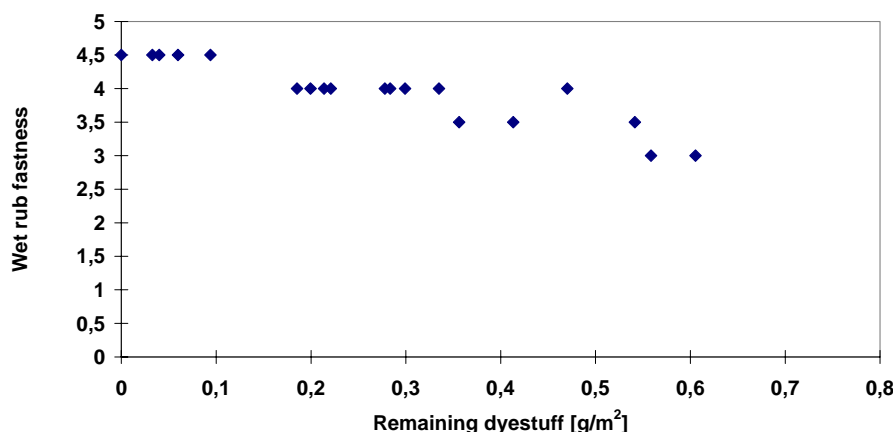
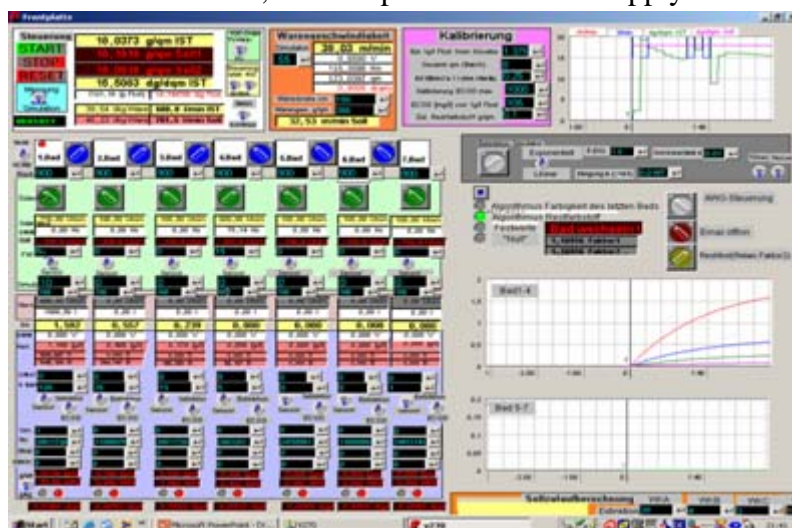


Fig. 1: Interdependence of remaining dyestuff on the fabric and fastness properties of washed fabrics (Cotton, 5% Colouring with R.Red 120)

As shown in fig.1, the fastness properties depend on the remaining dyestuff on the fabric. Fastness properties improve stepwise, according to a decrease of remaining hydrolysate. Best fastness properties were obtained below a quantity of approx. 0,1 g/m<sup>2</sup> remaining dyestuff on the fabric. This means, that unfixed dyestuff must not be removed for 100%, in order to get best fastness properties. These results were also confirmed in the washing off of other reactive dyes. A remaining quantity of approx. 0,1 g/m<sup>2</sup> hydrolysate on the fabric does not decrease fastness properties. On the basis of the monitoring results a computer program “INNOWASH” and a new online-immersion sensor (ITCF) were developed which enables the online-controlling of a washing process on the basis of advanced rinsing algorithms. The total quantity of removable dyestuff per m<sup>2</sup> has to be determined first as well as dyestuff content in each compartment will be measured and/or calculated via online-sensors. On the basis of this data, fabric speed as well as supply with fresh water will be calculated and



optimised. Furthermore, this computer programme enables the simulation and optimisation of the washing process on the basis of measured washing off properties of the dyestuff. The display of the computer program is shown in Fig.2.

The Online sensor is shown in Fig.3.

Fig.2: INNOWASH software



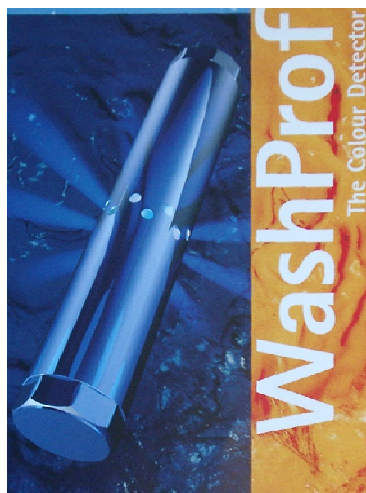


Fig.3: Online-Sensor

### 8.3. Main achievements:

The new online-immersion sensor (developed by ITCF) and the INNOWASH software were installed in industrial washing machines. The whole system, including the sensor and the software, enables the engineering companies to offer a complete controlling system to the textile industry, which enables water savings of 50% and more. This allows a very flexible and optimised rinsing for each dyeing house according to the specific products and needs. The sensor-based controlling system is also a good tool for the dyestuff producers, to study the washing off properties of their dyes and textile auxiliaries with respects to high quality products. This ensures a safe process conditions with regard to a minimum of energy and water consumption under real industrial conditions.

Membrane filtration methodology and equipment has been set up and successfully used in industry. The overall conclusion is that both nanofiltration and reverse osmosis membranes can effectively treat effluents from reactive dyeing. Pilot tests have proved that the rinse water reclaimed by membrane filtration can be reused for rinsing purposes which results in closed water loops.

### 8.4. Marketing and exploitation strategies:

At present time, the involved textile dyeing and printing houses are using this new technology in cooperation with ITCF successfully and the consortium is in contact with engineering companies as well as with dyestuff and auxiliary manufacturers and textile machinery industry in order to exploit and disseminate project results to its optimum. The ITCF, as the main inventor/developer of the system, is going to put the software-tool into production and sell it, after the software is modified and adapted for easy use in industry. This also includes the marketing of a new service for improving individual washing and rinsing conditions in industry. ITCF will also contact individual suppliers of rinsing machines in order to adapt and optimize the developed techniques to their own machines. This will ensure a perfect transfer of knowledge to the machinery industry and to the enduser. It is also planned, that the new sensor system will be put into production under license by Küsters Maschinenfabrik (Krefeld, Germany) and be provided to the worldwide market under the name "WashProf" in 2004. On the other hand, the water recycling technology will be further improved by the involved IPU and be disseminated to MDS-Prozesstechnik GmbH (Moers, Germany) and other suppliers of membrane technology for the implementation of closed water loops in textile rinsing industry.

Furthermore, individual members of the research team will also aim to publish the results in relevant scientific journals, textile magazines and possibly through all other applicable electronic media. This also includes the oral presentation of the results on international conferences, seminars and round-table meetings, which will guarantee the appropriate transfer of specific know how to potential endusers from textile companies.

### **8.5. Contacts:**

Interested users are invited to contact ITCF (Dr.R.Schneider, Coordinator) for any transfer of knowledge and demonstration purposes.

Project Partners are:

- Institute for textile chemistry and Man-Made Fibers (ITCF),  
Körschtalstr. 26, 73770 Denkendorf Germany. Dr. R. Schneider.  
(Coordinator; e-mail: reinhold.schneider@itcf-denkendorf.de)
- Institute for Textile Chemistry, Ecology and Colour Science Maribor,  
Smetanova 17, 2000 Maribor, Slovenia. Prof. Dr. S. Sostar Turk.
- Bekleidungsphysiologisches Institute Hohenstein, Schlossteige 1,  
74357 Bönningheim. Dipl-Ing. T. Guschlbauer.
- Institute for Product Development, Building 424 Technical University  
of Denmark 2800 Lyngby Danmark. Dipl.-Ing. H.H. Knudsen.
- Tekstilna tovarna Prebold d.d, Tovarniska 7, 2312 Prebold, Slovenia.  
Dipl.-Ing. Univ. N. Cukjati.
- Textilveredlung Drews Meerane, Äußere Crimmitschauer Str. 80,  
08393 Meerane, H. Wehner
- Girmes ProMa-Tex GmbH, Johs.-Girmes-Str. 27, 47929 Grefrath-Oedt
- MDS-Prozesstechnik GmbH, Bahnhofstr.315, 47447 Moers,  
Dr.D.Böttger (Subcontractor)

## **9. WATER SAVING PUMP: NEW WAY OF WATER AND ENERGY SAVING CLEANING TECHNIQUE TO IMPROVE THE HYGIENIC RESULT**

Contract: EVK1-CT-2001-30013

Duration: Jan 2002-Dec 2003

### **9.1. The project**

Food-, pharmaceutical- and agricultural-industry all over the world, uses high-pressure water cleaning to get rid of contamination, micro organisms and bacteria's. Enormous amounts of water are used every day for different cleaning purposes. Still lots of people get poisoned every year, due to insufficient or incorrect cleaning. In this project we focus on improving the high-pressure cleaning technique, to reduce the water consumption and improve the hygienic cleaning result.

Increased hygienic demands from authorities and consumers result in more frequent cleaning and increased water consumption. In many parts of Europe, and all over the world, there is a limited supply of good quality water. This means increased water and purification costs. Therefore there is an urgent need to improve high-pressure cleaning techniques with the objective to reduce water consumption. Another need is to secure the hygienic cleaning result and optimise the cleaning effect on different surfaces to minimise the risk of contaminating food production. Parameters like water-flow, pressure, type of chemicals, cleaning time and temperatures are conclusive for the hygienic result.

### **9.2. Main objectives and achievements**

The issue of this project was to develop a new water saving cleaning technique.

The main objective with this RTD project was to improve techniques for high-pressure cleaning by improvements of pump technology in combination with high-pressure nozzles. By doing this it has been a number of positive effects; improved cleaning results, reduced water and chemical consumption and reduced cleaning time due to more flexible equipment. All these parameters have impact on the total cleaning result and the cleaning economy.

The main problems to be solved have been:

- To investigate and map down how the cleaning result depends on the spray pattern, the water pressure, the water flow and the distances for different surface structures and for different contaminations. The objective was to find the most effective combinations. Maybe we had to develop new spray nozzle principles to deliver the optimum water spray.
- To find a new high pressure pump principal that is more flexible regarding the pressure/flow regulation compared with today's traditional plunger-/piston pumps. This would give us new possibilities to optimise the cleaning results for all type of cleaning. The new pump must also be able to adjust fast to avoid falls and blows of pressure (when the number of working operators in the system vary).
- To develop ergonomic equipment that fast and simple can be adjusted to work with optimised performance data for different cleaning situations. To study the ergonomic situation for the user.

#### *9.2.1. Water energy*

One of the main achievements for the project group is the new knowledge regarding water energy – meaning how the rate of efficiency in the spray pattern is optimised concerning the kinetic energy and the size of the water droplets. A number of different tests and experiments were done to find the best combinations for different cleaning purposes. By using a high speed camera we have created close pictures of how different spray compositions cleans. This information in combination with

laboratory tests of different flow/pressure combinations, distances, spray patterns and spray angles gave us new information of what the water pump and the spray gun should perform.

We have also studied the ergonomics in high-pressure systems. This is an important factor not only regarding personal costs but also considering water and energy costs by way of saving time. The most important interface between the user and the high-pressure system is the spray gun. The spray gun controls how the strain, all in all from the system weight and the reaction force, are transferred to the human body. This new knowledge is very important for the design of the spray gun. The pictures show the new design of the triggerless spray gun and how it is used.



### 9.2.2. *The new high-pressure pump technique*

We have developed a complete new pump technique that solves our regulation problems and reduces the water consumption. The pump gives us new possibilities to adjust the water flow and water pressure independent of each other and thereby optimise the energy consumption. This pump provides a very smooth flow of water without pulsations and pressure falls/blows when the number of users in the systems varies, which makes the work environment for the user much better. Technical benefits are that water-pumping parts, which have poor lubrication conditions, are moving very slowly while more sensitive parts work within oil. Another benefit is the water capacity for the water pump. One single pump unit can easily serve e.g. five users. Field tests of this pump shows that we can reduce the water and energy consumption and also avoid all problems with pressure drops and thereby improve the working conditions for the operators. We have applied for patent regarding the technology.



The new high-pressure pump

### 9.2.3. *The light pressure turbo nozzle*

Different turbo nozzles are available on the market today but no one was found that suit, regarding flow/pressure combinations, for cleaning in the food industry. This nozzle is a result of our studies regarding the efficiency of different spray patterns. The light pressure turbo nozzle creates a new technique and spray pattern to transport the water energy with and will be a good complement to the flat fan nozzle in cleaning applications. We have applied for patent regarding the technology. The adjustment possibilities, the robust design and the low weight give us new cleaning possibilities.



The new turbo nozzle

### 9.2.4. *The pre-rinsing nozzle*

This nozzle makes it possible to accomplish the pre-rinse operation with the high-pressure system due to variable cast length between 0,5 to 7 meters. This makes it possible to decrease the fresh water consumption during the pre-rinse.



The new pre-rinse nozzle

### 9.2.5. *Example of saving effects using our new products in a chicken slaughterhouse*

Field-tests of our products have been performed in a chicken slaughterhouse in Sweden. During these tests water and energy consumption were controlled. During the test period we also interviewed end users regarding their apprehension and understanding of our products.

- Interviews:
- The new pump is more comfortable to work with because there is no falls or blows in pressure while the number of user in the system vary.
  - The new pump is easy to adjust to the optimum flow/pressure combination.
  - The turbo nozzle makes it easier to clean from longer distances
  - The pre-rinse nozzle reduces the need of low-pressure outlets in our locals which often are used with high flows.

### 9.2.6. *Benefits measured at the field tests:*

Water consumption: about 20% lower than before

Energy consumption: about 15% lower than before

Ergonomics: as there is no falls or blows in the pressure the problem with damages in the arms and shoulders of the operator are eliminated.

Costs: the cost of this new water saving pump is not higher than the state of the art.

The field tests are done with a 'prototype' machine. It is expected that the benefits will be larger when the product developing phase is completed.

## **9.3. Exploitation - Marketing**

The market potential for the water pump is industrial cleaning with a need for a number (more than two) operators at the same time. Example of customers are; slaughterhouses, breweries, farmers, pharmaceutical industries, dairies, bakeries, fish industries and other food producers.

The new nozzle will fit all the customers above. However the robust and low-cost design will also open up possibilities for private customers with need for a better cleaning result.

The new water pump and nozzle has been field tested at different industrial plants as e.g. slaughterhouses and breweries. Next step will be full-scale production. The marketing strategy is to start with marketing/sales to existing customers in Sweden, Denmark, Norway and Finland in the year 2004. Next step will be to continue with the expansion on the European market. The company Lagafors Fabriks AB are today searching for partners in countries outside the Scandinavian market. The Swedish Trade Council is also working with identifying new markets outside Europe.

## **9.4. Partnership and contacts**

The partnership of the project consists of the following companies: Lagafors Fabriks AB (SE), Trönningeverken AB (SE), Arena Kemi AB (SE), Hygienteknikk AS (N), Utvecklingsbyrå AB (SE), Chalmers Industriteknik (SE), Institutet for Produktudvikling DTU (DK), Technical Research Centre of Finland (SF)

### Contact persons:

Lagafors Fabriks AB, Box 5, 312 21 Laholm, Sweden, Magnus Elmblad (tel.+46 430 781 00)

Utvecklingsbyrå AB, Tekno Center, 302 50 Halmstad, Sweden Anders Rosengren (tel +46 35 174761)

## **10. AWACS : AUTOMATED WATER ANALYSER COMPUTER SUPPORTED SYSTEM**

Contract: EVK1-CT-2000-00045

Duration: Mar 2001-May 2003

URL : <http://www.barolo.ipc.uni-tuebingen.de/awacss>

### **10.1. The Project:**

Despite the fast developments of chromatography-based techniques over the past decades, up till now almost no technology exists that can monitor trace levels of organic micro pollutants in water in real-time and at reasonable costs. Therefore the project focused on the development of a robust, cost-effective water-monitoring device based on immunochemical technology that can measure several tens of organic pollutants at a low nanogram per litre range in a single few-minutes analysis without any prior sample concentration step. Having in mind actual needs of water-sector managers related to the implementation of the Drinking Water Directive (98/83/EC) and Water Framework Directive (2000/60/EC), drinking, ground, surface and waste waters were major media used at the evaluation of the system performance and the instrument was equipped with remote control and surveillance facilities. Target compounds were selected mainly from the groups of modern pesticides, endocrine disrupting compounds and pharmaceuticals. Four water-monitoring groups from the project team were extensively assessing various fields of potential application of the system and measurement sites that could accommodate the final instruments for testing. The experience of water laboratories has been utilised at the design of the instrument's hardware and software in order to make the system rugged and user-friendly. Several market analysis surveys were conducted during the project to assess the applicability of the final system.

### **10.2. Marketing strategies:**

Rising pollution levels lead to increased legislation. Increasing water quality demands of the EU (i.e. 98/83/EC & 2000/60/EC) exceed current analytical instrumentation capabilities at cost. The situation creates an opportunity for the exploitation of the market with a system that can monitor organic micro pollutants in water in real-time and at reasonable costs. The AWACSS instrument represents the development of a robust, cost-effective water-monitoring device based on immunochemical technology that is uniquely suited to take advantage of the current market condition.

Initial Market Surveys covered 12 European countries and the USA. The data of this survey represent the present situation in sampling practise in the different countries based on the present legislative needs and actually available laboratory equipment and assays. The collected data are covering lists of substances and data on the number of sites, sampling frequencies, the number of samples, detection limits and methods, numbers of detection, numbers of detection below  $0.1 \mu\text{g L}^{-1}$  as well as prices for detection and analytical costs.

For a more detailed survey about end user requirements an inquiry was conducted in the EU member countries, as well as the Czech Republic, Cyprus, Lithuania, Malta, Poland, Slovakia (all EU candidate countries) and the USA. Institutions dealing with water quality matters in these countries received the standardized questionnaire. A comparison of the suppliers of Enzyme-Sensors and Data Transmission Systems for water monitoring networks was carried out as well.

Real time sensing, improved regulatory and public acceptance and less expensive monitoring were found to be prime end user requirements. The system not only meets the market demand but exceeds the current competitive detection methods in terms of meeting end user requirements for current and future expenditures and expectations.

The data were examined and the market volume was determined. The actually 30 most frequent compounds in terms of numbers of detection and market size were ascertained. A survey of the 46 most to be controlled micro-pollutants (determined by EU and member state directives) is also included in the study. Within the AWACSS project a number of analytes already contributes to the 30 most frequently analysed compounds of today. The modular antibody based detection system shows in an impressive way the possibility of transducer adaptation using already available assays. Together with a customised antibody design a huge number of substances could be covered by the AWACSS system. This flexible and expandable detection principle will be one of the key features of the future success of the AWACSS instrument not only for important substances of nowadays but even for suspicious substances with growing importance in the future.

Today's situation in water monitoring could be depicted as follows. European expenditure for analysis of organic compounds for 1 year of monitoring is in excess of 29 Million Euro. The top 30 compounds account for more than 58.7 % of the total expenditure. The total number of examinations performed to detect all compounds in one year is 1.8 million. The top 30 compounds account for more than 50 % of total measurements conducted. A system equipped to measure a higher number of these 30 compounds could be well placed to the actual market with increasing acceptance in the future due to the flexibility of adaptation of new compounds as well as the capability of on-line, unattended and central controlled monitoring and surveillance.

### 10.3. Sensor system: Detection

The experimental system for immunoassay measurements is shown in Figure 1.

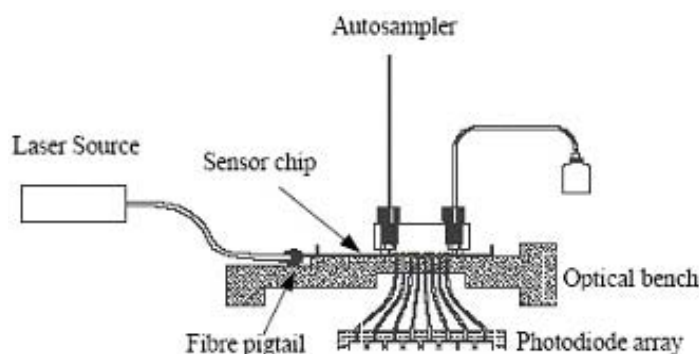


Figure 1: TIRF experimental set-up and the immunoassay principle.

Light from a semiconductor laser emitting approximately 5 mW at  $637 \pm 2$  nm is coupled into the input waveguide of the sensor chip using the polarization maintaining single mode fibre pigtail. This input power is divided equally into the four parallel waveguides using three Y-junction splitters and, in the 32 exposed sensing regions, the evanescent field is able to interact with the fluorophores of the labelled antibodies, forming spatially separated sensing spots. The fluorescence light is collected by an array of 1mm core diameter high numerical aperture polymer optical fibres located under the sensor chip, filtered to remove scattered light, and detected by a silicon photodiode with integral amplifier. The signal is amplified to give a responsivity of approximately 54.6 mV per pW and low-pass filtered with roll off at 1.4 Hz. A micro-flow-cell is affixed on top of the chip over the 32 patches to supply sequences of solutions to the sensor surface. The pumps and valves which supply the solutions, the laser, and the data acquisition system are controlled by a computer integral to the instrument. The power signal from the photodiodes (correlated to the fluorescence light) at each sensing site, the laser power, the instrument temperature and the temperature at the sensor backside are recorded at a rate of 8 Hz. The data are analysed and presented by the computer system within a user-friendly software interface. The optical detection limit of the



system, defined as  $3 \times \text{NEP}$ , has typically been found experimentally to be equivalent to approximately 500 fW of fluorescence light power. Therefore, this multisensor platform can be applied to a wide range of analytes according to Drinking Water Directive (98/83/EC) and Water Framework Directive (2000/60/EC).

#### 10.4. Sensor system: Immunochemistry

The AWACSS instruments are based on Total Internal Reflection Fluorescence TIRF technology and are shown in Figure 2.

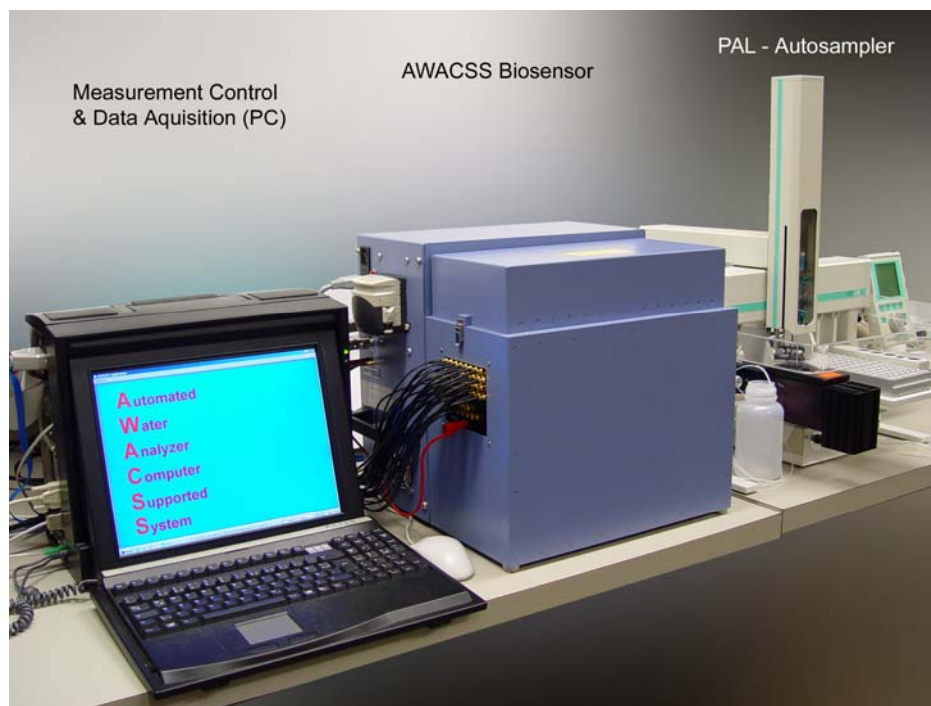


Figure 2: AWACSS biosensor with measurement control station and autosampler

The immunochemistry utilised in the project takes advantage of a binding inhibition assay that requires (polyclonal) antibodies with a high affinity constant against specific analytes (mostly small organic pollutants). The transducer surface is chemically modified with analyte derivatives. Therefore, the analyte derivatives are coupled to an aminodextran and this modified dextran is covalently bound to the glass substrate of the transducer. The antibodies and their 3 corresponding analyte derivatives have been produced for a variety of small organic compounds (emerging pollutants). After being purified and labelled with a fluorescent marker, the antibodies were developed into immunoassays and used in the project.

The analyte recognition is based on a binding inhibition assay. Analyte derivatives are immobilised onto the transducer surface prior to the assay. Next, analyte-specific antibodies labelled with fluorescent markers are added to the analyte samples. After a short incubation period, the analyte solution flows over the transducer. Only analyte-specific antibodies with free binding sites will bind to the transducer surface whereas, at the same time, antibodies that have two analyte molecules bound to each epitope will not bind to the surface. The surface bound labelled antibodies (temporary) are excited in the evanescent field and fluorescence light can be detected. As a result, an inverse analyte signal is measured, with

samples having low analyte concentrations giving rise to high fluorescence signals and samples with high analyte concentrations resulting in low fluorescence signals.

### **10.5. Innovations:**

A previous EU project entitled, “River Analyser (RIANA)” (ENV4-CT95-0066) successfully utilised the biosensor technology. AWACSS was building on the achievements of the RIANA device with major improvements in three critical areas:

- Expanded multi-analyte analysis capability allowing for simultaneous measurements of up to 30 analytes. A set of new immunochemical reagents was developed for a number of organic micro pollutants to be analysed in water.
- Novel design approaches to the optical detection and fluidics including miniaturised integrated optics and micro fluidics.
- Intelligent remote surveillance and remote control that allows unattended continuous monitoring. Internet-based networking between measuring and control stations for global management and alarm systems.

### **10.6. Results:**

Two fully automated AWACSS systems consisting of the newly developed optical biosensor with measurement control and assay programming software have been constructed and successfully tested. The software allows also for the Internet-based networking between the measurement and control stations for global management, trend analysis and early-warning applications. An easy-to-use web-based AWACSS database was created for automated evaluation and storage of the obtained data in a format compatible with major databases of environmental organic pollutants in Europe.

So far more than 15 different polyclonal antibodies have been isolated and their corresponding analyte derivatives were synthesised:

Atrazine, Simazine, Isoproturon, Bisphenol A, Estrone, Carbofuran, Sulphonamides (Sulphadiazine, Sulphamethoxazole, Sulphadimethoxine, Sulphamethoxypyridazine, Sulphamethizole, Sulphadimidine & Sulphathiazole), Pentachlorophenol & Propanil. For all analytes a very low limit of detection could be achieved and for some analytes assays for the lower nanogram per litre range with limits of detection below  $1.0 \text{ ng L}^{-1}$  could be established.

The target analytes were selected mainly from the classes of pesticides, endocrine disrupting compounds and antibiotics. Project partners of the water-monitoring group have systematically investigated various types of water around Europe and addressed possible water matrix effects related to the AWACSS immunoassay chemistry. Immunoassay measurements of Estrone, Atrazine and Bisphenol A by the AWACSS system showed good reproducibility even at concentrations below  $10 \text{ ng L}^{-1}$  in both Milli-Q water and industrial wastewater. Results of the marketing survey and the fact that many of the AWACSS compounds are being frequently detected in real water samples all over Europe gives good perspectives for the system to be placed among the current state-of-the-art analytical instruments.

### **10.7. Partners in the project:**

IPTC - Institute of Physical and Theoretical Chemistry, Eberhard-Karls-University of Tuebingen, Germany.

CID-CSIC - Department of Environmental Chemistry, IIQAB-Instituto de Investigaciones Quimicas y Ambientales de Barcelona, Barcelona, Spain.

King's College London, University of London, London, United Kingdom.

EI - Environmental Institute, Kos, Slovak Republic.

Siemens, Erlangen, Germany.

DVGW - Technologiezentrum Wasser (TZW), Karlsruhe, Germany.

ORC - Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom.

CRL - Central Research Laboratories Limited, Hayes, United Kingdom.

WRI - Water Research Institute, Bratislava, Slovak Republic.

Project coordinator was Prof. Dr. Guenter Gauglitz at the Institute of Physical and Theoretical Chemistry (IPTC), Eberhard-Karls-University of Tuebingen, Auf der Morgenstelle 8, D - 72076 Tuebingen, Germany.

Contact: Jens Tschmelak, email: [jens.tschmelak@ipc.uni-tuebingen.de](mailto:jens.tschmelak@ipc.uni-tuebingen.de)

# 11. PHYTO-PLANKTON-ON-LINE: INTERACTIVE REGULATION OF PHYTOPLANKTON SUCCESSION BY PHYSICAL FORCING AND INTERNAL PHOSPHORUS LOADING: A COMPARATIVE STUDY IN EUTROPHIC FRESHWATER LAKES FROM DIFFERENT CLIMATIC REGIMES

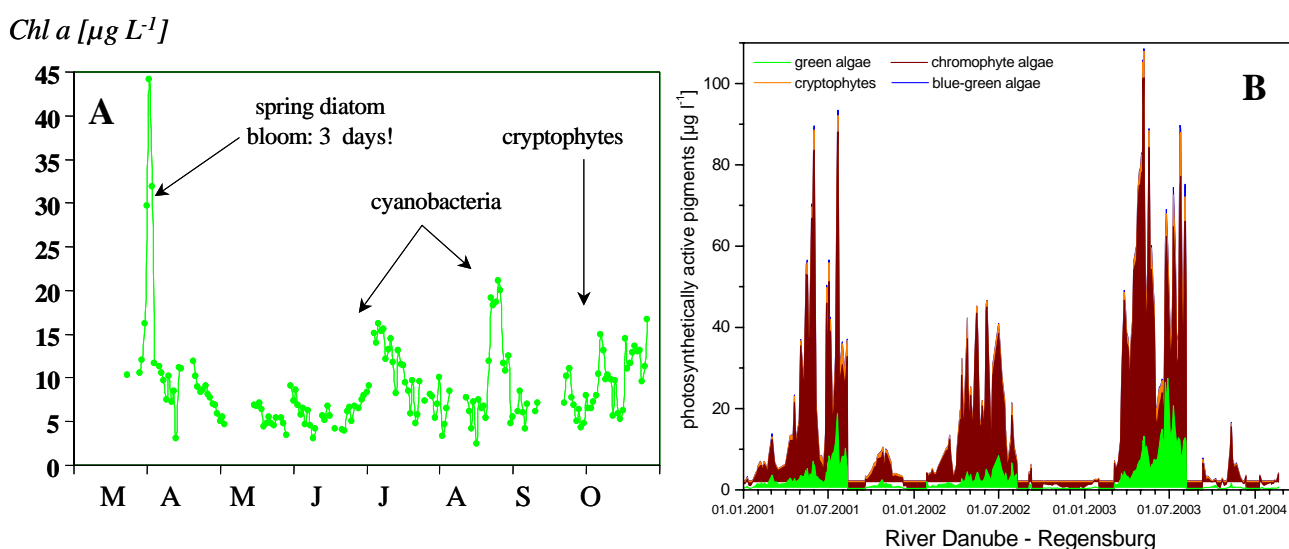
Contract: EVK1-CT-1999-00037  
 URL : <http://phyto-online.ocean.org.il>

Duration: Feb 2000-July 2004

## 11.1. Project Summary

Eutrophication of valuable freshwater resources is a worldwide problem expressed by high primary production with the tendency of a species shift to toxin producing cyanobacteria (blue-green algae). The information on phytoplankton assemblages and abundance is critical for the quality assessment of aquatic systems and has been included as an integrate monitoring parameter by the European Water Framework Directive (2000/60/EC). Following the Directive's advice monitoring frequencies should be adapted to the seasonality in order to identify changes due to anthropogenic pressure.

As indicated by the three-day lasting diatom bloom that occurred in Lake Balaton in spring 2003 (Fig.1A), bloom events can be extremely short and as such would escape conventional microscopic methods. The same is due for the large variability found with regard to the intensity of phytoplankton booms as shown below for the River Danube (Fig. 1B).



**Fig.1:** Time series of active chlorophyll data measured on-line by the DF unit. A) integrated chl. a data from Lake Balaton, B) color class distribution over time in the River Danube

The results to Fig.1 were derived from the application of the delayed fluorescence excitation spectrometer developed within the scope of this project. Due to its unique features to distinguish *in situ* four major phytoplankton color classes (Cyanophyta, Dinophyta, Chlorophyta, and Cryptophyta) while measuring only photosynthetically active chlorophyll at a linear range between 0.5 and 1000  $\mu\text{g L}^{-1}$ .

The development of the DF-Online spectrometer has been a critical prerequisite for this research. Following its implementation at the fieldsites (Lake's Erken, Balaton, Kinneret) in 2002 this unit is producing real-time data at a time resolution down to 15 minutes (7 minutes in the case of three channel system).

In combination with physiochemical measurements the unit is being used for studying phytoplankton-nutrient relationships as well as daily cycles triggered by the changing light regime. Further objectives of the project were aimed at methods to quantify phytoplankton in benthos and sediments via DF spectrometry and the benthic recruitment of cyanophyta.

## 11.2. Description of the DF

Delayed fluorescence is a unique characteristic of photosynthetically active cells due to the reversed electron flow in the dark. It is produced only by those absorbed photons, which transferred their energy into charge separation. DF is emitted only from the reaction center P680 - not from the antenna pigments. The DF spectrometer can be described as a continuous flow system where an algal suspension is pumped through an excitation cell into a dark emission cell. By varying the excitation wavelength from 400-730 nm by means of a monochromator, the intensity of the delayed fluorescence is measured by a photon counter. The resulting excitation spectrum represents those pigments that contribute to photosynthesis. The differentiation and quantification of the main taxonomic algal groups in the algal suspension becomes possible due to the occurrence of signature peaks and the ratio between these signature peaks and the universal chl. a peak (670 nm). The separation of the measured sum spectra into taxonomic groups is achieved mathematically by a deconvolution program (Fig. 2).

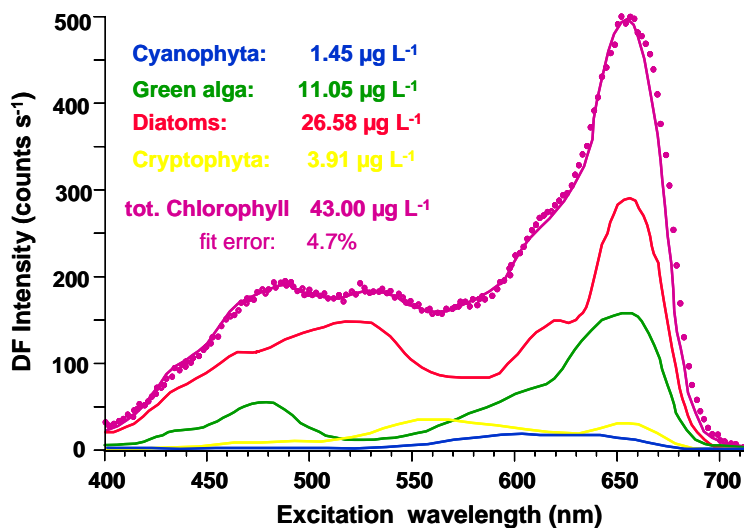
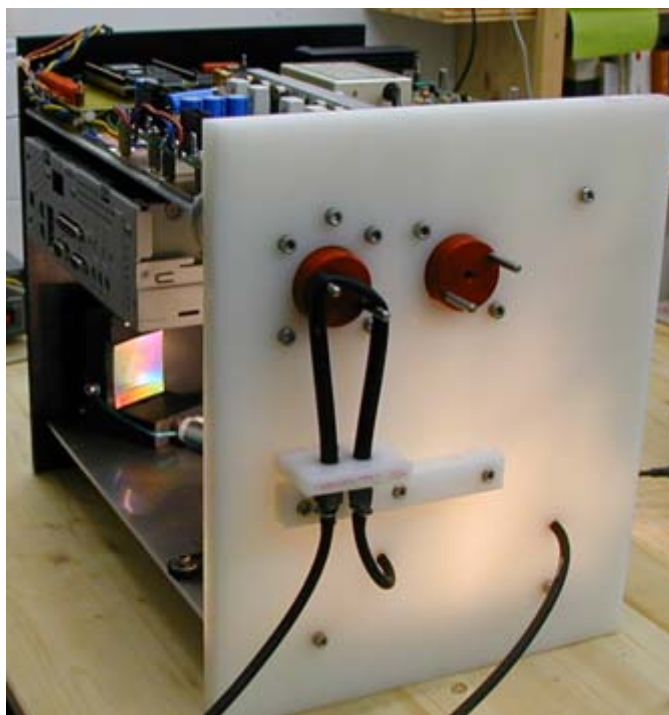


Fig.2: DF excitation sum spectra analyzed for the different color classes

Before measuring excitation spectra the sample has to be dark-adapted for 10 minutes in order to reset the photosystem. To prevent algal growth on wetted parts during continuous measurements, the unit has to be cleaned regularly. Technically this is achieved by two additional pump cycles, one for sampling into the dark-adaptation vessel and one for an acid cycle during which acid is pumped from a reservoir in a closed cycle through the DF-spectrometer. Based on the experience gained at the three experimental sites Prototype III has been developed (see Figure 3) and is presently tested.



**Fig. 3** Prototype III of the DF-Online excitation spectrometer

### 11.3. Partners:

Name	Institution/Organisation	Telephone N°	Fax N°	E-Mail
Eckert, Werner Co-ordinator	Israel Oceanographi and Limnological Research, The Yigal Allon Kinneret Limnological Laboratory, P.O.Box 447, 14-950 Migdal, Israel	+972-4-6721444	+972-4-6724627	werner@ocean.org.il
Istvanovics, Vera	Technical University of Budapest, Department of Environmental and Sanitary Engineering, Muegyetem rkp 3, 1111 Budapest, Hungary	+36-14632162	+36-14633753	istvera@goliat.eik.bme.hu
Padisak, Judit	University of Veszprem, Institute of Biology Egyetem u. 10, 8200 Veszprem, Hungary	+36-88-422022	+36-87-446326	padisak@tres.blki.hu
Hakanson, Lars	Uppsala University, Department of Earth Sciences and Sedimentology Olofsgatan 10 B, 75105 Uppsala, Sweden	+46-18-471 38 97	+46-18-47127 37	Lars.Hakanson@natgeog. uu.se
Pettersson, Kurt	Erken Laboratory, Dept of Limnology, EBC, Uppsala University, Norr Malma 4200	+46-176 229000	+46-176 229315	kurt.pettersson@ebc.uu.se
Stone, Lewi	University of Tel Aviv, Department for Ecological and Environmental Studies, Ramat Aviv, 69978 Ramat Aviv, Israel	+972-3-6409806	+972-3-6409403	lewi@lanina.tau.ac.il
Gerhardt, Volkmar	University of Regensburg, Institute of Experimental and Applied Physics, Universitätsstr. 31, 93053 Regensburg, Germany	+49-941-943 2141	+49-94- 943 4226	volkmar.gerhardt@physik. uni-regensburg.de

## **12. GEOWATERS: INTEGRATED GEOPHYSICAL TECHNIQUES FOR SURVEYING AND QUANTIFYING POTENTIALLY POLLUTED SEDIMENTS IN EUROPEAN WATERWAYS**

Contract: EVK1-CT-2001-300009  
URL : [http:// www.geowaters.com](http://www.geowaters.com)

Duration: Jan 2002-Dec 2003

### **12.1. Problem addressed by the GEOWATERS project:**

New sediment layers accumulating on the floors of rivers, canals, lakes, and harbours in industrialised countries contain varying amounts of contaminants which have been discharged from a range of activities, both legal and illegal. These contaminated sediments are known collectively as sludge, and have been accumulating for decades. The contamination is often startling; the River Rhine discharges 13 tons of Cadmium annually to the North Sea, of which 8 tons comes from Dutch industry. The Rhine, together with similar surface waters, provides 65% of drinking water in the Netherlands. The identification of contamination in waterways like these has led to the realisation that there is a need to carry out surveys of the pollution, in many cases followed by remediation. Contaminated water floors, though probably created in the past, continue to disperse their pollutants in the water, thus creating a potential effect on the quality of drinking water and recreational water. Remediation work can only be carried out in a cost effective way if it is preceded by a site survey which provides high resolution data. 95% of current site surveys are done by collecting hand drilled cores for examination and analysis. These point sources of data are then used to try to give an impression of the sludge layers, but the resolution is extremely poor. Contamination may be found, but the volumes cannot be quantified. *Aim of the GEOWATERS project* was to develop, test and describe a *survey methodology* which is significantly more *accurate and provide a cost effective* alternative to conventional site surveys. The technology is non-invasive, with very low environmental impact.

### **12.2. Techniques used and developed during the GEOWATERS project:**

High resolution shallow seismics, and water-borne, or submerged GeoRadar survey technologies were combined and further developed during the project. As a complementary technology modern Direct Current Resistivity (DCR) surveys were successfully tested as well. In order to obtain an advanced environmental surveying technology several technological improvements have been implemented. A new, underwater radar antenna has been designed and constructed for the purpose of the project, the seismic and the GeoRadar systems have been fitted onto the same survey vessel providing parallel recording facility.

The geophysical site surveys were combined with conventional analysis of the sludge samples. Magnetic susceptibility measurements were performed at selected sites as well to test this new and innovative geophysical method of contamination detection.

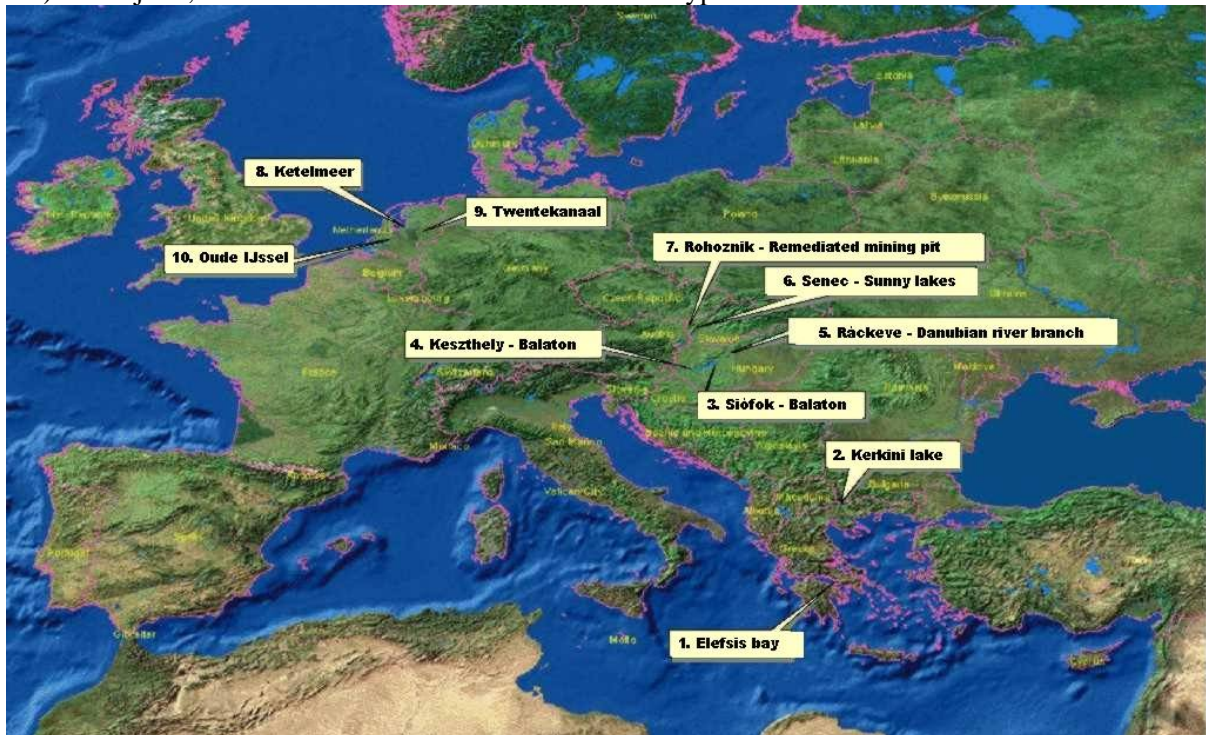
### **12.3. Site surveys performed during the GEOWATERS project:**

The developed surveying technology underwent an extensive field trial during the project. Selected test sites included the widest possible range of different scenarios, including freshwater and brackish lakes, natural and artificial, still and flowing waterways. Water depths ranged from practically 0 to more than 10 m depth. In total 10 different test sites were measured in 4 countries as shown in *Figure 1*.

Contamination types at the selected sites varied from hydrocarbon contamination to heavy metals deposited together with the sludge layers. Organics and pesticides were present in the sludge layers at some of the sites. At other places simply the volume of the accumulated sludge is presenting a problem. This can adversely affect shipping or recreational purposes.

Summary of the test sites with the problem present at the site is as follows:

<u>Site location:</u>	<u>Problem at he site:</u>
1.) Elefsis bay Koumoundouros lake, Greece	heavy metals, organic contaminants, hydrocarbons
2.) Kerkini lake, Greece	sludge deposition filling up the lake
3.) Lake Balaton, Siófok-harbour, Hungary	sludge deposition, communal waste
4.) Lake Balaton, Keszthely-bay, Hungary	sludge deposition, phosphate contamination
5.) Danube, Ráckeve-branch, Hungary	sludge deposition, heavy metals
6.) Senec, Slnečne jazera, Slovakia	heavy metals, organic contamination, eutrophication
7.) Rohozník, Konopiská, Slovakia	heavy metals, fertilizers
8.) Ketelmeer, Holland	sludge, heavy metals, PAKs, PCBs, organic contamin.
9.) Twente-kanaal, Holland	sludge, heavy metals, organic, pesticides, maintenance
10.) Oude IJssel, Holland	industrial type contamination



**Figure 1.:** Selected test sites of the GEOWATERS project

#### 12.4. Main results of the GEOWATERS project:

Most important results of the project can be grouped into three categories.

First of all hardware developments have to be mentioned. This includes:

- Design and construction of a new, submersible GeoRadar antenna.
- New antenna configuration to tow the submersible GeoRadar antenna at the required position.



- Integration of the GeoRadar and the shallow seismic systems for parallel recording. An example for this integration using a 3 m inflatable Zodiac is shown in *Figure 2*.
- Improvement of the integrated positioning and navigation techniques to ensure the required accuracy.

Next to the hardware improvements new processing and interpretation software modules have also been developed. Main improvements were:

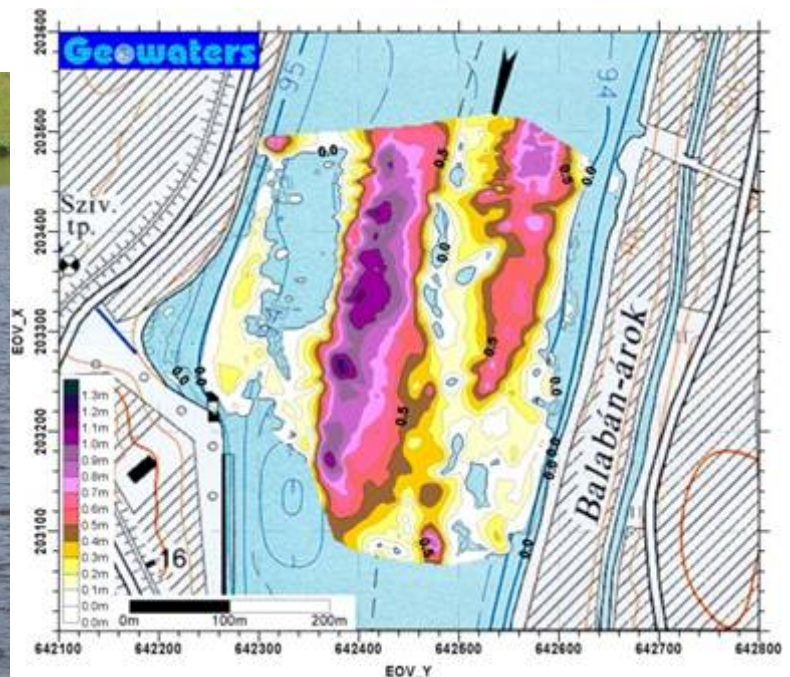
- Integration of processing functionality into the data acquisition software.
- Enhanced, real-time imaging system for data visualisation and presentation
- Development of general data format for interchangeability with clients IT-platforms.
- Integration of modules for handling different coordinate systems.
- Development of layer discrimination software for water/sludge/base sediments.
- Combined seismic/GeoRadar methodology for mapping and quantifying sludge layers in waterways
- 

Last but not least survey results at the selected test sites and the developed methodology has to be mentioned. An example is shown in *Figure 3* displaying the thickness of the sludge mapped at one of the sites.

An *Inventory List* has been developed for all of the test sites containing information about the locality, type of the problem/contamination, survey details and result.



**Figure 2:** Minimal configuration used during the project to perform GeoRadar and seismic surveys parallel.



**Figure 3:** Measured thickness of the sludge layer at the Ráckeve-Danube site, Hungary. Estimated volume of the sludge layer is almost 45000 m<sup>3</sup> in the mapped area.

## **12.5. Estimated impact of the GEOWATERS project results:**

The project will contribute to the stated aims of securing sustainable water supplies through the development of a tool for mapping, characterising and monitoring pollution sources. The data output from the developed integrated geophysical surveying technique forms the basis of a management tool to be used by the potential end users, such as local authorities or dredging companies. The savings realised by using the new combined technologies of this project are 30% of standard survey costs, while the quality of information provided is far more detailed. Remediation work could therefore be planned and monitored more effectively using the GEOWATERS project results.

## **12.6. Marketing strategy of the GEOWATERS project results:**

Marketing of the project results depend on the type of product and can be grouped in three different categories accordingly.

### 1) Marketing of hardware developments:

This includes the developed underwater GeoRadar antenna and the digitizing system for the seismic profiler.

Radsys Inc., manufacturer of the GeoRadar antenna already received a number of requests for the submersible antenna, therefore decided to put the antenna on the market. The Consortium approved this step during the group meeting of the project.

The developed high-frequency digitizing system for the seismic profiler attracted market interest as well. The manufacturer of the seismic profiling system (IKB-Technologies Ltd., Canada) expressed his interest in the hardware-software configuration, therefore Geomega Ltd. and IKB-Technologies Ltd. agreed to replace the existing 16 bit A/D card with one of the latest technology 24 bit A/D cards and offer the high-frequency digitizing system as an optional accessory with the IKB-SEISTEC™ profiling system.

### 2) Marketing of software products:

Three different software modules have been developed during the GEOWATERS project. These offer processing and data management capabilities for the seismic and GeoRadar datasets collected, interpretation and volumetric calculations and advanced interpretation facilities for sediment discrimination. First versions of distribution copies are available for evaluation.

3) The survey technology developed will be offered by Consortium members as a new service. First marketing steps were made in the countries hosting the test surveys. Some of the test sites were chosen for their combined scientific and marketing value and in every country a positive response was received. An example of this is a survey ordered in one of the closed branches of the Danube, Hungary in 2003. Marketing outside Europe is on its way too, early 2004 one of the Consortium Partners made the first test survey in the USA.

It is estimated by the Consortium Partners, that full potential of the technological developments of the GEOWATERS project can be exploited after a few years following the project completion.

## 12.7. List of Project Partners:

### SMEs:

Geomega Kft. (Project coordinator)	Mester u. 4., 1095 Budapest, Hungary Dr. Tamás Tóth, e-mail: info@geomega.hu
Scanlink BV	Asselerweg 3, 7217 MA Harfsen, Holland Dick van der Roest, e-mail: scanlink@wxs.nl
SELOR eeig	Saffierstraat 101c, 1074 GP Amsterdam, Holland Dr. James Baker, e-mail: selor@tiscali.nl
TerraMentor eeig	Androutsou 6, 17455 Alimos/Athen, Greece Dr. George Sideris, e-mail: terramen@otenet.gr

### RTDs:

MAP BV	PoBox 485, 6800 AL Arnhem, Holland Contact person: Hugo de Boom, e-mail: info@mapgpr.nl
Geophysical Laboratory, University Thessaloniki	PoBox 352-1, 54124 Thessaloniki, Greece Prof. Gregory Tsokas, e-mail: gtsokas@geo.auth.gr
Hydeko-KV	Viedenska cesta 5, 852 51 Bratislava, Slovakia Dr. Kamil Vrana, e-mail: hydeko@hydeko.sk
Fractal Bt.	Óda u. 37., 1155 Budapest, Hungary Sándor Puszta, e-mail: puszta@fractal.hu
Radar Systems Inc.	Lomonosova str. 1, B-406, LV-1019 Riga, Latvia Dr. Vladimir Zolotarev, e-mail: radsys@radsys.lv

## 13. MULINO: SUPPORTING INTEGRATED DECISION-MAKING FOR SUSTAINABLE MANAGEMENT OF WATER RESOURCES IN EUROPEAN CATCHMENTS.

Contract: EVK1-CT-2000-00082

Duration: Jan 2001-Dec 2003

URL : <http://www.feem.it/web/loc/mulino/index.html>

### 13.1. The Project

The Energy, Environment and Sustainable Development Work Programme of the Fifth Framework of the European Research emphasised the necessity to de-couple economic growth from the degradation of the environment. This issue is particularly important in the management of multi-sectoral conflicts about water resources in highly developed areas of Europe.

European water policy has been revolutionised with the approval of the EU Water Framework Directive (Directive 2000/60/EC), which calls for a holistic approach much suited to tackling water demand conflicts. The problems associated with piecemeal or fragmented regulations, which have failed to find long term, sustainable solutions to competing water demands, continue however to be exacerbated by the plurality of policies at different levels that have a bearing on water management.

The European policies for the protection of water resources evolved along multiple, independent pathways. Firstly, from an approach in which human health took a central role, reflected in a series of legislative instruments<sup>2</sup> which date mostly from the beginning of the seventies, completed by the most recent Drinking Water Directive (Council Directive 98/83/EC) in the late nineties. Secondly legislation focussed on dangerous substances and controlling emissions, which dates from the late seventies and runs through to the early nineties. Finally, other related European policies with an environmental aspect, such as Agenda 2000, and the Habitat Directive (Council Directive 92/43/EEC) in particular, have a bearing on the management of water resources. Despite the fact that many of these instruments will be superseded or absorbed by the Water Framework Directive (WFD), the institutional structures and mechanisms for water management in Europe have been conditioned by the way in which European law has divided up the problem of sustainability along sectoral lines.

The lack of a multi-sectoral perspective and adequate tools for water resource management are seen as a threat to socio-economic stability in European society, if left uncorrected over the longer term. Water is probably the most relevant resource for which increasing conflicts among different users (including the environment) are foreseen.

These evolving problems and policies require that policy makers and decision makers in Europe improve their approach to making choices and decisions, by implementing new paradigms, such as public participation, sustainability analysis, transparency and uncertainty management in decision processes.

The MULINO project was developed within the European water policy context, as defined by the WFD, with three main *objectives*:

1. To design and implement an operational decision support system for the management of water resources that is based on hydrologic modelling, multi-disciplinary indicators and a multi-criteria evaluation procedure.

---

<sup>2</sup> Directive on surface water for drinking water abstraction (75/440/EEC); Bathing Water Quality Directive (76/160/EEC); Freshwater Fish Directive (78/659/EEC); Shelfish Water Directive (79/923/EEC); Drinking Water Directive (98/83/EC)

2. To test the system in representative case studies in co-operation with local water management administrations.
3. To demonstrate the potential of the tool in supporting the sustainable management of water resources in Europe.

The project spanned the period from January 2001 to December 2003. A primary challenge for the project was to produce a general methodology that includes a DSS tool that could be applied in each of the selected 6 case studies, without compromising the requirements for integrated assessment and relevance to national and European water policy frameworks. The collaboration with real world decision makers (water management competent authorities) proved to be a very challenging effort, particularly in co-ordinating interactions between ongoing decisional processes with the work plan of the research project.

### **13.2. Main achievements**

The final *result* is a tool that has been developed as a stand-alone software, and an overall methodology within which the tool can be applied for an integrated approach to decision problems related to water management. The software incorporates integrated analysis modelling (IAM), multi-criteria analysis (MCA) and the European Environment Agency's DPSIR framework, adopting state-of-the-art data formats to guarantee interoperability. The system does not require additional software, which should improve the potential for its utilisation by water management administrations. Optional links with GIS software, hydrological models and/or meta-models are provided, and in the last version of the software a full coupling procedure links mDSS3 with the CRASH hydrologic model. The software can be coupled also with any hydrological model which respects a standard input/output procedure.

The MULINO DSS "mDSS" software was released in 3 versions (mDSS1, mDSS2 and mDSS3) during the project period, and the first version was presented to the project's end users before the end of the first year. Early involvement of potential end users proved to be an effective strategy for the success of the Project, allowing the research consortium to progressively adapt the software development to their needs. The system has undergone significant changes since the release of the first prototype, as a result of feedback from both project partners and the potential end users. Examples are the software routines to involve a range of stakeholders in a group decision process and capabilities for decision management, such as improved criterion weighting procedures and sensitivity analysis of the outcomes.

The integration of the primary *components* which make up the MULINO methodology engaged the project members in multidisciplinary problem solving to achieve the project objectives. The DPSIR conceptual framework is used to structure decision problems in terms of **D**iving forces – **P**ressures – **S**tate – **I**mpacts – **R**esponses, thus establishing a systemic and dynamic view of the decision context. The indicators to be used in the decision process can be grouped according to those categories. A hydrological model is used to explore and visualise interactions between pressures and state. Four different models were used in the case studies: SWAT, CRASH, VIDRA & SFARMOD, the last being a land use model. The use of the mDSS software has been envisioned as part of a process, which can include the involvement of stakeholders in the decision process through the use of a questionnaire designed to structure their contributions and collect the data necessary for a local network analysis. This information includes the respondents' opinions about the decision context in general, their preferences for alternative options, suggestions for decision criteria and their ranking, as well as the roles and responsibilities of different stakeholders. The heart of the decision tool itself is based upon multi-criteria analysis methods.

*The MULINO methodology was conceived for a specific application context, which is defined in terms of a decision which will affect the use of water resources. Such a decision might be related to ordinary water management activities or be connected to unusual events. This decision process is envisaged in connection with the planning and management required for the implementation of the Water Framework Directive. Such work is needed to design the programmes of measures (PMs) and to develop the River Basin Management Plan (RBMP) for a River Basin District (RBD) or specific plans for sub-basins within the RBD.*

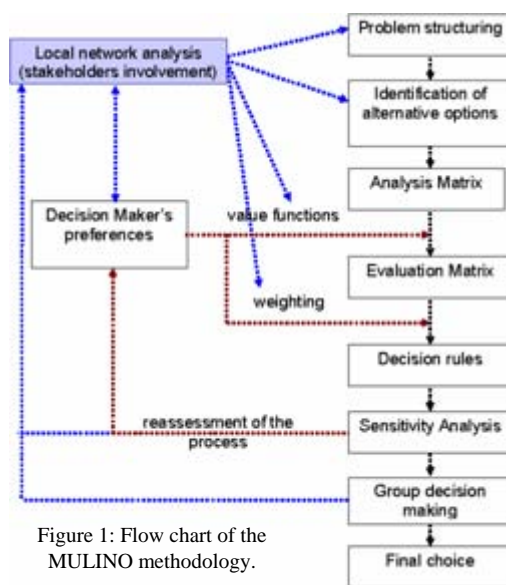


Figure 1: Flow chart of the MULINO methodology.

The MULINO methodology approaches the choice among a finite set of options through Multi-Attribute Analysis (MAA) methods. MAA decision rules are used by mDSS to identify the “best” option. mDSS guides the user through three decision phases: “Intelligence phase”; “Design phase”, and “Choice phase”<sup>3</sup>.

The mDSS tool is one of the components of the MULINO methodology, which starts with the formalisation of a problem which triggers a decisional process in which various actors are involved. A typical list of involved parties can include the decision making body (including policy makers and technicians), other administrations at higher and lower levels, associations of various economic sectors,

concerned citizens’ groups, research organisations, environmental groups, and water companies.

The MULINO approach envisages a decisional process based upon the phases shown in Figure 1. Various actors can be involved in the process, their contributions co-ordinated by the competent authority, responsible for decision implementation. The mDSS can be used throughout to document the selection of criteria and the preferences of the various parties and to identify the “best” option, given the set of choices that have been made to set up the decision problem.

In a typical application, the first step is the identification of the area where water resources are to be managed: either the entire RBD, or a sub-basin within the area. Having identified the study area, its socio-economic and environmental characteristics are described according to the DPSIR conceptual framework. Causal relationships and dynamic interactions within the catchment are conceptualised in an procedure through which the user is asked to construct DPS “chains”, so identifying the main cause-effect relationships between human activities and the state (or change of state) of water resources.

This first phase is termed “**Conceptual or Intelligence Phase**”. The decision-maker structures the problem in collaboration with stakeholders, through questionnaires or other forms of communication targeted to the decisional problem in question. The MULINO methodology introduces a “local network analysis” to be completed through a series of interviews with selected stakeholders, and the application of modelling tools to analyse the dynamic aspects of the water cycle. The socio-economic and environmental information is stored in indicator catalogues, and organised according to the DPSIR approach in formats that allow the user to deal with spatial and temporal data series.

<sup>3</sup> Simon, H. A., *The New Science of Management Decision*. New York: Harper and Brothers; 1960.

The user is then ready to enter the “Design Phase” where he/she describes the options, selects the decisional criteria taking into account the results of the local network analysis. He/she identifies then the correct qualitative-quantitative indicators from surveys, census, monitoring, modelling or expert judgements, and, after adequate preprocessing techniques provided by mDSS, stores them in the Analysis Matrix (AM). The AM is structured with options in the columns and decisional indicators in the rows.

In the “Choice Phase” the evaluation and normalisation of multidimensional indicators brings the user to provide comparable criteria to be stored the Evaluation Matrix (EM). Weighting procedures are subsequently implemented and one or more decision rules are applied to identify the “best” option. these procedures can be performed with the direct involvement of stakeholders in joint or parallel decisional processes, or indirectly through the implementation of stakeholders’ views extracted from the questionnaires. These preferences can be finally combined in the mDSS’s group decision making routine. Through sensitivity analyses and a simplified graphical “sustainability assessment” the mDSS software allows the user to analyse the variables that influence the selection of the “best” option, and explore their relevance.

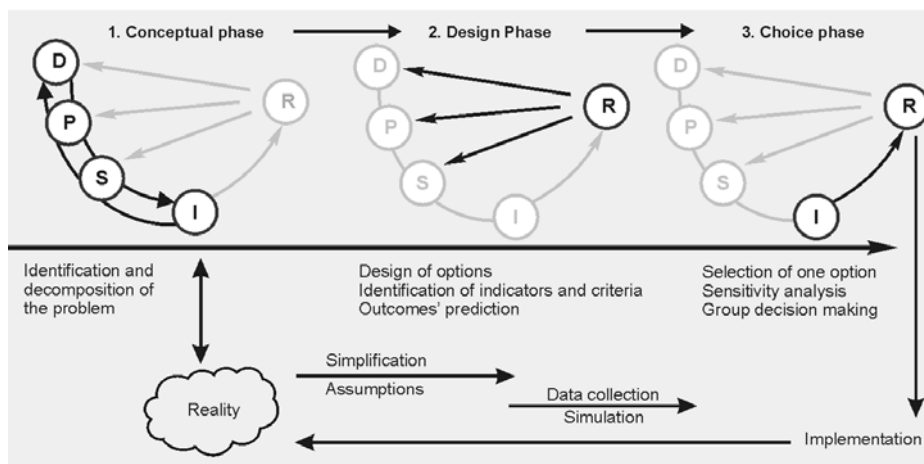


Figure 1. Conceptual framework of mDSS, in accordance with the DPSIR approach (EEA, 1999)

and decision theory proposed by Simon (1960)

To test the software during its development, the project’s participant end users worked with local project partners to apply the MULINO methodology and mDSS to a real decision problem. Six *case studies* were used to develop and test the MULINO approach over the course of the project in Romania, Portugal, the United Kingdom, Belgium and Italy. An additional European scale study sought to use the system in a much broader application in the EU15 area.

The MULINO methodology showed to be applicable at a variety of scales, thus offering water management administrations a powerful learning tool with particular relevance to the modern legal framework that is set out by the *EU Water Framework Directive*. The multi-sectoral, cross disciplinary and application-based methodology of the MULINO research activities contributes to creating a common understanding and communication about sustainable water management for that could be seen as a prerequisite for many of the goals reflected in the WFD. MULINO can support “a sound planning process” that is the objective for WFD implementation:

**-Long-term vision for the River Basin District (RBD).** Through the mDSS scenario functionality, MULINO supports the development of “a vision of what the RBD will be in

the future” and through the use of the sustainability chart, helps to determine what measures have to be taken in the perspective of a sustainable development.

**-Knowledge and information management and capacity building.** mDSS allows the decision-maker to store socio-economic and environmental information in the DPSIR conceptual framework. The user identifies the main cause-effect relationships between human activities and the state of water resources within the catchment. Many data formats are compatible with mDSS, and can be used in the “Conceptual” phase of mDSS tool, facilitating greater access to the information supporting the decisional process. A participatory multi-level approach supports capacity building and the raising of public awareness, an informal transfer of know how through the exchange of experience between river basin managers, and formal training both, internal and external.

**-Integration at the operational level.** Different bodies can be involved at different scales, and at different steps of the planning process. Since the scale is a very relevant aspect for a good integration the MULINO methodology has been developed and tested at both local and regional scales. MULINO’s flexibility allows the user to adopt the same approach at different scales and stages of decisional processes. A common methodological approach can help to establish better overall co-ordination at the river basin level and to achieve more integration at the operational level, especially among bodies involved directly with water management.

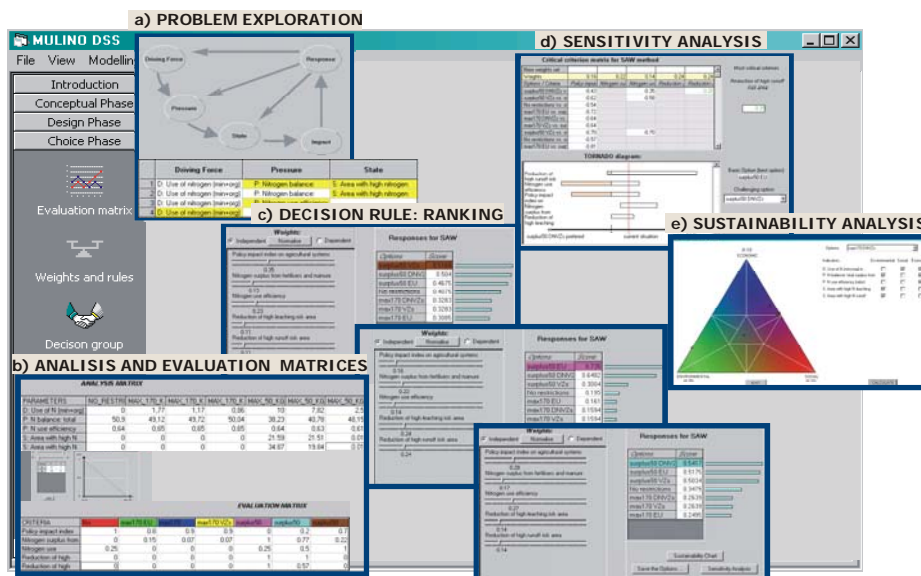


Figure 3. Collection of screens representing a typical sequence of mDSS implementation steps.

### 13.3. Marketing and exploitation strategies

Experience demonstrated that the application of the mDSS introduces a new approach to decision making, which may be, at the beginning, unfamiliar to many water managers. Therefore the first application requires an investment of time and effort to learn how to use the software and organise relevant information in a compatible way. Applications carried out so far suggested that, a part from the potential improvements of the decisional process, such investment could be worth at least to facilitate structured and efficient communication with interested parties.

Given the potentials of the Project results for operational implementation, the issue emerges of a possible **commercial exploitation**. Since the beginning of the project, the MULINO Consortium agreed to make mDSS available for free in a CDrom available on request, or through the Project web site. CDrom and Web site are structured in the same way and provide all the project results including mDSS, a manual in 7 languages, background



documentation, tutorial, etc. Two aspects are clear at this regard: on the one hand potential users can make practical use of the project results at zero cost, but, on the other, they may also benefit from adequate training and they may need support. Moreover, as yet the methodology is still undergoing experimentation and more cases are being added to the original set in various research projects. From the above an **exploitation strategy** has been designed to develop improved versions of the MULINO approach, in accordance with the evolving scientific and normative contexts and the provision of a new package is envisaged, which include upgraded versions of the various components of the MULINO approach, plus a training and assistance module, which may be offered at water management competent authorities, in particular those involved in the WFD implementation.

#### **13.4. Concluding Remarks**

The MULINO methodology was developed and tested in case studies of varying geographical scales from local to continental, driven by the needs of potential DSS users. Different decisional contexts in countries within the EU and abroad have confirmed the flexibility of the tool. The result is a general approach and a software tool, which support decision-makers in conducting a flexible, dynamic, cyclic and prospective planning process in order to implement the Water Framework Directive in a socially acceptable manner, with the participation of stakeholders. In brief, MULINO can be useful to water managers because it proposes a framework for integrating (i) different methodological approaches; (ii) the preferences of the various actors involved in a planning process; and, (iii) a series of different modelling tools and data formats.

All of the materials are available from the project website:  
<http://www.feem.it/web/loc/mulino/index.html>

As a final remark, it is strongly advised that the supporting documentation be studied carefully to avoid any misuse of the methodology.

### 13.5. The MULINO Consortium: institutions and contact people:

FEEM - Fondazione ENI Enrico Mattei	<b>Prof. Carlo Giupponi (Project Co-ordinator)</b>  Campo S. M. Formosa, Castello 5252, 30122 Venezia, Italia. Tel. +39 041 2711453 Fax. +39 041 2711461 e-mail. mulino@feem.it
Italy	
UATLA Universidade Atlântica	<b>Prof. Doutor Nelson Lourenco</b>  Antiga Fábrica da Pólvora de Barcarena, 2745-615, Lisboa, Portugal. Tel. +351.21.4398.227 Fax. 351.21.4302.573 e-mail. nelson.lourenco@netcabo.pt
Portugal	
UCL Université Catholique de Louvain	<b>Prof. Mark Rounsevell</b>  Place Pasteur 3, 1348, Louvain-La-Neuve, Belgique. Tel. +32.10.472.872 Fax. 32.10.472.877 e-mail rounseve@mail.geog.ucl.ac.be
Belgium	
SRI Silsoe Research Institute	<b>Eric Audsley</b>  Wrest Park, Silsoe, Bedford MK45 4HS, United Kingdom. Tel. +44.1525.860.000 Fax. +44.1525.860.156  e-mail eric.audsley@bbsrc.ac.uk
UK	
CEC-JRC European Commission Joint Research Centre	<b>Roland Hiederer</b>  Via E. Fermi, 21020 Ispra, Italia. Tel. 39.033.2785.798 Fax. 39.033.2789.029 e-mail roland.hiederer@jrc.it
Italy	
CRS4 Centre for Advanced Studies, Research and Development in Sardinia	<b>Claudio Paniconi (4)</b>  VI Strada OVEST Z.I., Macchiareddu, C.P. 94, 09010 Uta (CA), Italia. Tel. +39.070.2796.291 Fax. +39.070.2796.216 e-mail Claudio_Paniconi@inrs-ete.quebec.ca
Italy	
RISSA Research Institute of Soil Science and Agrochemistry of Bucharest	<b>George Cojocaru</b>  Bd. Marasti 61, 71331 Bucharest, Romania. Tel. +40.21.2225.979 Fax. +40.1.2225.979 e-mail gco@icpa.ro
Romania	
TIAMASG Fundatia Pentru Tehnologie Informatiei Aplicate in Mediu, Agricultura si Schimbari Globale	<b>Catalin Simota</b>  Sfintii Voievozi 6, 78109 Bucharest, Romania Tel. +40.21.6502.900 Fax. +40.1.6502.900 e-mail c.simota@icpa.ro
Romania	
IWE Institute of Water and Environment- Cranfield University	<b>Ian Holman</b>  Barton Road, Silsoe, MK45 4DT United Kingdom Tel. +44.1525.863.252 Fax. +44.1525.863344 e-mail i.holman@cranfield.ac.uk
UK	

<sup>4</sup> Now at Institut National de la Recherche Scientifique, Centre Eau, Terre et Environnement (INRS-ETE), Université du Québec, Sainte-Foy, Québec, Canada

## **14. GOUVERNE: GUIDELINES FOR THE ORGANISATION, USE AND VALIDATION OF INFORMATION SYSTEMS FOR EVALUATING AQUIFER RESOURCES AND NEEDS.**

Contract: EVK1-CT-1999-00043

Duration: Mar 2000-Feb 2003

URL : <http://www.futuretec-gmbh.de/gouverne/>

### **14.1. Project context:**

The EU Water Framework Directive 2000/60/EC (WFD) is a critical piece of legislation in safeguarding water resources for both people and nature. It provides a common approach across Europe to address many of the entrenched problems in water policy stemming from the piecemeal development of previous regulatory instruments. Under the WFD, six year plans will be drawn up for each River Basin District (RBD). The timescale for implementation of the WFD is short as the environmental objectives identified under the first River Basin Management Plans (RBMP) are to be achieved by 2015. The WFD represents a new approach in that it is an ongoing process of planning rather than a plan itself, it adopts a strategic and integrated approach, and the approach is participatory. With regard to participation, Article 14 of the WFD states that, "*Member States shall encourage the active involvement of all interested parties in the implementation of this Directive, in particular in the production, review and updating of the river basin management plans.*" Article 14 also sets out specific but somewhat limited provisions governing consultation on river basin management plans and availability of background documents and information.

Additional to the social and institutional momentum behind wider public participation, there has been a growing endeavour to explore the conditions for effective participation in decision and policy making. High stakes issues require extended decision-making processes and it is almost unavoidable that the concepts of the information society and electronic governance together with the practical deployment of new Information and Communication Technologies (ICT) become the driving forces of these processes. The involvement of citizens in decision processes through ICT necessitates skilled design of interfaces which can connect issues with intended audiences, following closely the same principles that sustain new styles of governance: congruency, trust, resources and knowledge sharing.

Over recent years, the role of decision tools, in particular for environmental issues, in which Decision Support Systems (DSS) are included - has been enhanced not only because of technological advances but also because of greater skill and openness in the actual use of such tools for participation purposes. In a sense, this enhanced role has assisted a change of function for decision tools within environmental decision-making processes.

The expansions in opportunities for participation has generated new tools to support the process itself and well over fifty such methods have been identified. These include frameworks for organising face-to-face dialogue and debate, consultation techniques based on interviews or questionnaires and, increasingly, the deployment of customised ICT platforms and Internet applications.

## 14.2. The GOUVERNe Project

The GOUVERNe project aimed at *designing and prototyping a user-based and scientifically validated tool (...) to improve the management of [mainly] groundwater resources at the catchment and sub-catchment levels.*

In recent years there have been increased calls for "science based policy". There are also increased calls for the better integration of "stakeholder perspectives" in public policy, and in the performance obligations placed on the business community. The overall goal of the GOUVERNe project has been to contribute to the development of a comprehensive Europe-wide network of activities for the production, deployment and exchange of teaching and training resources in the field of water resources governance and sustainable development. The consortium has demonstrated the revolutionary possibilities of the new multimedia information and visualisation technologies for the development of governance support tools and procedures that facilitate the effective participation of individuals and groups as "stakeholders" in water resources policy, management and governance processes. Thus, following the style and terminology of a number of recent European projects, (e.g., VALSE, ULYSSES, VISIONS), we choose in GOUVERNe to speak of Tools to Inform Debates, Dialogues and Deliberations – TIDDD (©European Communities) and Deliberation Support Tools – DST rather than the traditional "decision support" concept. It is the process of multi-stakeholder deliberation that furnishes the basis for good decisions, and this comes about (according to the underlying social theory) because deliberation engenders learning.

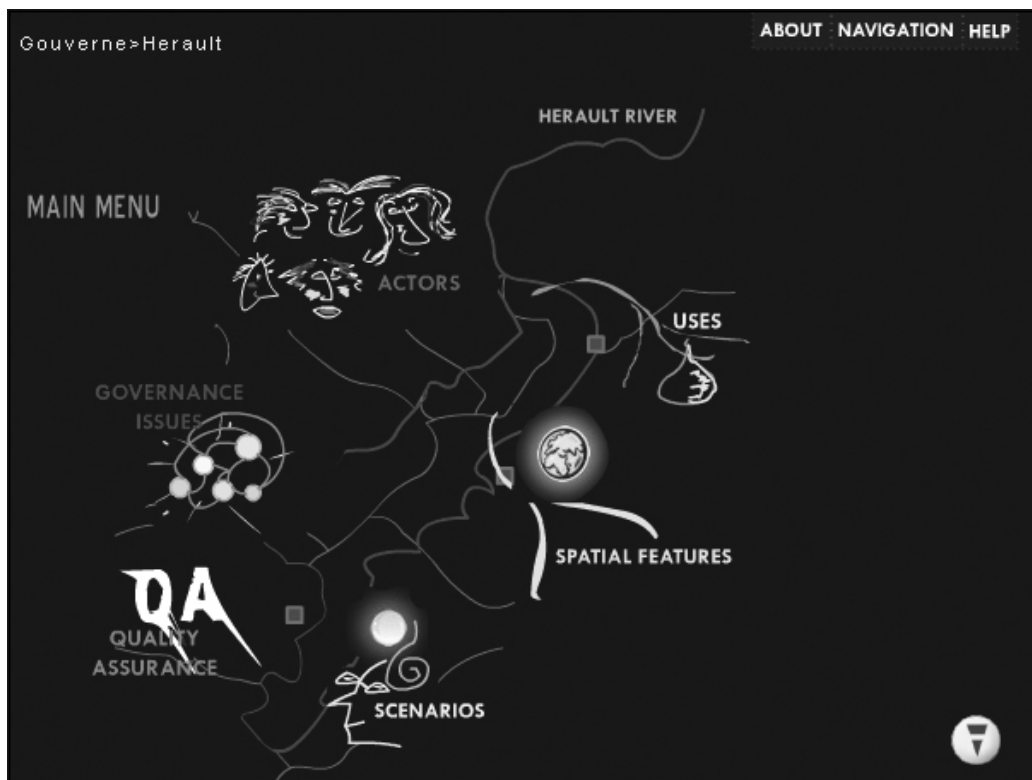


Fig. 1: Main Menu of the TIDDD – Tools to Inform Debates, Dialogues and Deliberations for the Hérault Valley

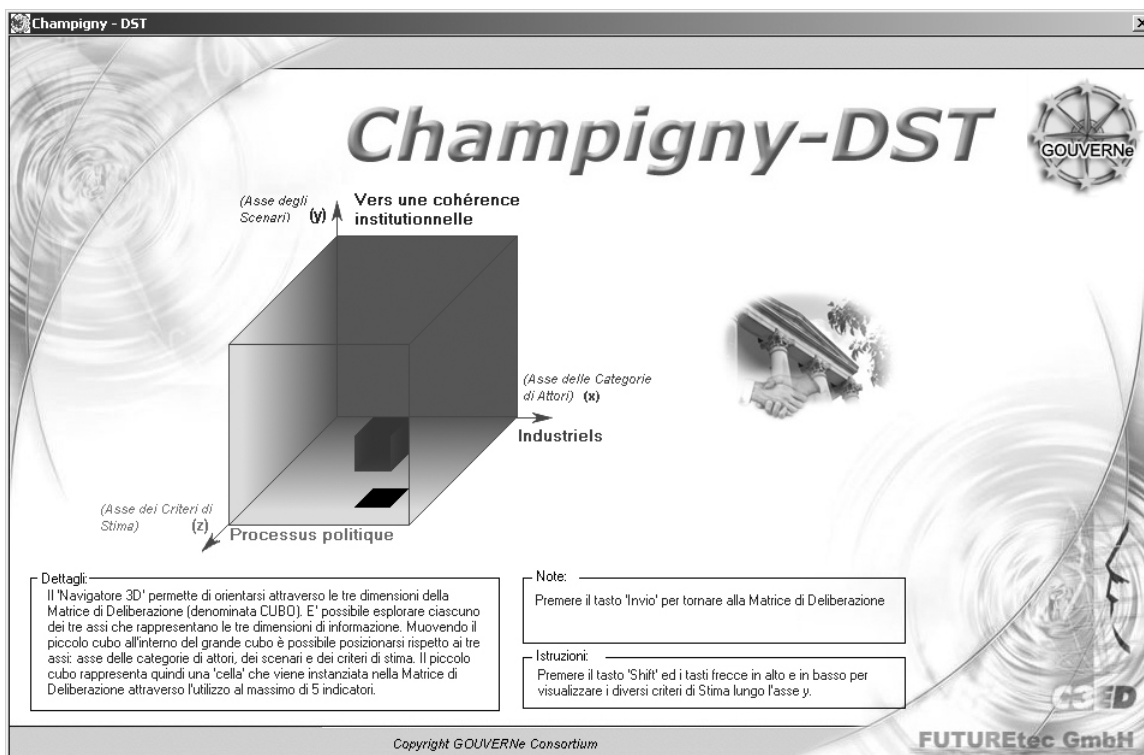


Fig.2: DST– Deliberation Support Tools

### 14.3. Main Achievements

The results of GOUVERNe are the mature development of two fully functional prototypes, the TIDDD - Tools to Inform Debates, Dialogues and Deliberations (see Fig. 1) for the Hérault Valley (France) and for the Argolid (Greece) case studies; as well as the DST - Deliberation Support Tools (see Fig. 2) for the Champigny (France) case study and Milano (Italy) DST analysis system.

The DST and TIDDD systems are tools that deploy new Information & Communication Technology in order to organise the information that feeds into a dialogue process about a governance issue, in this case water resources. The DST and TIDDD are designed to support participatory processes through presenting information, policy scenarios, and evaluation indicators in an accessible way. Quality assurance procedures as developed and documented in the project are not only about the software and the scientific models or scientific information deployed by the software system, or about the usage context, but also about the combination of all of these aspects. The quality assurance thus goes beyond software quality assurance or scientific quality assurance. It addresses aspects related to communication of science to non-scientific audiences and the use of these types of tools in participatory contexts.

Apart from the development of the TIDDD and DST, the GOUVERNe project developed several methodological aspects, namely:

- Methodology to initiate debates across social actors of a river basin governance process

- Methodology to incorporate different perspectives in a complex problematique such as river basin governance
- Methodology to quality assure the knowledge deployed to address governance issues in water planning and governance
- Multi-criteria quantitative evaluation as a tool to facilitate dialogue among different perspectives

#### 14.4. Market Potential

The most innovative elements of the TIDDD and DST prototypes are the combination of the representation of these systems with social science. Having an interdisciplinary approach, they merge the knowledge from different sectors and disciplines and offer very good possibilities for high user-interaction.

The prototypes use innovative methodologies and software elements like the deliberation matrix implemented, as well as the multimedia framework. They deploy new state of the art ICT, which is tailored for the audience and follows a number of good practice software developments for stakeholder participatory processes. The prototypes are more "brainware" than "software".

The vision of future markets for the GOUVERNe products shows potential for exploitation:

- The Water Framework Directive acknowledges that there is a large number of societal groups interested in water planning. These groups need some reliable method for providing information about water resources and supporting debate about the management of these resources.
- The Aarhus convention is turned into a directive by the EC and generates demand for the type of tools developed by the GOUVERNe consortium.
- Immediate take up of GOUVERNe by all secondary schools and higher education institutions, as a model for explaining deliberative democracy.
- A winning point can also be that many stakeholders share at least a conceptual view on groundwater (indicators, properties, actors, compelling requirements, etc).
- As a further step in capacity building for research and professional training, a new collaboration has been developed, engaging several of the GOUVERNe partners, in the general field of Building Knowledge Partnerships for Sustainable Development.

#### 14.5. Marketing strategies

The consortium has consistently envisaged applications and **commercial exploitation** of the GOUVERNe technological products and methods, which can be grouped in the following categories:

1) Software:

- the TIDDD is available as DVD in three languages (English, French and Greek) and needs to be tailored to the geographical, hydrological and socio-economic requirements of each region.
- the DST is available as CDrom, as well as on-line demo in two languages (French and Italian). It also needs minor tailoring following the requirements of the customers.

2) Services and advice, as well as tutorial and training:

- The services can comprise organising the participatory/debate context of water management e.g. in how to use, how to integrate the tools etc. The methodology and software design concept are readily transportable into other sectors of environmental governance and evaluation of company or policy performance against sustainability goals.

3) Methodologies in form of advice, as well as tutorial and training to:

- a) initiate debates across social actors (river basin governance process);
- b) incorporate different perspectives in a complex problematic;
- c) quality assure the knowledge deployed to address governance issues in water planning and governance.

No patents are currently envisaged; however the software developments involve several original concepts which, as Intellectual Property Right (IPR), have been and are being protected by appropriate copyright, trademarks and exploitation agreements amongst the consortium partners.

## **14.6. The Partnership**

### ***1. C3ED Centre d'Economie et d'Ethique pour l'Environnement et le Développement***

Université de Versailles – Saint Quentin en Yvelines (F) –  
47 Boulevard Vauban, 78047 Guyancourt Cedex, France  
Coordinator: Martin O'Connor, email: [Martin.OConnor@c3ed.uvsq.fr](mailto:Martin.OConnor@c3ed.uvsq.fr)

### ***2. FUTUREtec Gesellschaft für angewandte Informatik mbH (D)***

Hauptstrasse 188 - D 51465 Bergisch Gladbach (Köln), GERMANY  
Contact: Caterina Rehm-Berbenni, email: [crehm@futuretec-gmbh.de](mailto:crehm@futuretec-gmbh.de)

### ***3. INTECS - GIS Laboratori***

Via L. Gereschi, 32/34, I - 56126 Pisa, ITALY  
Contact: Andrea Musone, email: [andrea.musone@pisa.intecs.it](mailto:andrea.musone@pisa.intecs.it)

### ***4. School of Water Sciences, Cranfield University (UK)***

MK 43 OAL Bedfordshire, UNITED KINGDOM  
Contact: Paul Jeffrey, email: [p.j.jeffrey@cranfield.ac.uk](mailto:p.j.jeffrey@cranfield.ac.uk)

### ***5. Istituto di Economia delle Fonti di Energia***

Università Commerciale Luigi Bocconi  
Viale Filippetti 9, 20122 Milano, ITALY  
Contact: Antonio Massarutto, email: [antonio.massarutto@uni-bocconi.it](mailto:antonio.massarutto@uni-bocconi.it)

### ***6. BRGM Montpellier Service EAU - Unité RMD***

1039 rue de Pinville, 34000 Montpellier, FRANCE  
Contact: Petit Vincent, email: [v.petit@brgm.fr](mailto:v.petit@brgm.fr)

### ***7. Joint Research Centre of the European Commission, IPSC and KAMS***

TP 268 I- 21020 Ispra (VA) ITALY  
Contact: Ângela Guimarães Pereira, email: [angela.pereira@jrc.it](mailto:angela.pereira@jrc.it)  
Silvio Funtowicz, email: [silvio.funtowicz@jrc.it](mailto:silvio.funtowicz@jrc.it)

### ***8. Conseil Régional Ile de France Direction de l'Environnement et du Cadre de Vie***

Bureau 211, 35 boulevard des Invalides 75007 Paris, FRANCE



Community Research

For many years the Community is supporting research in the area of environmental technologies.

A selection of projects financed during the FP5 are presented briefly in this publication with the intention to give some examples of completed projects and their contribution to areas as waste water, drinking water or industrial water technologies. Other described projects are dealing with monitoring and sensor development or developing tools for water management and decision support systems.

Increased and focused efforts are required for research, demonstration and dissemination in the area of water and soil-related environmental technologies. The European Commission is supporting those objectives through the current 6th Framework Programme and the on-going establishment of a Water Supply and Sanitation Technology Platform

