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▲ *Cascades in Krk, Croatia.*

Water quality preservation *and restoration*

Preserving the quality of water resources raises major environmental, sanitary and economic issues for our societies. Aquatic ecosystems host a broad variety of animal and vegetal species whose conditions and dynamics are sensitive to the chemical, biological and physical composition of water. Moreover, water is a vital resource for humans and an essential resource for the development of their societies. Yet, human activities can also be a threat to water quality, because of the substances they release in the environment. The degradation of the physico-chemical and biological qualities of water can induce pathological risks for human beings. This degradation in turn compromises the sustainability of human activities and the environmental functions of the water resource. The impact of agriculture on water resources is particularly illustrative of the challenges science has to take up in order to preserve water quality. Water is increasingly needed for agriculture, industrial processes and energy production. But at the same time, agricultural inputs such as fertilisers and pesticides and industrial effluents are as many sources of water contamination. In an attempt to overcome the challenges of production within a context of water scarcity, agriculture looks for new practices, such as the use of non conventional water (such as treated waste water). Yet, there will be no sustainable agricultural development without a control of the release of contaminating substances and of their mobility in the environment. In that respect, the use of non conventional water may lead to potential contamination of surface and underground water, due to the presence of toxic and pathogenic compounds in waste water.

Many of these issues are being tackled by the regional scientific community: the development of innovative processes for waste water treatment (industrial, domestic, urban); the understanding and forecasting of contaminants concentrations and mobility in hydrosystems; the design of landscape development and management approaches to limit the scattering of contaminants in the environment; the development decision-support tools for risk evaluation and water use optimisation. The research efforts concentrate not only on usual contaminants such as metals, fertilisers (nitrogen, phosphorus) and pesticides, but also on emerging contaminants such as drug substances, viruses and bacteria.

One way to reduce environmental pollution is to develop and implement efficient treatment processes of agricultural and industrial effluents. Conventional treatments have mainly been guided by output water quality. The current scientific challenge is to design new processes that meet environmental requirements broader than the sole quality of the effluents processed, integrating energy constraints (development of low-energy processes, or even bioenergy-producing processes). An array of biological, physico-chemical and membrane-based processes are being explored.

The evolution of the contaminants in the environment can only be understood by means of analytical research works that examine the processes involved, be they biological, physical or chemical, and the interactions among processes. In particular, the specific properties of each environment (geology, soils, landscape structures, rural and urban developments, etc.) have to be taken into account. The evolution of contaminants with regard to micro-organisms activity, degradation or modification of chemical compounds, is also an issue. The effect of contrasted climatic and hydrological conditions on the mobilisation and transport of contaminants is a research topic of upmost importance, especially in Mediterranean and tropical contexts.

Finally, water quality preservation necessitates the design of generic decision-support tools, useable in the long term and over large areas, to evaluate, monitor and optimise the effects of human activities on water quality. Associated scientific issues concern time and space integration of the processes involved in contaminants evolution. In particular, digital modelling of contaminants evolution, life cycle assessment and the development of indicators of pollution stresses are areas of major interest.

Jérôme Molénat, Olivier Grünberger & Marc Voltz (UMR LISAH)

Water quality preservation *and restoration*

Membrane materials *and processes for water* treatment intensification

The ***European Membrane Institute Joint Research Unit – UMR IEM*** **(CNRS, ENSCM, UM2)**, founded in 1998, is a world-renowned laboratory specialised in membrane materials and processes. Its research objectives are based on a multidisciplinary, multi-scale approach:
- Elaboration and characterisation of new membrane materials;
- Implementation of such materials into membrane-based processes used in particular for effluent treatment, gas separation, and biotechnologies related to food and health sciences.

IEM comprises three research departments:
- Design of membrane materials and multifunctional systems;
- Interfaces and physico-chemistry of polymers;
- Membrane-based process engineering.

Within a context of increasing water demand compounded by the scarcity and degradation of the resource, IEM develops multifunctional and innovative membrane materials and processes to intensify water treatment. IEM works with a number of industrial and academic partners through national and international collaborative research programmes.

The following application fields are specifically targeted:
- Water treatment to reach the required water quality (drinking water, process water, etc.);
- Waste water treatment for environmental preservation and/or reuse of treated water (irrigation, cooling water, wash water, etc.);
- Sea water desalination.

Both physical and biological methods are explored to treat water. Physical approaches include:
- Treatment of organic compounds:
  - Coupled processes for the treatment of phytosanitary products, endocrine disruptors, drugs and colouring agents (photocatalysis, enzymatic catalysis, adsorption and membrane processes);
  - Separation by pervaporation;
  - Treatment of the polycyclic aromatic hydrocarbons, using ozonation and membrane processes.

- Treatment of mineral pollutions:
  - Selective electro-extraction of metal cations in diluted solutions;
  - Boron extraction through nanofiltration;
  - Membrane distillation and reverse osmosis for sea water desalination;
  - Extraction and concentration of heavy metals with hollow fibre membrane contactors.

Coupling of membrane separation and biological pathways is also developed in the lab:
- Membrane bioreactor for domestic effluents;
- Treatment of effluents containing phenolic compounds using a membrane enzymatic reactor;
- Treatment of urban residual water coupled with energy production using a membrane reactor.

Moreover, IEM develops innovative materials with specific functionalities:
- Super-hydrophobic membrane for the treatment of water (membrane distillation);
- New membrane synthesised by self-assembled copolymer blocks;
- Copolymer synthesis for the sorption/complexification of metals in the treatment of industrial waste water and the recovery of metals. •••

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▶ Presentation page 31

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...continued on page 28

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▲ *Industrial effluents have to be treated before their release in the environment (factories near Alexandria in Egypt).*

>WATER QUALITY AND ECOLOGICAL FUNCTIONS

Control of the ecological quality of rivers

The riparian corridors, associating human activities (agriculture, urban development, transport infrastructures, etc.) and natural or semi-natural plant formations (prairies, riparian forests), are factors of control of the ecological and physical conditions of rivers. Hence, they constitute key elements to comply with the European Water Framework Directive (WFD). The restoration of riparian corridors involves various stakeholders at the local level (structures in charge of the management of catchment basins), district level (Water Agencies) and national level (State).

To facilitate the multi-level and multi-stakeholder decision making process, it is necessary to develop tools to assess the anthropogenic impacts on aquatic environments. The *Rhône-Méditerranée-Corse* water agency has commissioned TETIS to design methods to characterise the anthropogenic pressures along rivers and to spatially model the relations between these pressures and the ecological status of aquatic environments.

TETIS has developed an innovative methodology based on "object-oriented" classification, using satellite or airborne images with a very high spatial resolution, associated with exogenous data. This gives rise to land-use maps of riparian corridors, with the required precision about the nature and localisation of the objects (riparian vegetation, buildings, agricultural plots and associated developments, road infrastructures…). The land-use maps are then synthesised as spatial indicators of environmental pressure.

The relations between pressure indicators and water condition indicators (biological or physico-chemical indicators) are then modelled within the framework of the DPSIR conceptual diagram (Driving force, Pressures, State, Impacts, Responses). This modelling approach is original in the way it takes into consideration the imbrications between functional levels (the station: local level and the catchment basin: global level), and the inherent upstream/downstream dependences in rivers.

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▲ *Mediterranean rivers are submitted to strong flow rates seasonal variations, affecting water quality (the Hérault River during summer).*

Environmental *assessment, modelling* and technologies *to serve water quality*

The ***Information – Technology – Environmental Analysis – Agricultural Processes Joint Research Unit – UMR ITAP*** **(IRSTEA, Montpellier SupAgro)** develops the scientific and technical bases to design equipment for a more sustainable agriculture and environment-related services. ITAP's three main areas of research are:

- Information and associated systems: on the one hand, ITAP designs sensors based on optical measurements (vision, spectrometry) for the characterisation of agrosystems and environmental processes. On the other hand, ITAP develops new indicators derived from environmental data (climatic, expert, plot-related, etc.), integrated in decision-support tools, in order to assess the status of agro-ecological systems.
- Technologies: development of ecotechnologies for sustainable agricultural production. New design methods that integrate environmental constraints are studied: eco-assessment, eco-design, built-in design. ITAP specifically works on equipment for the protection and maintenance of crops that minimises the sanitary and environmental impacts of pesticide application techniques. It facilitates the regional platform "ecotechnologies for agro-bioprocesses*", and is a reference centre for agricultural spraying.
- Environmental assessment: ITAP develops and implements environmental and social impacts assessment tools, based on life cycle analysis (LCA) and seeks to optimise the performance of the processes studies. It facilitates the ELSA cluster network**.

Here are some examples of ITAP research works in relation to water:

- FISPRO software: design and optimisation of fuzzy inference systems (IRSTEA – INRA free software);
- Implementation of control facilities of new sprayers and associated procedures;
- Digital modelling of phytosanitary deposits;
- Atomisation of agricultural sprays: influence of certain properties of the liquid;
- Influence of phytosanitary spraying quality on the transfer of pesticides into the environment;
- Phytosanitary products drift in vineyards: real scale tests in controlled environment;
- DRIFTX model of the atmospheric transfer of pesticides during the applications of phytosanitary products in vineyards;

* www.ecotech-lr.org

** Pôle Environmental *Lifecycle and Sustainability Assessment :* www.elsa-lca.org

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▶ Presentation page 8

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Integration of ecological stakes in the management of intermittent Mediterranean rivers

The MIRAGE project (Mediterranean Intermittent River manAGEment), involving the HSM JRU, associates fourteen European research institutes, two basin management entities and a Moroccan university. The objective of the project is to study the applicability of specific management measures of flash floods and severe low water levels in Mediterranean intermittent rivers, taking into account ecological stakes. It contributes to the enforcement of the European Framework Directive on Water and Aquatic Environments around the Mediterranean Sea. It will also give rise to improved management and development schemes for catchments of intermittent Mediterranean rivers.

Indeed, intermittent rivers of Mediterranean catchments are characterised by a long period of accumulation of pollutants during the dry period and their fast transfer towards the downstream coastal area during flash floods. The combination of irregular flow regime and sudden mobilisation of pollutant masses creates major difficulties for the managers: water resource availability, flood control, water quality and ground contamination. When applied to Mediterranean catchments, the management solutions developed in the context of non-intermittent rivers do not yield the expected results, due to the non-linearity of responses of intermittent rivers and to the absence of reference situations in this type of environment.

The MIRAGE project addresses the following issues: definition of indices specific to the hydrology and ecology of these rivers; development of solutions to control the dynamics of contaminants (organic matter, nutrients and priority substances) in water and sediments; control of the effects of floods on the remobilisation of pollutants. These actions are carried out on five study sites and integrated in two pilot catchments submitted to a broad range of anthropogenic pressures.

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- TISCAD software for the traceability of pesticides;
- Eco-design and methodologies for the innovative fabrication of spraying machines;
- Life cycle analysis of waste water sanitation plants.

For its experiments, ITAP relies on *ReducPol*, a 3,000 m² technological platform for spraying systems assessment. *ReducPol* is one of the four experimental sites of the regional platform "ecotechnologies for agrobioprocesses". ITAP also develops industrial relations and promotes the creation of businesses (Lisode, *l'Avion Jaune*, Oléobois, 3Liz, Ondalys…) via its MINEA*** cluster.

Transformation of *polluting elements*

The ***Environmental Biotechnology Laboratory Internal Research Unit – UPR LBE*** **(INRA),** located in Narbonne, is attached to the INRA centre of Montpellier from an administrative point of view and to the INRA departments "environment and agronomy" and "microbiology and food chain" from the scientific point of view. It focuses on the concept of "environmental bio-refinery".

For more than 25 years now, LBE research efforts have been targeting the treatment and/or valorisation of wastes from human activities, be they liquid effluents (especially from agro-food), solid residues (agricultural residues, domestic waste and sludge from waste water treatment plants), or biomass such as micro- or macro-algae. The pollutants transformation processes are carried out by microbial communities, whose complexity stems from their composition, diversity and functional dynamics. The characteristics of these communities – combined with the fact that they can only operate in an "open" environment – have led the laboratory to work on the operating conditions of the bioprocess, with the aim to orientate the microbial reactions of transformation. These developments also take into account health innocuousness constraints (i.e., linked to the presence of pharmaceutical, detergent and/or pathogenic residues).

The transformation processes of the pollutants are studied at different scales:
- Sequences: through the characterisation of kinetics, key physiological systems and microbial population dynamics;
- Processes: through the development of innovative processes, the optimisation of hydrodynamics and bioreactors operations, the implementation of physico-chemical co-treatment techniques.

LBE research efforts have taken these two scales into account, within the context of sustainable paths. The objective is to develop remediation or valorisation devices for effluents and residues, under economic and regulatory constraints, in order to achieve sober, performing, reliable and evolving bioprocesses.

LBE develops six main research axes:
❶ Research on generic indicators for the characterisation of organic matter and related co-products;
❷ Knowledge and role of the biotic/abiotic parameters with regard to the services provided;
❸ Means of action and management of processes and associated ecosystems to act rather than to suffer;
❹ Control of behaviour and environmental and sanitary impacts of the products issued from the treatment processes;
❺ Descriptive/explanatory/predictive models in engineering and ecology;
❻ Engineering and eco-design of industrial chains.

These research efforts concern several domains of competence: microbiology, microbial ecology, biological engineering, process engineering, automatic modelling, life cycle analysis, project and industrial transfer engineering. •••

*** http://minea.montpellier.cemagref.fr

>HUMAN-INDUCED WATER POLLUTION

Study of chronic water pollution by pesticides: the case of chlordecone in the French Antilles

© J.B. Charlier

▲ *Banana cultivation in the French West Indies.*

Chlordecone is an organochlorinated insecticide, used from 1971 to 1993 in the banana tree plantations in the French Antilles. Chlordecone residues are still present in the environment, especially in soils. This situation leads to chronic contamination of rivers, underground tables, (including large drinking water resources) and even of certain crops. Little is known either about the dispersion modalities of this pesticide – which is significantly adsorbed in organic matter-rich soils submitted to tropical rainfall – or about the modalities of plant contamination.

The Chlordexco project, supported by the National Chlordecone Plan and the "Contaminants, Ecosystem, Health" programme of ANR, implies the research units *HortSys* and *Systèmes Bananiers* of CIRAD, the LISAH JRU (INRA, IRD, Montpellier SupAgro), the INRA centre of Guadeloupe, the IRD centre of Martinique and the Agrosphere Institute in Germany. It aims at studying the contamination of water bodies through:

- The identification of the determinants of the molecule release within the soil profile and of its transfer to underground tables: the characteristics of chlordecone adsorption/desorption mechanisms are examined taking into account the type of soil, the quality of the organic matter and the mineral composition. A forecasting model of chlordecone migration is elaborated depending on soils hydrodynamic properties and climatic events.
- The identification of sources and dynamics of river contamination at the catchment scale: several measurement stations have been installed in Guadeloupe to characterise the hydrological behaviour of an elementary basin (20 ha) and of a resource basin (400 ha). Environmental contamination is analysed in soils and water of tables and rivers. The transfer pathways and the dynamics of the pollutants are being modelled.

These research works will allow identifying the main zones that contribute to the pollution and to the evolution of the polluting pressure over time at different scales. They will contribute to diagnose the importance and the short and long terms evolution of underground and surface water contamination. They will help to better understand the chemical stresses suffered by aquatic organisms. Finally, they will end up with recommendations for a better environmental management.

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▶ Presentation page 15

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LBE is one of the world leading laboratories in the field of anaerobic digestion. It promotes excellence in research, thematic plurality, multidisciplinary approaches, innovation and technology transfer (6 patents, 11 licence contracts, *Pollutec* Innovation Awards in 2007, 2009, 2010). Its facilities cover more than 4,700 m², including a 1,900 m² experimental hall, high performance scientific and analytical equipment, with more than 50 digesters (from 1 litre to several cubic meters), running on a 24/7 basis.

Analysis of minerals *in water*

The Water, Soils and Plants Analyses Internal Service Unit – US Analyses **(CIRAD)** is an analyses laboratory with a staff of 19, based in Montpellier. It is specialised in the analysis of mineral constituents, including metal trace elements, in plants, water, soils and other media related to agriculture (harvest residues), environment (waste water treatment plant sludge), or the food industry (table oil). It plays a cross-disciplinary role by serving other research units of CIRAD and other public institutes (INRA, CNRS, IRD, etc.).

The lab is accredited by the Ministry of Agriculture to import and analyse soils from non-European countries. It is well-equipped with analysis devices such as inductive coupling plasma (ICP), inductive coupling plasma mass spectrometry (ICP-MS), continuous flow colorimeters, automatic granulometers, pH-meter automat controller, C, H and N elementary analysers, atomic absorption spectrometer with electrothermal atomisation, polarographic chain.

The lab is also accredited to train students and researchers in analytical techniques. It carries out methodological studies on laboratory and field experiments. It is also destined to train, control and evaluate other analyses laboratories in terms of metrology and quality control. Since 2000, the lab is certified by the French Association for the Improvement and Management of Quality according to the ISO-9001-2008 standards for four types of services (analysis, training, expertise and methodological developments). With regard to water, the lab analyses elements present in natural water (rivers, lakes, underground water tables), or in waste water, including mineral pollutants such as heavy metals. ■

© M. Soulié

▲ *Lowland cultivation in Majorque, Baleares .*

>HUMAN-INDUCED WATER POLLUTION

Monitoring sea water intrusion into coastal aquifers through hydrogeophysics: the Campos Observatory in Majorque (Balearic Islands)

The experimental and observation site of Campos (12,000 m²) is dedicated to the study of sea water intrusion in coastal aquifers. It is located within a highly permeable carbonated reef terrain (Miocene) exhibiting some karstic cavities a few meters in size. In this part of the island, intensive farming and irrigation cause the overexploitation of the coastal underground table, leading to sea water intrusion (up to 15 km inside the island), and the progressive pollution of underground water by chlorides. The experimental site comprises a network of 14 deep drillings (100 m on average, plus one 250 m deep), six of which have been bore drilled.

This site has been developed with the support of the Study and Planning Service of the Water Resource Department (Balearic Ministry of Environment), within the framework of the European project ALIANCE (5th European Union Framework Programme, 2002-2005) coordinated by the Tectonophysics Laboratory of Montpellier, now part of the GM joint research unit.

Currently, the project is monitored by the "transfers in porous environment" team of GM, in the framework of the OREME observatory *(see page 13)*.

The main scientific objectives are:

- On site characterisation of the heterogeneous geological medium, by means of drilling measurement campaigns: geological structures (wall imagery), petrophysical characterisation on cores and *in situ* (electrical, acoustic, natural radioactivity), flow characterisation through hydrogeophysical methods (flowrate by spontaneous potential, hydrodispersive behaviour).
- The continuous drilling-based monitoring of the aquifer using a specific instrumentation designed within the laboratory: i) in geophysics (igeo-SER), for daily measurement of parameters such as electrical resistivity or electrokinetic potential, and ii) in hydrodynamics (Hydreka piezometers or Schlumberger probes), for measurement of pressure and temperature fields and ionic charge of *in situ* fluids (using a WestBay multi-packers tubing).

The main goal is to study the response of the reservoir to external stresses, be they anthropogenic, natural or induced by controlled experiments. Recently, a partnership between GM and the imaGeau (Montpellier) and Schlumberger-Westbay (Canada) companies has allowed the implementation of systematic observation routines of underground fluids.

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▲ *Water sampling in the Carnoulès River (Gard, France).*

© M. Héry

▼ *Polluted water from the Carnoulès mines.*

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>HUMAN-INDUCED WATER POLLUTION

The role of micro-organisms in the transformation of contaminants in aquatic environments

Sources of chemical contamination of water have increased in amount and nature throughout the last century. They can be organic or inorganic, and have a natural or anthropogenic origin. The purpose of the research works carried out by the HSM JRU is to get a better picture of the mechanisms involved in the evolution of these chemical contaminants (metals, metalloids, organometallic compounds, endocrine disruptors, medical drug residues, etc.) in the environment, especially in the water cycle.

Besides the physico-chemical characteristics of the environment, micro-organisms activity plays a key role in the dynamics of these contaminants, by conditioning their chemical form and thus their mobility. Owing to their adaptation capabilities, micro-organisms have developed metabolic or detoxification mechanisms enabling them to interact with chemical contaminants, including xenobiotics. Microbial activity can lead to the biodegradation of organic forms, to the modification of chemical forms, or to the immobilisation of the compounds through precipitation or complexation.

Given the complexity of influencing factors, it is essential to develop multidisciplinary approaches, combining microbiology and chemistry, in order to understand, forecast and possibly control the processes of contaminant transfer into the environment. This is perfectly illustrated by the research works of HSM on acid mine drainages. These research works have made it possible to partly decipher the biogeochemical mechanisms involved in the dynamics of metallic and metalloid elements in the hydrosphere downstream from the former mine of Carnoulès (Gard), which forms part of the OREME Observatory *(see page 13)*. Micro-organisms are both actors of the generation of acid drainages from mine wastes, by controlling the sulphide oxidation reactions, and actors of the natural attenuation of water pollution, by promoting iron and arsenic oxidation, leading to their immobilisation in the sediments.

This approach has also been developed to study the transfers and ecotoxicity of the metallic and organometallic pollutants from port sediments, during the ECODREDGE-MED project (funded by FUI). It has also been applied in the study of the evolution of drug substances in the coastal environment during the PEPSEA project (funded by ANR).

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>HUMAN-INDUCED WATER POLLUTION

Household-scale purification system for arsenic-contaminated drinking water in Cambodia and Vietnam

© Davin Uu

A project on the evaluation of the characteristics of underground water tables in zones contaminated by arsenic in Cambodia and Vietnam, in order to develop a household-scale water purification system (2009-2010, funded by the *Agence Universitaire de la Francophonie)* has been coordinated by the Cambodia Technological Institute (Pnom-Penh) and operated jointly with the Hochiminh Technological University (Vietman) and the CIRAD Analysis lab. The objective of the project was to design a simple, low-cost and efficient device to lower the arsenic content of water taken from the underground water table of the Mekong River in Cambodia and in Vietnam, used as drinking water by the village populations.

▲ *Skin disease caused by drinking water contaminated with arsenic in Cambodia.*

The high concentration of this element in water (from 40 to 1,200 µg/l whereas the maximum concentration recommended by WHO for human consumption is around 10 µg/l) is partly of anthropogenic origin (pesticides) but essentially natural, through simple dissolution from arseniferous pyrites present in the upstream portion of this large Asian river. In these regions, the recently evidenced arsenic toxicity causes skin necrosis (arsenicosis) which can be lethal.

The device designed is a simple sand bio-filter, made from ordinary materials. It comprises an airing system in the shape of a watering syringe, a nail bed to enrich the iron content and foster the ferric hydroxide formation that traps arsenic, a sand filter with increasing granulometry and a final polishing device made of rice chaff. This device is easy to use, to maintain and efficient at household or small village scale. For this study, the CIRAD Analysis lab provided an analytical support for the characterisation of water sampled in different sites in the two countries and for the validation of the efficiency of the device, leading to arsenic concentrations below 10 µg/l post-treatment.

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>TREATMENT OF WASTE WATER AND EFFLUENTS

CreativERU project: intensive treatment and valorisation of urban residual waters

The CreativERU project (collaboration between the research units IEM, LBE, the Laboratory of Engineering of Biological Systems and Processes of INSA Toulouse, Veolia Water Research and Innovation) is funded by the ANR "Ecotech" programme, open to French-Chinese collaboration. It concerns the development of advanced water treatment technologies, more specifically the treatment of urban effluents. The rather innovative aim is to reach very low carbon and water impacts.

This project should remove the last scientific locks and validate at the industrial pilot scale a new intensive path for urban waste water treatment. This treatment enables producing very high quality treated water suitable for direct reuse (as it is disinfected), while reducing the size of the facilities and the operational costs, or even the equipment costs.

The aim of the project is to define a new treatment concept, with the following differences from conventional systems:

- Production of quality treated water using a porous membrane filtration technology, enabling the resource to be reused directly;
- Strong reduction of the oxygen needs (hence of energy inputs), through the physical extraction of the organic fraction, that is further concentrated for easier fermentation;
- Optimisation of a significant biogas production;
- Optimisation of nutrients treatment to facilitate their elimination and/or recovery;
- Demonstration of the possibility to treat urban waste water to produce fresh water of a defined quality, with a positive energy balance and a minimal environmental impact within a context of sustainable development.

Such a technology would constitute a real breakthrough compared to existing intensive systems only taking into account the requirements for treated water quality, without consideration for the carbon release (linked to energy consumption) and the advantage of saving water.

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▲ *Experimental hall of LBE at INRA Narbonne, France.*

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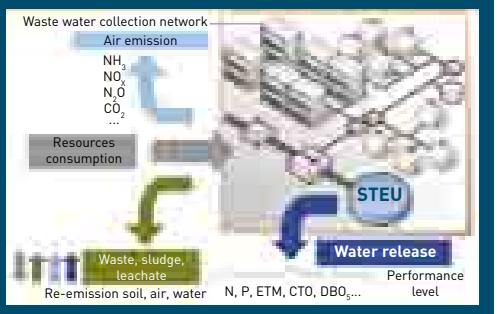
>TREATMENT OF WASTE WATER AND EFFLUENTS

Environmental assessment of water management and uses: impacts quantification and pollution transfer identification through life cycle analysis (LCA)

>LIFE CYCLE ASSESSMENT (LCA)



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The Life Cycle Assessment (LCA) is an efficient and systematic mean to assess the environmental impact of a product, service or process. The purpose of the "life cycle" principle is to reduce the stresses imparted by a product on the resources and on the environment throughout its life cycle, from the extraction of the raw materials up to the discarding at the end of life, a cycle often referred to as "from cradle to grave".

LCA is a conceptual framework, a procedure (a sequence of standardised steps) and a set of models allowing the conversion of flows of substances discharged or consumed into potential environmental impacts.

▲ *Application of the Life Cycle Assessment method to a waste water treatment plant.*

Regardless of its use – agricultural, household or sanitation – the quality of water or the efficiency of its use and of its treatment is always a matter of compromise between, on the one hand, the use of the water itself and, on the other hand, the consumption of material and energy to save or treat the water. Conventionally, the efficiency of a waste water treatment plant used to be measured only through the final quality of water back to the environment. Yet, such a treatment generates other environmental impacts during the construction, operation, running and decommissioning of the whole sanitation system. Thus, the reduction of local impacts such as eutrophication of aquatic environments or ecotoxicity in fresh water bodies, are impaired by regional or global impacts linked to the infrastructure and operation of the waste water treatment plant. The environmental LCA is the only assessment method able to quantify such impacts over the whole life cycle, from the extraction of the raw materials used to the end of life of the systems studied. Associated with local approaches such as environmental impact assessment studies which take into account the specificities of the site, LCA makes it possible to prevent as much pollution transfers as possible.

The ELSA* cluster, based in Montpellier, comprising amongst other ITAP, LBE and LGEI research units, works in close collaboration with G-EAU on these environmental assessment issues related to water management and use.
Since 2010, a project funded by the National Bureau for Water and Aquatic Environments *(Office National de l'Eau et des Milieux Aquatiques),* aims at assessing the environmental performance of the sanitation system of small and medium size local authorities (sanitation networks and waste water treatment plants). Other research efforts related to water uses are in progress within the ELSA cluster: territorial LCA applied to the management of the Thau Lagoon, to an irrigated area, to water uses of a large city, to the production of micro- and macro-algae (INRA-LBE and Montpellier SupAgro). The objective of all these works and associated research issues is to better take into account water and its treatment in the LCA, both as a limited resource and as an ecological medium.

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* *Environmental Lifecycle & Sustainability Assessment* (IRSTEA, CIRAD, EMA, Montpellier SupAgro, INRA): www.elsa-lca.org

Treatment of industrial effluents for the reuse of water: case of the ceramic industry

Water is fast becoming a concern and a major stake for the coming decades, due to an increasing consumption in all sectors of activity, compounded by the unbalanced renewal of the resource. This situation is especially critical in Mediterranean countries. Assuming they can be valorised by means of an appropriate treatment, effluents become a resource potentially and economically interesting for industrialists. In this context, the utilisation of membrane processes for the treatment of effluents proves to be a solution worthy of attention.

The ceramic industry in Spain is the first in Europe and the second in the world. It is concentrated in a small territory in the province of Castellon, around the city of Castellón de la Plana. The main bottlenecks for the reuse of the effluents from this industry stem, on the one hand, from a high content in calcium and sulphate ions and, on the other hand, from the presence of boron salts which are contaminants unfit for human consumption and for the cultivation of citrus fruits.

The Nanoboron project aims at trapping the boron present in the effluent by membrane separation. It is a collaboration between IEM, the *Instituto de Technologia Ceramica de Castillon de la Plana* [IMECA], *Gardenia Quimicas S.A.* and *Estudio Ceramico S.L.* The project was implemented in three steps: (1) identification of the processes applicable and feasibility at the laboratory scale, (2) modelling and design of a demonstration pilot system and (3) *in situ* tests and adaptation to the operating conditions with an economic balance.


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The laboratory feasibility step (IEM) has led to couple a microfiltration and a nanofiltration process. A demonstration pilot system has then been designed. The *in-situ* tests and the technico-economic study carried out by IMECA have validated the approach.

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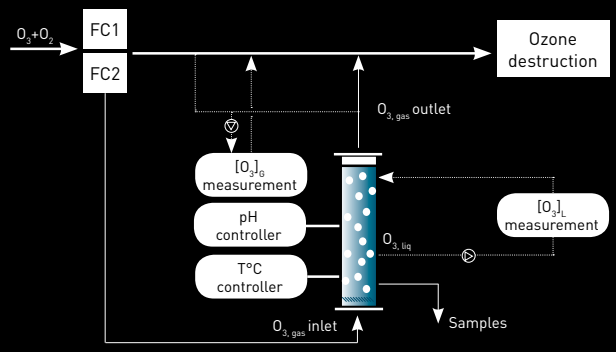
▲ *Pilot machine coupling microfiltration and nanofiltration for the treatment of industrial effluents built by IEM and IMECA PROCESS.*

PETZECO project: treatment of petrochemical aqueous effluents through ozone-zeolithe combination



Water and sediment pollution by polycyclic hydrocarbons is unquestionable and induces real environmental and health threats. This situation has led the European Commission to classify these substances as priority issues. The conventional operations of chemical oxidation or adsorption on active carbon show limits linked to cost and implementation. Advanced oxidation processes are suited to the degradation of the bio-refractory or toxic compounds, owing to the use of hydroxyl radicals. The aim of the research efforts made within the framework of the PETZECO project (collaboration between IEM, the Montpellier Charles Gerhardt Institute, the Chemical Engineering Laboratory of INSA Toulouse and Total) is to design a leading technique for the treatment of difficult industrial waste water.

The main idea of this project is to use ozone combined with innovative zeolithic materials, in order to associate the decomposition capacity of ozone into hydroxyl radicals with the adsorption properties of zeolithe. This combination triggers a synergy and should accelerate the degradation speeds. The utilisation of a mineral porous solid should guarantee a good resistance to oxidation and maintain long term adsorbing and catalytic properties.

The development of this new zeolithe-type solid mesoporous adsorbant/catalyst is one of the major challenges of this project, since very few studies have been done in this domain. The implementation of this catalysts/ozone combination in an efficient, low cost process is another challenge for this project. The chemical and mechanistic aspects will be studied in depth to target the most interesting functionalities of the solid during the zeolithe synthesis. The parameters used to size the oxidation process in different configurations are studied in depth (from fluidised bed to the membrane-based separation of the catalyst). The ultimate goal of the project is to use monolithic materials that contain the new catalyst on real petrochemical effluents.

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>WASTE AND TREATED WASTE WATER VALORISATION

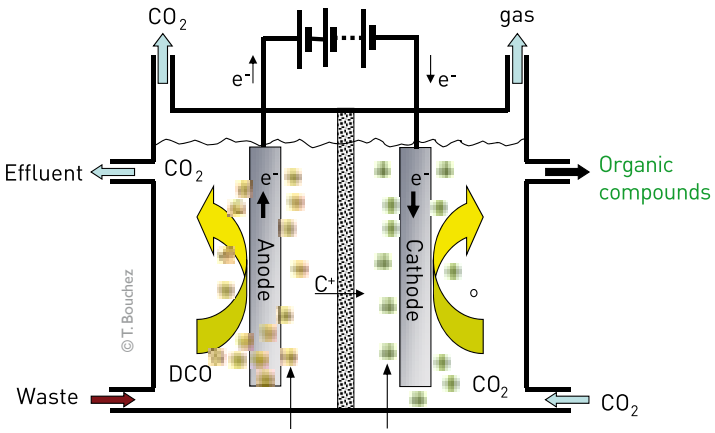
The BIORARE project: bioelectrosynthesis for residual waste refining

BIORARE is a collaborative project that involves the IRSTEA research units "Hydrosystems and Bioprocesses" and "Environmental Engineering and Biological Treatment of Wastes", the joint research unit "Chemical Engineering Laboratory" (CNRS, INPT, UPS), the INRA research unit LBE and the company *Suez-Environnement*. It focuses on the modalities of use of the concept of "microbial electro-synthesis" for the bio-refining of wastes and effluents. This recent discovery allowed the production of high value-added molecules using organic matter and energy present in wastes.

The main idea consists in using the technology of the bio-electro-chemical systems, not to produce electricity as in "bio-energizer", but to orientate the metabolic reactions of the bioprocess towards the production of molecules of interest, usable in green chemistry. These microbial electro-synthesis systems offer essential advantages:

- Physical separation between a "dirty" compartment that receives the organic matter to be treated and a "clean" compartment in which the synthesis of the molecule of interest takes place;
- Possibility to orientate the metabolic flows and to select the oxidation reactions that occur at the cathode, through voltage regulation.

In order to elaborate a detailed specification for the application of microbial electro-synthesis, the key components will be identified as well as the specifications associated with the elaboration of a subsequent industrial development strategy. First, it will be necessary to strengthen the microbial electro-synthesis scientific and technical bases. The relations between the operating conditions and the molecules effectively synthesised will be validated experimentally at laboratory scale. Multidisciplinary approaches shall be combined in order to better understand and appreciate the technological potential of these systems. In parallel, there will be an environmental assessment of the strategies used to couple these systems to the existing industrial facilities. This work will be carried out on the basis of reference scenarios which will allow the identification of environmentally sensitive components, in order to orientate the technical or industrial choices. Finally, an economic, societal and regulatory analysis shall be undertaken to achieve a better definition of the future industrial development strategies. The intellectual property right measures will be taken whenever necessary.



▲ *Illustration of the bioelectrosynthesis concept.*

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>WASTE AND TREATED WASTE WATER VALORISATION

Treated waste water for irrigation: towards better risk assessment

The world faces a problem of water scarcity caused by global warming, demographic growth and diversification of water uses. The reuse of treated waste water could be one of the solutions to this problem. It makes it possible to use in priority conventional waters for uses that require high quality, and to prevent the overexploitation and salinisation of coastal aquifers. The treated waste water used for irrigation is therefore not discharged in rivers, in the aquifers or in the sea, and the agriculture benefits from its fertilising potential (nitrogen and phosphates). However, the use of treated waste water for irrigation induces environmental and health risks. It could contain various toxic compounds harmful to the flora, fauna and humans, as well as human enteric pathogens. Its salinity may cause soil degradation. The risks depend on the origin of the water, its treatment, its management, the health condition of the populations, etc.

EMMAH is currently taking part in a European survey about the use of treated waste water with regard to practices, risks qualification and quantification, epidemics linked to water quality, evolution of pollutants and pathogens in the environment, regulations with their advantages and their implementation difficulties. EMMAH has initiated research efforts on the evolution of viruses in the environment, notably with a substitute to the hepatitis A virus (mice *Mengovirus*). It wishes to extend its work to the *Norovirus* responsible for most of the viral gastroenteritis, or even to the *Rotavirus* responsible for the same disorders in children. It looks into the evolution of this virus in the soils, at the surface and in the atmosphere. It will also look into the evolution of certain antibiotic-resistant bacteria detected at the inlet and outlet of waste water treatment plants, as well as into the effects of the salinity of waste water on the structural stability of soils. EMMAH uses various methods and develops models that couple different processes: site visits with reuse of the treated waste water, *in-situ* and laboratory experiments, analysis of the processes underlying the evolution of the pathogens studied.

The final objective is to gain a better knowledge of the processes associated with the evolution of certain viruses and bacteria in the environment, to integrate this knowledge in mechanistic models and finally to develop decision-support tools for public authorities. Through this project, EMMAH will also be involved in the setting up of new warning sensors.

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▲ *Traditional irrigation system in Syria.*

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