The Catalan Institute for Water Research (ICRA)

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Introduction

The Catalan Institute for Water Research (ICRA) is a research center devoted to the study of water-related issues from scientific and technological perspectives. The ICRA was established in October 2006 by the Catalan Autonomous Government within the framework of the Research Centers Network Program (CERCA). The ICRA is a private foundation whose trustees are the Catalan regional government's Department of Innovation, Universities, and Enterprise (DIUE), the University of Girona (UdG), and the Catalan Water Agency (ACA). The H2O building, the Institute's official headquarters, has housed the institute since 7 October 2009, during which time the ICRA has progressively defined its main lines of research and its internal structure.

Fig. 1. External view of the ICRA's H2O building.

Research in water issues requires integrative solutions

Compared to other regions of the world, the Mediterranean basin is one of the most vulnerable to climate changes and a prominent "hot spot" for potential changes in water availability. The Mediterranean climate is subject to complex planetary scale processes, but also to local processes induced by the physiography of the region and by the influence of the Mediterranean Sea. Arid and semi-arid regions are particularly water-thirsty, and excessive pressure on water resources is the rule of thumb. The conjoint result of climate and human-related (including abstraction) changes on water availability is visible in several long-term hydrological patterns. The effects of water scarcity on drainage networks extend from associated hydrological irregularities to variations in geomorphological dynamics (higher channel incision, habitat simplification). Water chemical quality is affected, with higher nutrient and pollutant concentrations occurring under lower water flows. Biological communities respond to harsher environmental conditions with lower diversity, the arrival of invasive species, and a reduced efficiency of biological processes (nutrient uptake, primary production, decomposition, etc.). The increased pressure on water resources will undoubtedly cause additional effects on aquatic ecosystems, with scarcity-induced stress inducing other physical or chemical types of damage. Furthermore, water scarcity and its derived effects negatively impact ecosystems and thus the human beings that depend on them.

Potential alternatives to rising demands and harmful effects are neither single nor readily implemented. Growing population demands against a background of global climate change suggests a relevant conflict with the needs of ecosystems, as well as effects on water quantity and quality. Addressing the demands of both human and natural systems under conditions of shrinking water resources requires a multidisciplinary approach that considers the complete water cycle. This can only be achieved by integrating scientific, technological, and management solutions that address issues related to the ecological quality of rivers and seas, the development of new wastewater and drinking water treatment technologies, and the study of resource availability strategies that take into account sustainability, social perceptions, and the related (financial and social) costs.

The role of the ICRA in the Mediterranean

Faced with these needs and the awareness of the importance of water as a basic resource, the main aim in the creation of the ICRA was to implement a holistic, multidisciplinary approach to water, one that included all issues related to freshwaters and human-used waters. This has been accomplished through a coordinated, cooperative organizational structure that addresses a broad spectrum of water-related sciences and tech-

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nologies. This multidisciplinary approach is one of the Institute's distinguishing features. In particular, the ICRA seeks to provide scientific and technological perspectives to a number of issues derived from water needs, scarcity, and ecosystem conservation. The aims of the ICRA are:

- To develop research, knowledge transfer, and innovation projects related to all aspects of the complete cycle of water and its management
- To attract qualified researchers to participate in the ICRA's projects, and to train specialized researchers and technicians in the scientific and technological fields related to water
- To act as a center of knowledge exchange through specialized courses, workshops, and general meetings
- To become an umbrella institution for water research developed in Catalonia, as well as a qualified research center able to achieve relevance in the Mediterranean and in an international context

The ICRA's lines of research are organized in three main areas, referred to as (A). Water resources and ecosystems, (B). Water quality, and (C). Water technologies and evaluation (Table 1).

A. Water resources and ecosystems. This area investigates the spatial and temporal dynamics of water resources and its potential effects, especially on the structure and function of continental aquatic ecosystems. Special emphasis is given to irregularities in water resources and the effects of land use and climate change on resources and ecosystems, particularly in the Mediterranean area. The main research lines within this area are the following:

- Hydrological processes in lakes, reservoirs, and rivers, both in surface and subsurface waters; hydrogeological constraints in water resources; implications for water recharge
- Sedimentary and geomorphological processes in rivers, lakes, and reservoirs
- Anthropogenic influences on the biogeochemical fluxes, biodiversity, and ecological quality of aquatic ecosystems
- Effects of global change on ecosystem functioning, especially the influence of nutrients and pollutants, as well as flow and thermal regime alterations on the carbon cycle at local, regional, and continental scales
- Global change effects on ecosystem services at the basin scale, especially involving those services generated by freshwater ecosystems, such as pollution amelioration by riparian strips or wetlands
- Implications of water resource availability and ecosystem services for stakeholders and manager agents

B. Water quality. This area of research seeks to provide a complete and efficient response to the problems and challenges related to water quality, particularly in the Mediterranean area. The assessment of water quality as it is defined in this area—considering chemical, microbiological, and ecotoxicological quality—allows identification of the tools needed for the adequate management and preservation of water bodies. The main objective of this area is to define the concentrations, fate, and mechanisms of action of pollutants and pathogenic elements in natural and reused waters.

The most modern chemical, microbiological, and ecotoxicological analytical methods are being implemented to assess water quality and to examine the corresponding characteristics

Table 1. Research lines of the three ICRA areas

A. Water resources and ecosystems	Line 1. Analysis and modeling of hydrological and physical processes in inland waterbodies, both in superficial waters and groundwater
	Line 2. Biogeochemistry, biodiversity, structure and functioning of lacustrine ecosystems, including reservoirs
	Line 3. Biogeochemistry, biodiversity, structure and functioning of river ecosystems; valuation of river ecosystems and compartments in a watershed perspective
	Line 4. Management and restoration of ecosystems; watershed modeling and planning
B. Water quality	Line 1. Dynamics of organic pollutants in superficial and ground waters, sediments, and biota
	Line 2. Pollutants in drinking, treated, and reused waters
	Line 3. Microbiological diversity and quality of natural and reused waters
	Line 4. Ecotoxicological responses of the biota to priority and emergent pollutants
C. Water technologies and assessment	Line 1. Efficient conditioning and distribution of ground or surface drinking water
	Line 2. Wastewater treatment and reuse
	Line 3. Modeling and control of water-based systems
	Line 4. Unitary operational systems

of surface waters, groundwaters, and treated water, the latter including both drinking and wastewater. Risk assessment of water pollutants is determined by analyzing the environmental impact of organic compounds in water bodies. Studies of the presence, diversity, and activity of microbes in the aquatic environment are another objective in this area.

Research in this area focus on:

- Occurrence of pollutants in selected areas: analysis, speciation, and bioavailability in surface and ground waters, sediments, and biota
- Development of analytical methods for determining emerging and priority pollutants
- Water quality as a criterion for the proper management of wastewaters and reused waters, and the preservation of water bodies
- Determination of environmental data quality by organizing interlaboratory exercises and subscribing to the most advanced reference standards
- Microbiological quality and implications for human health in natural and reused waters
- Microbiological diversity (molecular approach) of natural and reused waters
- Ecotoxicological response monitoring of the biota in relation to priority and emerging pollutants, as well as through the consideration of additional environmental factors acting as stressors

C. Water technologies and assessment. This area of research develops and evaluates methodologies and technologies for optimizing resources, energy efficiency, and cost minimization of processes related to the urban water system. These objectives are achieved through the application of emerging, resource-optimization technologies of water supply, wastewater treatment, reclamation, and reuse. This area has an integral perspective of the integrated processes involved, from the river to human consumption and back to the system. The development of technologies is related to those best available but not entailing an excessive cost, while striving to achieve resource consumption reduction and optimization, related to water scarcity and improvement of the final product.

This area of research focuses on:

- Conditioning and efficient distribution of drinking water from surface and groundwater origins
- Wastewater treatment technologies, especially nutrient removal/recovery, elimination of priority pollutants, energy saving and reclamation, and water reuse
- Modeling of water technologies and development of decision support systems, applied to the management of water in the urban cycle; development of simulation tools for the interpretation of water and wastewater treatment units
- Management methodologies of urban water, aimed at synthesizing the path from the capture, transportation, and use of water until its return to the ecosystem
- Development and validation of technologies applied to water reuse (e.g., membrane bioreactors); benchmarking of water treatment technologies; analysis of biotechnological processes

Facilities at the ICRA

The 6770 m^2 that comprise the H_2O building include space for more than 15 laboratories equipped for chemical and biological analyses. Within the laboratory facilities, special mention must be made of the Scientific and Technical Services (SCTs), which provide specific instrumentation to ICRA researchers as well as to interested external users. The SCTs are currently divided into four units, encompassing the necessary equipment and related techniques for chemical analysis, mass spectrometry, microscopy, and biological and molecular techniques.

Fig. 2. View of the Scientific and Technical Services (SCTs) facilities at the ICRA.

The **Chemical Analysis Unit (UAQ)** is focused on chemical water characterization. It includes equipment such as potentiometric titrators (equipped with intelligent dosing units and different electrode types), analytical and precision balances, pH and conductivity meters, sample digestion units, and a multiple wavelength UV-VIS spectrophotometers.

The **Mass Spectrometry Unit (UMS)** is directed at the determination of emerging organic contaminants in natural, drinking, and waste waters. This unit provides access to mass spectrometry instruments able to characterize a wide range of compounds (pesticides, pharmaceuticals, PAHs, endocrine disruptors, drugs of abuse, etc.) at very low levels, as they occur in water samples. Target polar compounds can be identified and quantified at low concentration through a liquid chromatography (LC) unit coupled to tandem mass spectrometry (LC-MS/MS). Gas chromatography (GC) with selective and sensitive detectors, such as a tandem mass spectrometer (GC-MS/MS) and electronic capture detector (ECD), is used for the determination of non-polar compounds. The ICRA also has endowed the UMS with cutting-edge instrumentation:

- UPLC-QTRAP: Ultraperformance liquid chromatography coupled to quadrupole linear ion trap mass spectrometry (AcquityUPLC from Waters and QTRAP 5500 from AB Sciex)
- GC-QqQ: Gas chromatography coupled to tandem mass spectrometry (TRACE GC Ultra, TriPlu autosampler and TSQ Quantum GC from ThermoFinnigan)
- GC-ECD: Gas chromatography coupled to electron capture detector (ThermoFinnigan)

UPLC for chromatographic separation uses columns packed with sub-2-μm particles, resulting in better chromatographic resolution and increased peak capacity as well as a multi-fold increase in linear velocity (speed) and efficiency (peak capacity). The latest generation of hybrid MS, quadrupole linear ionTrap (QqLIT) for mass spectrometry detection, provides both qualitative and quantitative information due to its ability to run in quadrupole linear ion trap mode, which is very useful for the precise identification of target compounds in complex environmental samples.

The triple mass spectrometer is the most advanced, sensitive, and powerful technique available for the identification and quantification of non-polar compounds at low levels. The unique fast acquisition rate provided by the TSQ Quantum GC has made the rapid analysis of multi-residues a routine procedure in modern laboratories and addresses the main challenges posed by this type of analysis. The autosampler configured for liquid and gas injection permits automation and productive sample injection.

The ECD enables certain environmental chromatography applications due to its extreme sensitivity to halogenated compounds such as PCBs, organochlorine pesticides, herbicides, and halogenated hydrocarbons.

The **Biological and Molecular Techniques Unit (UTBM)** includes the most advanced equipment necessary for high-quality molecular approaches. Modern methods have facilitated determination of the microbial diversity in natural samples, in which < 1% of the bacterial species are culturable. The UTBM is equipped with the following:

- Thermocyclers, including conventional thermocyclers for most PCR analyses and a gradient thermocycler aimed at optimization of PCR methods
- Molecular imager, to reveal the results of PCR analyses in a completely automated operation, allowing the accurate detection of traces of DNA in an electrophoresis gel. This has a wide range of applications, such as automated quantitative analysis of DNA samples
- Nanodrop spectrophotometer, to test the yields of DNA isolations and able to perform quantification with 1 μl of sample
- Denaturing gel gradient electrophoresis (DGGE), to discriminate among the bacterial diversity. DGGE results in the separation of different bacterial populations, and the distinguished bands can then be sequenced
- Real-time PCR system to quantify, in real time, bacterial populations and/or gene expression. In an optical system (laser or xenon lamp), the light excites a dye that hybridizes with the DNA, with the excitation registered through a CCD camera. The registration allows the controlled formation of DNA amplicons in each sample and thus final quantification of the bacterial population and/or gene

The **Microscopy Unit (UM)** provides the ICRA's researchers with the equipment to perform epifluoresence, high-contrast differential interference contrast, phase-contrast, and laser-scanning microscopy. It includes direct and inverted microscopes as well as stereomicroscopes.

Finally, the **Water Science and Technologies Research Platform (PLANTEA)** is a research infrastructure that supports the ICRA's research areas and transfer activities. PLANTEA consists of pilot plants of different sizes that enable basic and applied research projects in advanced treatment processes for waste, treated, or drinkable water. This facility is to be fully equipped with state-of-the-art equipment and instrumentation. The Platform's several fixed treatment systems can be used as a reference, applying either the systems that are most commonly used at the moment or designing a benchmark configuration [www.benchmarkwwtp.org]. Suitably equipped spaces will allow companies or research groups to perform tests using a particular technology.

Ongoing ICRA research

Several projects, covering a broad spectrum of research areas, are underway at the ICRA:

1. SCARCE (Assessing and predicting effects on water quantity and quality in Iberian rivers caused by global change) is a CONSOLIDER-INGENIO project [www.idaea.csic.es/scarceconsolider] that began in 2009 and will continue until 2014. It aims at understanding the effects on rivers of multiple stressors arising from conditions of water scarcity. SCARCE examines four river watersheds in the Mediterranean basin in order to understand the trends and potential consequences operating at different scales. Iberian rivers and most of those located in the Mediterranean area are under strong environmental stress due to alterations in water flow, enhanced light and temperature conditions, varying nutrient concentrations, and the increasing arrival of toxicants. Potential effects in arid and semiarid regions are related to decreasing resources, variations in water quality, and ecosystem effects. These may be a response to climate change but also to human pressures. The effects of habitat deterioration, point-source or diffuse inputs of nutrients and contaminants, and species invasion or extinction are relevant to ecosystem functioning and services, but also have social and economic implications. Results obtained prior to the project addressing the same topic have already been published in a special issue of *Journal of Hydrology* (383:1-147) and in the book *Water Scarcity*

in the Mediterranean: Perspectives Under Global Change (Springer, 2010; Heidelberg, Germany).

2. VIECO (Desarrollo y validación de plataformas integradas de Vigilancia biológica y química optimizadas económicamente) is an integrated research and transference project [www.proyectovieco.com] involving the ICRA and water companies. The main objective is to improve water quality by developing a monitoring platform that assesses the environmental quality of surface waters in the Llobregat River. The project goes beyond the environmental quality standards (EQS), since these are not necessarily representative of water status. Instead, this platform provides a better-defined, simpler, and economically sounder approach than those currently being used in the field.
3. OPTIMAR [www.optimar.info] is a coordinated research project funded by the Spanish Ministry of Science and Innovation within the sub-program of Supporting Singular and Strategic Projects (PSE). The general objective of the project is to optimize the operation of drainage and sanitation systems of urban waste waters whilst efficiently managing all knowledge and information available. The strategy consists of the design, development, and validation of new complementary tools able to process, synthesize, interpret, and utilize the heterogeneous information generated by the system for optimal global operation, combining environmental and economic objectives. There are three complementary operative objectives:

   a) Development and validation of new tools that simplify decision-making by EDAR operators
   b) Development and implementation of new advanced tools for automatic control of all the parts of sanitation systems that can be operated automatically
   c) Development and validation of new tools for the education and training of sanitation system operators

4 DEGRAPHARMAC. Non-conventional fungal degradation of selected pharmaceuticals from effluents: process development, monitoring, and risk assessment. The project (MICINN CTQ2010-21776-C02-02) will run from December 2010 to January 2014 and seeks to develop and evaluate an alternative biodegradation process using selected fungi (known for their powerful unspecific enzymatic system, able to degrade a wide range of xenobiotics) for the elimination of a set of target pharmaceuticals from wastewaters. Recently, pharmaceutical residues have been found in several environmental compartments across a wide variety of hydrological, climatic, and land-use settings. Current wastewater treatment plant technologies are unable to remove pharmaceuticals in significant amounts such that these compounds are continuously released into the environment, where their presence may lead to chronic toxic effects on aquatic life despite their low concentrations. Within the framework of this project, new analytical methods will be developed at the ICRA to analyze these compounds as well as their transformation products along the water treatment process. In addition, risk assessment studies to determine their potential environmental impact will be carried out.