Water resources: identification, functioning, mobilisation
The latest UNESCO world report on water resources was already characterised by a rather alarming tone. For instance, it stipulated that “despite the vital dimension of water, this domain is plagued by a chronic lack of political attention, poor governance and insufficient investment”, and that “action is urgently required to prevent a global crisis”.

Yet, it is estimated today that global annual withdrawals amount to 3,800 billion m³, representing only 25% of useable resources. But such a relative abundance does not reflect the huge disparities in the geographic distribution of this vital resource. Indeed, some regions are already facing hydric stress (less than 500 m³/year/inhabitant), while others are hit by disasters caused by chronic overabundant rainfalls. Such inequalities raise all kinds of difficulties and challenges.

Given the global population growth, water demand increases by 64 billion m³ each year. Water needs are becoming increasingly high in relation to strategic decisions and associated commitments being taken in areas such as agriculture, economic development and energy production.

The disturbances induced by climate change also have an impact on the hydrological cycle. Indeed, in many regions of the world, the Intergovernmental Panel on Climate Change (IPCC) forecasts all point towards longer droughts and/or more frequent floods. Such disturbance further aggravates the degradation of ecosystems, already facing growing anthropogenic pressures.

From the health point of view, 80% of the diseases affecting developing countries are water-related. This is due to insufficient access to drinking water and lack of sanitation infrastructures, owing to both poor funding and poor political and strategic decisions.

This alarming water situation is further compounded by the general public’s growing environmental concerns and international and global thinking about water issues. “Blue Gold” is slowly emerging as one of the most critical stakes of the 21st century, with the growing looming threat of “water wars”.

Within such a context, it is more than ever important to control as completely as possible the resource, in order to feed the reflexion on how to better manage and govern water. It is therefore necessary to be able to locate, identify, evaluate and mobilise water resources. These are major stakes. They call for the analysis, understanding and modelling of all water cycle processes, be they natural or man-made.

The regional scientific community has the skills required to play a leading international role and to provide answers to some of the society’s concerns. For this purpose, it has developed proven observation capabilities on which research is being based: the Universe Sciences Observatory OREME, the Environmental Research Observatories OMER, AMMA-CATCH, OHMCV and H+, the KARST Observation system, etc. Recently, the regional scientific community has received significant equipment subsidies from the French Ministry of Research, thus reinforcing its position as a leader in the field of spatial information for environmental purposes.

The expertise of regional teams in the field of underground water has long received the highest acclaim, especially in the key area of karsts. This research field is particularly strategic for the Mediterranean coastal regions as these contain almost 60% of the water resources exploited.

The regional research community has become a reference for its research on surface water. Although the fundamental issue of the transformation of rain water into running water – and hence into a resource available in different forms (infiltration, runoff, storage) – is a core concern for hydrologists, numerous other issues are also addressed by the community. One such issue is the use of water in agriculture, deemed to be essential, especially within the Mediterranean context. The issue of floods, mainly considered from the viewpoint of extreme events (destructive floods and rainfalls), is another key topic to which many experts are devoted.

Finally, other approaches are future-driven. Using available climate scenarios based on varying environmental, economic and demographic hypotheses, these aim at assessing water resources.

Clearly, the region hosts a wide range of skills and expertise. These are all called on to tackle the challenges of tomorrow in terms of sustainable management of water resources, which is such a vital issue for the societies and every person in the world.

Éric Servat (UMR HSM)
Water resources: identification, functioning, mobilisation

Biogeochemistry, extreme events, underground water and hydrological cycles in Mediterranean and tropical regions

The Montpellier HydroSciences Joint Research Unit (JRU) – UMR HSM (CNRS, IRD, UM1, UM2) is devoted to research in water sciences covering a broad range of domains from biogeochemistry to extreme events, including underground water and the hydrological cycle.

HSM carries out most of its scientific activity in the Mediterranean and tropical regions, in four scientific fields:

- Biogeochemistry, contamination agents and health.
- Karstic and heterogeneous environments: hydrogeology, hydraulic models and transfers.
- Climate, environmental changes and monitoring of their impacts on water resources.
- Hydrological cycle mechanisms, surface-atmosphere transfers and interactions.

In addition, the laboratory develops four cross-disciplinary technical approaches: (a) hydrodynamic modelling and couplings; (b) hydrophobic technologies; (c) modelling methods: assimilation, spatialisation and sensitivity; (d) information systems.

HSM is highly involved in research-oriented training and education. The training courses provided by the laboratory attract French and foreign students alike (especially students from developing countries): “Water” Master’s degree, “Health Engineering” Master’s degree, “Water sciences and technologies” engineering degree of Polytech’Montpellier. Besides, the whole HSM staff is involved in training from the science degree to Ph.D. levels.

Much of its research being based on observation, the laboratory is a member of the Universe Sciences Observatory OREME (see page 13). It also participates to several observation systems (MEDYCISS, OHMCV, AMMA-CATCH, OMER), while playing a leading role in the development of the KARST Observation System. In addition to its water chemistry and microbiology equipment, the laboratory have access to other major technical facilities: the large regional technical platform for the “analysis of trace elements in the environment” and the collective laboratory for the analysis of stable isotopes in water.

HSM strength relies on its involvement in a number of national and international projects, its extensive network of collaboration with research laboratories and institutions worldwide, giving the lab a high level of international recognition.

HSM also works with public partners (DRE: Regional Directorate for the Environment, AFSSET: French Agency for Environmental and Occupational Health Safety, local authorities: communities of municipalities, joint basin organizations, etc.), private consultancy and engineering companies (SDEI, BioUV S.A., SOMEZ, etc.). HSM has also filed several patents, especially in metrology, and has developed “professional” software tools, particularly around data management. Besides, the study of organic contaminants is one of HSM’s fields of excellence. It has set up, in partnership with the company Veolia, a training and research chair devoted to the “Risks analyses in relation to emerging contaminants in aquatic environments”. Moreover, HSM is involved in the “Water” and “Local Vulnerability and Risk Management” competitiveness clusters.
The Mediterranean basin is characterised by unevenly distributed and limited water resources as well as by increasing anthropogenic pressures. Hydro-climatic projections suggest a progressive diminution of the mean annual flows in this region, accompanied by more frequent and severe drought periods. Moreover, water demand has doubled since the nineteen fifties and is likely to continue to grow as irrigated surfaces increase and urban areas spread. Within the HSM JRU, the RESCUE-Med team focuses its research on the prospective evaluation of water resources under pressure of climate change and uses at different scales in the Mediterranean region.

As part of a current PhD and in partnership with the “Blue Plan”, the future availability of water resources is modelled at the regional scale according to various scenarios of climatic and water demand evolution, for agricultural and household purposes. A hydric stress indicator was developed, emphasising regional disparities concerning the capacity to meet various water needs at different periods in the past and future. Alternative scenarios, such as supply networks with improved efficiency, are being tested to assess the efficacy of adaptative strategies. The team also studies the impact of these changes on the water resources at more local scales. Hydrological modelling coupled with water uses is thus implemented in the river basins of Ebre (Spain) and Hérault (France). These research efforts seek to elaborate scenarios of climate change and water demand evolution adapted to these working scales. The objective is to assess the volumes and dynamics of flows, taking into account anthropogenic pressures (storage, withdrawals, consumption and transfers), in order to provide water resource managers with decision-making support tools.

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Water resources: preservation and management

**Water resources and Global Changes**

**SICMED: The evolution of Mediterranean anthropo-ecosystems**

The Mediterranean region is one of the focal points of global changes. The region evolves swiftly under the effects of severe climatic and anthropogenic pressures, while the resources produced are already unable to meet the population needs. The current intense exploitation of resources aggravates social and environmental weaknesses and induces high stresses on the hydrological and biogeochemical cycles. Critical situations and conflicts of use are increasing in frequency and intensity. The quest for new ways of sustainable development calls for a deeper knowledge of anthropo-ecosystem degradation, resilience, flexibility and rehabilitation factors.

Within this context, the SICMED programme (continental surfaces and interfaces in the Mediterranean) carries out research, training and transfer activities dedicated to the study of evolving Mediterranean rural and peri-urban anthropo-ecosystems subjected to global change-induced stresses. It is one of the components of the MISTRALS (Mediterranean Integrated Studies at Regional And Local Scales) project, and for the last decade it has been developing a multi-disciplinary research project to study biophysical, technical and social mechanisms at work. The programme pursues three objectives:

1. To identify and analyse the scientific locks preventing efficient forecasting of the evolution of the bio-hydro-geo-chemical processes subjected to current and future anthropogenic and climatic stresses;
2. To develop knowledge and tools for the rationalised management of the systems studied;
3. To transfer such knowledge and tools to decision makers and managers in the private and public sectors.

The SICMED programme is funded by IRSTEA, CNRS-INSU, INRA and IRD. It is based on a broad multilateral partnership involving scientific institutions and stakeholders representing various Mediterranean countries, but also other countries involved in research and development towards the Mediterranean region.

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More information on SICMED: www.sicmed.net
More information on MISTRALS: www.mistrals-home.org

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**Other teams involved**

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**Mass and energy transfers in porous, fractured and karstic aquifers**

The Montpellier Geosciences Joint Research Unit – UMR GM (CNRS, UM2) has developed a global approach to earth dynamics and their surface manifestations. This takes into account the couplings between the various layers including the hydrosphere. The objective is to gain a better understanding of the dynamic processes at different scales, and to bring this in line with societal expectations such as:

- Supply of non-energy resources (mineral and hydric);
- Energy choices for the future, from extending carbon-based reserves to developing new energy technologies (natural hydrogen, geothermal energy);
- Waste storage and confinement (downstream from the nuclear cycle, CO₂, mining wastes, etc.);
- Natural hazards (earthquakes, tsunamis, gravity hazards, floods, etc.);
- Environmental and climatic changes with high anthropogenic impact (coastline evolution, sea water intrusion in groundwater).

GM comprises five multidisciplinary teams working in three scientific fields:

- Geodynamics (“Lithosphere Dynamics” and “Mantele and Interface” teams)
- Reservoirs (“Basins” and “Porous Environment Transfers” teams)
- Risks (“Risks” team)

Research on water is undertaken by the “Porous Environment Transfers” and “Risks” teams. It concerns the characterisation and modelling of mass and energy transfers in porous, fractured and karstic aquifers. The main scientific challenges lie in the *in situ* measurement of these transfers, taking into account the heterogeneities controlling them at all scales. These research works target four objectives: the development of (1) instrumented sites (Majorca, Maguelone, Roussillon, Larzac and Lodève) dedicated to observation and experimentation, (2) devices allowing controlled dynamic experiments, (3) surface and bore hole...
Research Observatory, being in charge of several observation tasks (SO-LTC, GPST2, GEK, Bore Hole Hydrogeophysics).

GM is involved in the large regional technical platform for the “analysis of trace elements in the environment”. It also houses equipments for the “Gravimetry” and “Experimentation” platforms of the National Institute for Universe Sciences (absolute gravimeter and EBSD SEM).

GM is also part of a wide national and international cooperation network including countries and programmes from Europe (Marie-Curie, FP7 networks), the Mediterranean region (North Africa, Middle East), and all over the world (Taiwan, Japan, India, Australia, New-Zealand, Iran, Brazil, Mexico and the USA). GM collaborates with the private sector, namely via the creation of businesses by PhD students and for the funding of research contracts and theses. It belongs to the Geosciences cluster initiated in 2011 and involving key regional companies (Geoter, Cenote, imaGeau, Schlumberger, Fugro, Antea, Areva, Lafarge) and R&D and training organisations (GM, BRGM, EMA, CEFREM, HSM). A large number of these stakeholders are active in the field of water.
The OpenFLUID platform: modelling and simulation of the spatial functioning of agricultural landscapes

The spatio-temporal functioning of agricultural landscapes results from complex interactions between biophysical processes and human activities. Modelling the functioning of such systems and simulating their changes under the impact of climatic changes and anthropogenic pressures (pollution, development, changes in land use), involves taking into account all these interactions and coupling many processes/pheno-mena distributed in the area studied. In order to implement such modelling processes and run simulations based on these coupled models, the LISAH JRU has developed an advanced and generic software tool.

Thus, the OpenFLUID platform can provide a software environment to model and simulate the spatial functioning of agricultural landscapes. It allows models to be developed and implemented during simulations. These models are developed as plug-in software tools for OpenFLUID. Then they can be used to create coupled models adapted to (i) the modelling context, (ii) the simulation objectives and (iii) the data available. The simulations are based on digital representations of the landscapes studied. These include the geometries and properties of the actual landscape elements. OpenFLUID has been used for numerous projects and Ph.D. theses. It has been applied to Mediterranean and tropical environments, for the modelling of water and pollutant flows and erosion, especially under the impact of agricultural practices. OpenFLUID also provides software support for the development and implementation of the MHYDAS (distributed hydrological modelling of agro-systems) model, among others, as well as the digital representation of agricultural catchment basins, and the simulation of water and pollutant flows. OpenFLUID has a user graphic interface and can also be used in a command line (in a calculation cluster for example). It is an open-source, free licence software and can be downloaded from the OpenFLUID internet site.

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* www.umr-lisah.fr/openfluid

Analysis of the hydrological cycle for research, economic and industrial activities

The Industrial Environment Engineering Laboratory – UPR LGEI – is an Internal Research Unit of Alès Engineering High School (École des Mines d’Alès, EMA), a national public institution reporting to the Ministry of Industry. Its research work covers a broad field of applications based on complementary disciplines: process engineering, analytical chemistry and metrology, microbiology, molecular biology, hydrology, hydrogeology, geomatics, geostatistical methods, computer sciences and modelling, simulation tools and decision support systems.

Water issues are addressed from several angles: control of disastrous impacts for a resilient environment; understanding and spatialisation of hydrological processes in catchment basins (modelling); diagnosis of the chemical and ecological quality of water and effluents; development of processes and process couplings for the treatment of water and effluents; integrated management of polluting flows (industrial environments, water resources) according to a “local ecology” type approach; geomatics and collective intelligence for decision support. These different levels of water cycle analysis make it possible to answer the questions raised not only by science, but also by economic and industrial stakeholders.

LGEI is part of the Institut Carnot M.I.N.E.S., reflecting its privileged relationships with the economic sector. The laboratory is active in the “Water”, “Trimatiec”, “Local Vulnerability and Risk Management” and “Eurobiomed” competitiveness clusters. It collaborates with academics and industrialists at national and international levels, participating and coordinating several European projects.

The laboratory hosts all the facilities needed in a chemistry lab (HPLC/MS/MS, GC/MS/MS, ICP, extractors, etc.), as well as a test hall for semi-industrial pilot scale experiments. Academic and industrial teams have access to these facilities through the regional technical platforms, including Ecotech LR (Eco-technologies for agro-bioprocesses).

Moreover, the hydrometric monitoring of experimental catchment basins is a fundamental research effort for understanding the processes underlying flash kinetics floods. This research started in 2001 in collaboration with the ESPACE-DEV, HSM and TETIS JRUs. Several experimental catchment basins in the Cevennes are currently being monitored. Thanks to the diversity of the experimental devices, research work has focused on developing imaging applied to river velocities and flow rates as well as “low cost” devices for extending and refining distributed hydrometric analyses.

* SWIFT: Screening Methods for Water Data Information in Support of the Implementation of the WFD.

KNAPPE: Knowledge and Need Assessment on Pharmaceutical Products in Environmental waters
Observation for a better understanding of the dynamics and facilitated management of water resources

The Mediterranean Environment Research Observatory Joint Service Unit – UMS OREME (CNRS,IRD, UM2) is dedicated to the study of the uncertainties and vulnerabilities of Mediterranean environments. OREME focuses on natural hazards, resources and the impact of global and anthropogenic changes on the living and inert Mediterranean area. Its aim is to identify such systems’ response mechanisms to natural and anthropogenic forcing.

OREME’s mission consists in collecting, integrating and sharing long-term observation data to understand the evolution of resources and environments. This data is also essential for developing explanatory and predictive models.

OREME closely works with public partners (universe and ecology sciences laboratories, information science laboratories, local authorities and State agencies) and private companies (especially IBM).

In the field of water, OREME collaborates with other JRUs in order to develop hydrologic observation systems. These range from the basin scale to the in situ bore-hole scale:

- Geodesic, gravimetric, geophysical/hydrogeophysical systematic bore-hole observation at all scales;
- Multi-scale observation system of flood dynamics and underground hydrodynamics of fractured and karstic systems;
- Observation system for the pollution and biological adaptability downstream from mining sites;
- Monitoring of the Languedoc coastline, interface between catchment basin and marine environment.

These observation systems – included in French and international networks – provide information on water resource dynamics, especially karstic aquifers. They also make it possible to monitor the quantity and quality of the resource downstream from the aquifers. Geophysical methods are used to monitor underground water movements and link aquifer supplies with their discharge. The aim here is to understand their hydrological cycles and analyse it both in terms of resource quantity and hydrological hazards, such as flash discharges.

The quantity and quality of the resource available at each utilisation site are the result of complex processes. Their assessment needs combining models of water storage, flow and physico-biochemical couplings occurring in the various compartments. Complex simulations are necessary to understand these conditions: real-time modelling of the state of the resource, its uses and their immediate effects. At the core of this process of study, the data collected, calculated or associated with uses must be processed within the “acquisition-refinement-processing-decision” continuum.

Thanks to its network of partnerships and its expertise, OREME intervenes at different stages of this continuum, especially during acquisition (sensor network management), storage, sharing (management of query standards and norms, management of metadata, web services, etc.) and decision support (detection of changes, information fusion, reasoning, user interactions, visualisation, recommendation, forecasting and real-time operations).

The water resource must be managed in such a way as to prevent or better manage crises. This is why resource modelling must give a picture as close as possible to the reality, so that risks can be analysed and the necessary decisions taken in real time. For this reason, a shift to operational decision support models is required. Indeed, to avoid having to carry out time-consuming exhaustive modelling, “basic” simulations, based on reliable data, has to be performed upstream.
Mediterranean environment and modelling of agro-hydrosystems

The Mediterranean Environment and Agro-Hydrosystem Modelling Joint Research Unit – UMR EMMAH (INRA Avignon, UAPV) is focused on impact analysis of global changes on water resources, agricultural production and their interactions at the local level (from the landscape to the production basin and the aquifer). The research works target five cross-disciplinary goals:

- Quantification of the impacts of global change on the interactions between surface biophysical processes (agricultural production and water cycle) and water resources, especially underground.
- Identification of landscape changes and their driving forces, based on a retrospective analysis that stretches over several decades.
- Understanding of the modifications induced by extreme climatic events (such as drought/heat wave) on the functioning of agro-ecosystems.
- Understanding and modelling the impacts of heavy rainfall on the hydrological and hydrochemical functioning of the ground-table system.
- Study of alternative irrigation techniques, such as the use of water downstream from waste water treatment plants, particularly regarding quantification of the risks associated with the presence of human pathogens in these treated waters.

EMMAH’s work is based on the utilisation of remote sensing and geophysical data, intensive observation of instrumented sites, laboratory measurements and methodological development to better understand and model the functioning of Mediterranean ecosystems. EMMAH has set up a monitoring system of several observation sites representative of different hydro-geological and agronomic contexts (Crau-Camargue region, karstic aquifers of the Fontaine de Vaucluse, Avignon peri-urban zone).

In addition, two sites are dedicated to the study of hydric flows into the atmosphere and the water table. EMMAH is also equipped to carry out biological measurements (biomass, foliar index, chlorophyll content, etc.), chemical analyses of water and soils (organic and mineral chemistry), water isotopic analyses \( \text{H}^2, \text{C}^{14}, \text{C}^{13}/\text{C}^{12} \) ratio of dissolved carbon) and ground hydrodynamic properties. EMMAH also has access to the Rustrel (Vaucluse) low-disturbance underground laboratory in the karstic massif of Fontaine de Vaucluse, and to the INRA molecular biology lab in Avignon. It is also equipped with subsurface geophysical prospecting instruments (electrical tomography).

The researchers develop mechanistic models for hydrosystem functioning. These integrate and spatialise the elementary models associated with the different processes, on the one hand, and include new modelling approaches that take into consideration the heterogeneities of the environment and processes at different scales, on the other hand.

The disciplinary expertise and techniques implemented cover hydrology, hydrogeology, soil and water geochemistry and microbiology, agronomy, remote sensing, geophysics, applied mathematics, the physics of waves in porous media, digital simulation, parallel calculation and signal processing.

EMMAH collaborates with the French academic world (INRA: French National Institute for Agronomic Research, CEA: French Nuclear and Alternative Energies Centre, CNRS: French National Centre for Scientific Research, Universities, etc.) and the international academic world (Sfax National School of Engineering, Tunisia; Spanish Institute for Sustainable Agriculture and Valencia University, Spain; Dutch National Aerospace Laboratory and University of Twente, Netherlands; Universities of Maryland and Boston, USA, etc.). Moreover, EMMAH also develops partnerships with French institutional or managerial bodies (Rhône-Méditerranée-Corse Water Agency, irrigators’ and farmers’ unions, joint organisations for the management of underground water resources) as well as private partners (Veolia, Suez Environnement, engineering offices, etc.).
At the crossroad of soil sciences, hydrology and agronomy: the functioning of cultivated landscapes

The Laboratory for the Study of Interactions between Soils, Agrosystems and Hydrosystems (LISAH — INRA, IRD, Montpellier SupAgro) studies the functioning of cultivated landscapes resulting from the interactions between i) the underlying soil, ii) the agrosystem that modifies the geometry of the landscape and iii) the hydrosystem that transfers water and other elements. It serves the following specific objectives:

- The development of knowledge on erosion, water and material transfers and the evolution of polluting substances (pesticides) in soils and rural catchment basins with respect to their spatial organisation and temporal evolution;
- The elaboration of tools for diagnosing and preventing the risks induced by human activities (cultivated environments) on hydrological regimes and the evolution of water and land resources;
- The definition of new modes of sustainable management for the rural environment;
- The training of students on the concepts and tools used to analyse and model the spatial organisation and the hydrology of cultivated environments.

LISAH combines expertise in soil science, hydrology, agronomy and spatialisation. Its structure is based on three research teams:

- Water and pollutants in cultivated catchment basins;
- Erosion and sediment transport in cultivated catchment basins;
- Spatial and dynamic structure of soils and cultivated landscapes.

LISAH especially focuses on wine growing in the Languedoc-Roussillon region and banana tree farming in the French Antilles, with the following objectives:

- Study of soils and water pollution by phytosanitary products;
- Analysis of the “soil-crop” system hydrological cycle at various scales, from the elementary (a few km²) to the resource (a few hundred km²) catchment basins;
- Development of digital soil mapping methods and information systems;
- Analysis of factors and processes of soil erosion and sediment transfer in catchment basins;
- Study of the influence of hydraulic works (ditches, banks, hill lakes) on the hydrological functioning of cultivated soil and catchment basins.

LISAH scientific approach is based on in situ hydrological studies and experiments, methodological research for the acquisition and processing of soil and landscape spatial data and development of distributed hydrological modelling approaches, taking into account the specific heterogeneities of rural landscapes. To this end, LISAH runs the Mediterranean Observatory of Rural Environment and Water (OMERE, see page 11). The laboratory analyses the impact of anthropogenic actions on the physical and chemical erosion of Mediterranean soils and on the quality of water. Moreover, since 2006, LISAH has been developing the simulation platform OpenFLUID (Software Environment for Modelling Fluxes in Landscapes, see page 12).

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Aquifers in bedrock regions: a water resource to be managed

Bedrock (granite, schist, gneiss, etc.) occupies large surface areas in Europe and France and elsewhere across the planet. The water resources they contain are used substantially in agricultural and economic development in the regions concerned. This is particularly true for emerging economies where the context is arid or semi-arid and access to water is limited.

The BRGM EAU/NRE research unit contributes to the development of knowledge on the genesis, geometry, hydraulic properties and functioning of bedrock aquifers. Significant progress has been made in this corpus of knowledge. More specifically, it has been demonstrated that climatic alteration processes significantly influence aquifer properties through the development of alteration profiles. Moving downwards, these are made up of (see figure on the right): loose alterites (coarse sand in granitic zones), characterised by low permeability and significant underground water storage capacities; a stratabound “cracked horizon”, 50 to 100-metres thick, also strongly influenced by alteration processes and to which the bedrock aquifer owes much of its permeability.

Numerous practical applications stem from these geological and hydrogeological concepts. One such application is regional mapping of underground water potentialities and the regionalisation of hydrodynamic parameters for modelling.

Other applications concern water resource management tools for catchment basins. Indeed, such management is essential for intensive withdrawals for irrigation purposes. These applications also cover bore-hole layout techniques and methods leading to improved success rates for exploitable flow rates.

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>FUNCTIONING OF COMPLEX AQUIFERS

Aquifers in bedrock regions: a water resource to be managed

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Hydrogeologists and economists working on water resource management

The Water/New resources and Economy Internal Research Unit – UPR EAU/NRE – belongs to the BRGM Water Department. Its permanent staff comprises eight hydrologists and six economists whose research efforts focus on water resource management. EAU/NRE’s activities comprise two main scientific focuses:

- The development of alternative solutions to conventional water resources, that are suffering from increasing constraints, i.e. climate change, anthropogenic pressure, socio-economic evolution, urban growth, etc. The following topics are more specifically studied: (i) characterisation of the structure and functioning of complex aquifers (karst, fractured ground, volcanic environments) in order to assess their potentialities; (ii) development of modelling and decision support tools for managing these aquifers and forecasting impact of global changes; and (iii) development of active resource management methods (recycling of treated waste waters, artificial recharging of water-tables, inter-seasonal storage and controlled overexploitation).

- The development of economic approaches needed to evaluate water resource management scenarios at the basin scale. Research efforts focus on the economic evaluation of incentive programmes and resource management policies as a function of uses, the economic optimisation of resource management plans via cost-efficiency analyses, the weighting of benefits and drawbacks between economic development and environmental policies, the comparison of approaches (analysis of costs avoided), the contingent evaluation based on enquiries and the elaboration of medium and long-term water use scenarios (prospective analysis).

Several researchers are involved in teaching for vocational training, for the “Water” Master’s degree and others Master’s and engineering courses related to water.

EAU/NRE has developed a strong partnership with the French-Indian Research Centre on Underground Water. This joint BRGM-NGRI (National Geophysical Research Institute) laboratory, based in Hyderabad in the south of India, has developed research on base aquifers in tropical regions using the SOERE (H+) observation system. The lab develops tools for managing aquifers that are severely impacted by agricultural practices (irrigation pumping, pollution) and by climate change.

EAU/NRE specifically develops applied research activities directed to local authorities, water agencies and industrialists. Several projects have led to the development of methodologies to study mineral water deposits and their industrial management (i.e. Nestlé Waters and Danone Eaux France). Moreover, EAU/NRE is involved in the “Water” competitiveness cluster.
Karstic aquifers contain a significant share of water resources in France (35% of the country), all the more in the Mediterranean region (> 50%). Their heterogeneity makes these zones complex (with voids varying in size from cracks of a few centimetres to sinkholes several meters wide), which are characterised by a specific hydrologic functioning. Because of their complexity, they are still underexploited. Moreover, the use of this resource must take into account characteristics specific to the karstic systems, especially their vulnerability to pollution and overexploitation. In regions where water is already scarce and within a context of global change, a better understanding of their functioning has become essential to ensure they are optimally and sustainably exploited and protected.

To this end, the regional research units develop different complementary approaches.

The functioning of the non-saturated zone (NSZ) of karstic systems, which can reach up to tens or even hundreds of metres in size, remains poorly known and modelled. Yet, it is now obvious that it plays a major role in transfer dynamics and storage characteristics.

The Rustrel (Vaucluse) Low Disturbance Underground Laboratory (LSBB) is located in an artificial gallery opened for no hydrogeological reasons. The site of the laboratory spans flows within the limestone massif of the Mont de Vaucluse covering a distance of 3,800 metres and reaching depths ranging from 0 and 500 meters.

The site provides direct access to the karst NSZ, hence offering an exceptional research opportunity. Thanks to direct (geological, hydrodynamic, hydrochemical) and indirect (hydro-geophysical) measurements carried out on this site, the EMMAH JRU is developing an operational model of the karstic aquifer NSZ. Eventually, it will be possible to precisely assess the impact of the NSZ on the global functioning of these aquifer systems. The experimental site of the LSBB, located in the supply basin of Fontaine de Vaucluse, will serve as a reference site for the development of this model, which will then be validated and refined through its application to other systems.

In addition to studying the karstic aquifer as such, the work carried out in the Fontaine de Vaucluse catchment basin includes the whole upstream area: vegetation, land use, definition and mapping of drainage units. The impact of the karstic system on the environment downstream from the spring is also studied under different aspects (flood warning, biodiversity and green tourism).

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Water resources: identification, functioning, mobilisation

>FUNCTIONING OF COMPLEX AQUIFERS

Multi-uses management of the Lez river catchment basin karstic aquifer

The “karst and heterogeneous environments” research group within the HSM JRU focuses on underground and surface transfers in this type of environment. Within the framework of its research activities combining hydrogeological, hydrological and hydraulic characterisation and modelling, the laboratory participates to a broad-reaching research project. The project is entitled “Multi-Uses Management of Mediterranean Karstic Aquifers” and is being coordinated by BRGM for Montpellier Agglomeration, in collaboration with the G-EAU and TETIS JRU, the Biotope company and the European Centre for Research and Advanced Training in Scientific Computation. This 3-year project started in June 2009 (mainly funded by Montpellier Agglomeration with co-funding from the Rhône - Méditerranée - Corse Water Agency, the Hérault General Council, the BRGM).

It mainly concerns the Lez catchment basin (France) as well as the associated karstic aquifer, and deals with resource management and flood hazard mitigation issues. The project serves the following main objectives:

- To get a better knowledge of the hydrogeological underground environment, through a better understanding of underground flows and geology of this type of peri-Mediterranean hydrosystem;
- To assess the quantitative and qualitative vulnerability of the aquifer;
- To reassess the water resource that can be exploited within the aquifer and characterise the impacts of global changes using different models;
- To characterise the role of the karstic aquifer in the hydrological regime of the Lez river in order to better evaluate flood hazard as well as the chemical and geological quality of the hydrological environment;
- To take stock of the situation of the underground biodiversity of the Lez aquifer;
- To study the effects of actively managing the karstic aquifer on flood mitigation using coupled hydrological and hydrogeological models.

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>FUNCTIONING OF COMPLEX AQUIFERS

Geodesy to study water resources in a karstic environment

For several years now, the “Risk” team of the GM JRU has been conducting original research works on the monitoring and localisation of fresh water resources in karstic zones.

In 2011, within the framework of the OREME Observatory, and in partnership with the National Institute for Universe Sciences, the H+ Observatory, the Maison de l’Eau water science centre and the companies imaGeau (Montpellier), MicroG and GWR (USA), GM established a geodesic observatory on the Larzac plateau. The aim of the observatory is to bring new knowledge based on very high tech original observations over long periods of time.

The observatory includes the first new generation supraconductor gravimeter (iGrav) developed by GWR, as well as one of the 50 absolute gravimeters existing in the world (MicroG). Gravimetry consists in making surface ground mass measurements in order to determine water bodies and their temporal variations without drilling any bore hole. This type of measurement has become so successful that it is now being exported to other karsts such as the Vaucluse plateau.

The Larzac observatory also welcomes French and foreign researchers who wish to collaborate on research works in progress, both in geophysics and in hydrogeology. The observatory is a training site enabling students from UM2 and all over France to work on current topics using high tech tools. The data collected will make it possible to better understand and model karstic aquifers so that quantitative information can be provided to help with the exploitation/protection of the Larzac water resources and of karstic zones in general.

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The Lez spring near Montpellier, France.
Since 2004, the BRGM EAU/NRE research unit has been working on the issue of karstic flash floods. This work comprises several projects with the aim of providing long-term assessments. A first research project for the city of Nîmes (France) targeted the functioning of the Fontaine de Nîmes karstic system in flood conditions. It has evidenced the flood buffering role when the aquifer is undersaturated. It has also showed the karstic system’s major contribution to the genesis of devastating floods in Nîmes, especially that of underground waters during a flood peak.

A tight monitoring of the underground waters has thus been proposed to the Nîmes authorities. Furthermore, a warning tool was designed, based on an abacus. This tool is able to forecast flood magnitudes. It takes into account the saturation condition of the karst and the real-time weather forecasts. This type of approach has been replicated in other karstic catchment basins following a request from the Central Department of Hydrometeorology and Flood Forecast Support (SCHAPI). The tools developed for the forecasters are currently being tested by the Flood Forecasting Departments.

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Real-time flood forecasting is a complex issue with vital economic and societal implications. The complexity stems from the coupling between atmospheric, hydrological and hydrogeological models.

The EMA LGEI research unit studies and implements the methods it develops on the catchment basins of the Gardon river in Remoulins and its upstream outfalls in France. The site is known for the devastating “gardonnades” (river Gardon flash floods). The models developed will then be validated on the Cèze and Ardèche rivers, also known for their flash floods, and on the Somme river, known for its table floods.

The use of neuronal-type networks offers a new alternative: it consists in taking advantage of experimental data recorded during the elaboration of models, obtained through artificial learning. The first results show that floods of the Gardon river at Anduze can be anticipated without any rainfall forecast even for short time horizons (2 to 3 hours), thus enabling the local authorities to take the first decisions rapidly. The purpose of this method is to publish a “vigicrues” flood vigilance map on the internet. These research efforts are being carried out within the framework of the FLASH project (Flood forecasting with machine Learning, data Assimilation and Semi-physical modelling), in collaboration with national partners (SCMAP; Central Department of Hydrometeorology and Flood Forecast Support, School of Industrial Chemistry and Physics of the City of Paris, “Mountain environments, dynamics and territories” JRU), and with the financial support of the French National Research Agency.

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* www.vigicrues.gouv.fr

Methodology for the evaluation of rainfall runoff hazards

Rainfall runoff is a phenomenon poorly taken into account and rarely dealt with as a full scale risk. It is often confused or associated with floods. Yet, it may cause severe damage. The complexity of the phenomenon stems from its sudden and highly localised occurrence. It usually affects small urban and rural catchment basins. Its characterisation is very difficult since the phenomenon is influenced by numerous physical parameters but mainly because it is aggravated by human activities.

The methodologies currently implemented to study runoff are mainly based on quantitative studies and/or modelling. The work carried out by the EMA LGEI research unit uses a hydro-geomorphological approach to characterise and spatialise the phenomenon. A rainfall diagnosis method has been developed and applied to a rural community.

The qualitative approach used makes it possible to take stock of the general situation. All information and data can be integrated into a qualitative map. Using this approach, a global spatial analysis was performed. Associated with permeability measurements, the trends observed by the qualitative analysis have been confirmed.

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Satellite measurement of river flow rates

Satellites are very useful tools for quantifying global biophysical variables and monitoring their time-space dynamics. They contribute to water cycle knowledge by measuring atmospheric humidity, rainfall, ground humidity, evapotranspiration and the topography of hydrographic networks.

Measuring river flow rates is a major challenge for future satellite missions. The TETIS JRU carries out research work in this field together with the National Space Study Centre (CNES), the French Aerospace Lab (ONERA) and industrial stakeholders in the space industry (European Aeronautic Defence and Space Company; Thales Alenia Space; Collection, Localisation, Satellites, Noveltis). The work is devoted to measurement technologies for river surface variables. These variables are then integrated in order to derive river hydraulic parameters and calculate flow rates.

Three families of spatial techniques are being developed. Radar altimetry (Lidar) makes it possible to measure river levels; TETIS develops qualification methods for measuring river levels and quantifying their uncertainty. As part of the Surface Water and Ocean Topography mission (NASA-CNES), spatial radar interferometry is used to measure slopes; TETIS studies the roughness of water surface and its influence on radar retrodiffusion. TETIS is also involved in airborne campaigns to validate radar devices, processing chains and models. Finally, time interferometry makes it possible to measure surface velocities; TETIS takes part in exploratory airborne campaigns and explores the modelling of this technique on rivers.

In order to assess the flow rate of rivers by means of satellite measurements without in situ measurements, TETIS develops hydraulic equation inversion methods that make it possible to determine river bed parameters (level, slope, roughness of bed, velocity profile), using surface variables only. These methods constitute a coherent framework for specifying future space missions and improving knowledge of the world river flow rates within the next twenty years.

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▶ Rio Madeira in Brazil.
Utilisation of very high resolution satellite images: study of the geomorphological origin of water routes in Mediterranean catchment basins.

The intensity and variability of precipitations together with the complexity of hydrological processes in Mediterranean catchment basins somewhat limit predictability of extreme phenomena. A better understanding of the processes involved in the hydrological responses of catchment basins, which are responsible for the spatio-temporal variability of water routes, could make it possible to improve the modelling of this type of event. This research (LGEI/TETIS research units collaboration) falls within the framework of geomatics applied to hydrology. It calls on the use of satellites (especially very high resolution 3D products for the spatial characterisation of basins and their hydrographic networks), to study the geomorphological origins of the spatio-temporal variations of hydrological responses.

First, using spatial data, the "potential" drainage system representing the dry geomorphological network formed by the continuous thalweg lines of the basins is defined. An original algorithm using a terrain digital model structure in a triangular form has been developed specifically for this purpose. It makes it possible to faithfully plot the networks in relation to their real routes and provides information about their geomorphology and that of the basins. The second research area concerns the study of water or "real" drain dynamics. The purpose is to better understand the spatial dynamics of drain water filling over the course of different flood episodes. To this end, a spatialised network of light sensors has been distributed over two experimental basins (< 1 km²) located on the Anduze Gardon. The idea is to monitor the time-space variations of the hydrological dynamics in the water networks.

By comparing and contrasting the geomorphological characteristics and hydrological responses observed, the predominance of sub-surface flows in the basins studied has been confirmed. This has also led to evidence two types of networks with different functioning and has underlined the important influence of the slopes and their changes on the initiation and sustainability of flows within the networks. Finally, it has led to hypotheses about the different functioning of these networks in relation to episodes.

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Mapping of vine evapotranspiration from satellite images

The LISAH JRU has designed a simple vine evapotranspiration mapping method. The study concerned the lower valley of the Peyne river, a tributary of the Hérault river, where vines cover more than 70% of the surface. Twelve ASTER images were acquired between July 2007 and October 2008. These surface temperature images (with a spatial resolution of 90 m), were then converted into daily evapotranspiration maps using water deficit index (WDI) and simplified surface energy balance index (SSEBI) values, which so far had never been used on vines.

These maps were then validated by means of a measurement device installed on seven vine plots deemed to be representative of the soil-landscape variability of the Peyne valley. Evapotranspiration was measured directly using turbulent covariances on two of these plots. By means of regular soil moisture and water table level monitoring, it was also possible to precisely assess the daily evapotranspiration of the seven plots, via the HYDRUS1D hydric transfer model.

The evapotranspiration maps made from satellite images were then successfully validated, the SSEBI index being slightly more precise (0.8 mm/day) than the WDI index (1 mm/day). The evapotranspiration maps thus obtained exhibit a spatial stability over time, similar to that of 1:25 000 scale soil maps.

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Spatialisation of the hydric status of vines

The hydric status of vines and its spatial and temporal variations determine the quantitative and qualitative potential of the harvest. This knowledge is essential to trigger the corrective actions needed to optimise the management of grape quality and the water resources used for irrigation. Being able to spatialise changes of the vine’s hydric status over the cultivated areas is also a pre-requisite for diagnosing the current situation of the water resource and possibly forecasting the impacts of climate change in Mediterranean agricultural environments where vine growing is dominant.

The objective of this research effort (collaboration between ITAP, LISAH, Sciences for Oenology research units; INRA “Pech Rouge” experimental station, the French Wine and Vine Institute, Sydney University in Australia and Talca University in Chile), is to propose an estimation model of the hydric status of the vine in time and space. The model can then be scaled according to the vineyard and production area hence providing operational decision-making support for crop management. The project is thus scaled to offer interesting potential for vine growers.

The model uses and creates synergy so that the data available can be configured differently and according to the targeted scale. Thanks to recent technological progress, and to a network of local geo-referenced measurements to monitor the hydric condition of the vine, it is now possible to characterise the heterogeneous aspects of crops (near infrared air information) and soils (measurement of the apparent electrical conductivity of the soil using high space resolution sensors mounted on mobile vehicles).

These networks of communicating sensors (located in the soil and in the crops), make it possible to collect real-time continuous information (plant and soil monitoring systems). It is already possible to monitor variables and hence obtain indirect and local assessments of plant hydric conditions.

Based on a reference measurement, the spatial extrapolation approach has been validated at the scale of the plot and of the vineyard. It is currently being transferred to an industrial partner (Fruition Sciences) and validated on a larger scale (cooperative cellar).

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