As indicated in the last IPCC report, changes in rainfall patterns and melting snow and ice under way in many parts of the world are disrupting hydrological systems and impacting the quality and quantity of water resources, as well as dynamics and resources in the ‘critical zone’ for life on Earth. A marked depletion of renewable surface and groundwater resources is expected in most subtropical dryland regions during the 21st century. Moreover, current climate change patterns raise concerns that major problems could arise regarding relationships between societies and their environment, even threatening the ecosystem services from which they directly or indirectly benefit. The impacts of recent extreme weather events—heat waves, droughts, floods, cyclones, etc.—highlight the high vulnerability and extent of exposure of ecosystems and human societies to current climate fluctuations.

In this setting, research must shed light on the major issues by: (1) focusing studies on the impact of climate change on socioecosystems at various territorial levels and characterization of their vulnerability; (2) drawing up—in collaboration with the various stakeholders concerned—adaptation measures to mitigate the effects of climate change; and (3) developing assessment and monitoring tools to support decision making and adaptive resource management.

The Agropolis scientific community is particularly well equipped to provide, along with its many national and international partners, answers or ideas regarding these key questions, which arise in different manners in various socioecosystems on all continents and at several territorial scales.

Water resource research is federated within the Montpellier Institute for Water and Environment (IM2E), which combines research in hydrology, geology, chemistry/biochemistry, microbiology, agronomy, engineering science, economics, social science, modelling, etc. Building on substantial technical resources, some of which are provided by OSU OREME (permanent observatories, joint research platforms, large-scale technical platforms, etc.), the scientific questions addressed by the Institute’s research units are focused especially on:

- Analysis of water resources, flows and transfers and fluctuations related to climate change: functioning of complex aquifers (especially karstic aquifers typically found in the Mediterranean region, e.g. through the LEZ-GMU project); scenarios regarding changes in hydrological systems associated with global change via modelling and prospective approaches (REMedHE and ClimAware projects); and the impact of climate change on water resource quality.

- Analysis of the vulnerability of territories to climate change impacts: coastline modifications and flooding risks, impacts on freshwater ecosystems, societal risks associated with extreme events (floods, water shortages), the development of relevant monitoring and assessment indicators.

- Adaptation challenges: many studies are also focused on water use efficiency in agriculture, at scales ranging from landscapes (e.g. in the ALMIRA project), plots (e.g. with agroecological practices) to plants (HydroRoot and LeafRoll projects); while other studies concern rainfed or irrigated agriculture (studies on the impact of irrigation on water resources, development and dissemination of innovations to reduce water consumption, tapping of new resources through, for instance, wastewater reuse). Other adaptation research is focused on resource management arrangements on political, economic and institutional levels through multi-stakeholder approaches and the development of decision-support tools.

Beyond water resources, the regional scientific community addresses the broader issue of the dynamics of nature-society interactions through natural resource management (soil, mineral resources and biodiversity) and the governance of territories and environments. In this area, the research aims to gain insight into relationships between societies and ecosystem services provided by their environment, their evolution with respect to global change, their vulnerability or conflictual nature and their adaptation and resilience capacities. Adaptation strategies are analysed by assessing linkages between global and local dynamics, between issues and stakeholders—individuals, local, regional, national and international institutions (AFCAO, ‘Of lands and waters’, SERENA, EcoAdapt projects).

Finally, one of the driving forces of the regional scientific community is also the spatialization and historization of environmental knowledge for environmental monitoring and decision support, based on a range of methods: remote sensing and space observation, direct environmental observation, stakeholder surveys, data processing, development of indicators, knowledge and digital data modelling.

Éric Servat (IM2E)
& Nicolas Arnaud (OSU OREME)
Climate change & resources, territories and development

A federative structure that positions Languedoc-Roussillon as driving force for national water research

In view of the range of expertise and technology deployed by the Montpellier Institute for Water and Environment (IM2E – BRGM, CIRAD, CNRS, INRA, IRD, IRSTEA, AgroParisTech, CIHEAM-IAMM, EMA, ENSCM, Montpellier SupAgro, UAG, UM, UPVM, UPVD, UR), Languedoc-Roussillon (L-R) is the region where public research on water is the most substantial and diversified in France, excluding the Ile de France region.

Water resource and aquatic ecosystem management is a major challenge for humanity in the 21st century. Multidisciplinary approaches are required to take the corresponding issues into account (environmental, food, health, societal, economic and financial, political and geopolitical, etc.). In this setting, IM2E brings together a set of technical and human resources to:

- take up knowledge and adaptation challenges in order to address water related issues
- promote interdisciplinary research to meet environmental issues
- acquire international scientific visibility via its position in L-R
- produce technological innovations and expertise in interaction with the Competitive ‘Water’ Cluster of global scope (Pôle EAU), and with the SWELIA cluster (pooling over 100 L-R companies specialized in the water sector)
- support public policies through recognized multidisciplinary expertise
- become a leading European resource centre (training and research) attractive to both developed and developing countries.

The project implemented by IM2E is based on different areas of excellence shared by the scientific community that provide the basis for addressing primary challenges regarding sustainable ecosystem use and adaptation to climate change.

The aim is also to boost the production of innovations and research capacities in companies, and to put forward recommendations for institutions involved in public policy design, implementation and monitoring (ministries, water agencies, local authorities).

IM2E’s strengths and successes are based on the pooling of shared resources in many areas: training, technical and analytical platforms, observation and modelling resources. The aim of this federative structure, in the latter sector especially, is to develop complex and highly interactive hybrid models for the future.

Training has directly benefited from the emergence of IM2E, which is striving to foster relationships with companies and communities in order to enhance the employability of students who have received diplomas from its partner establishments and laboratories. IM2E also aims to internationalize the training, especially by ensuring that at least 30% of its students are foreign, while also hosting over 200 Master’s and PhD students.

…continued on page 14
ALMIRA: adapting landscapes for sustainable management of crop production, water and soil resources

The project 'Adapting landscape mosaics of Mediterranean rainfed agrosystems for sustainable management of crop production, water and soil resources' (ALMIRA) aims to mitigate pressure caused by climate and socioeconomic changes. It thus proposes to rationalize the spatial organization regarding land use and cropping systems in order to optimize the provision of several ecosystem services (agricultural biomass production, surface water production in man-made reservoirs, curbing erosion, etc.).

In this project, these spatial organizations are called 'landscape mosaics' and jointly viewed as:

1. networks of natural and anthropogenic elements that integrate relationships between biophysical and socioeconomic processes in a resource catchment basin
2. structures that impact flows within the landscape, from the crop plot to the catchment basin, with consequences on the landscape functions and resulting services
3. levers for the management of cropping areas via trade-offs between agricultural production and soil and water resource conservation.

ALMIRA proposes to design, implement and test a new integrated modelling approach to meet these goals. This approach integrates—from farm plot to small regional scales—stakeholders’ innovations and levers in prospective landscape mosaic change scenarios, as well as the spatial organizations, biophysical and socioeconomic processes considered.

Methodologically, implementation of this integrated modelling requires:

1. designing of spatially explicit landscape change scenarios
2. combining biophysical processes involved in the hydrology of cultivated catchment basins
3. digital mapping of landscape features
4. economic assessment of landscape functions.

This integrated modelling approach is being tested in three catchment basins in France, Morocco and Tunisia. ALMIRA brings together researchers from these three countries specialized in a broad range of scientific disciplines. Within this partnership, two research units of the laboratory of excellence LabEx Agro are working specifically on the characterization of cropping systems (UMR SYSTEM, see page 72) and biophysical processes (UMR LISAH, see page 71).

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▲ A cultivated landscape in Tunisia.
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Balancing water resources and uses—will future demands be fulfilled?


The aim is to assess potential climatic and anthropogenic patterns in 2050 on hydrological systems and water demand in the Hérault (2 300 km², France) and Ebro (85 000 km², Spain) basins in order to develop different water resource management strategies to maintain the balance between water supply and demand. These issues are assessed through the development of an integrative modelling chain calibrated and validated over a 40-year retrospective period. The modelling involves three steps:

- water resource simulation (natural flow and disturbance by dams and canals)
- representation of the spatiotemporal dynamics of water uses (domestic, agricultural, industrial and energy) and associated demand
- and assessment of water usage/resource balances via vulnerability indicators.

Complex prospective scenarios were formalized from the latest simulations of the Intergovernmental Panel on Climate Change (IPCC) and local socioeconomic scenarios in collaboration with managers. The preliminary results showed that the basins should be subjected to more deficit climatic conditions (increased temperatures associated with decreased spring and summer precipitation) and to increased anthropogenic pressure (increase in population and in irrigated areas).

The combination of these conditions should lead to a substantial decline in available water resources and an increase in domestic and irrigation needs, thus undermining the future balance between the resource supply and demand. Adaptation strategies to reduce water demand (improved network efficiency, changes in agricultural practices) or to increase the availability (alternative dam management, inter-basin water transfers) are thus currently being tested in the modelling chain. The aim is to assess the viability of trajectories in an uncertain future setting.

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Water science research and training

The HydroSciences Montpellier laboratory (UMR HSM – IRD, UM, CNRS) is a joint research unit (UMR) that is highly devoted to water science research. The studies span a broad range of domains from biogeochemistry to extreme events, including microbiology, underground water and the hydrological cycle. Most of its scientific activity is in the Mediterranean and tropical regions.

HSM activities are organized in four scientific fields:
- Transfers, contaminants, pathogens, environment, health
- Water, environmental and societal changes
- Transfers in ecohydrosystems
- Karsts, heterogeneous environments and extreme events.

The laboratory conducts two cross-disciplinary technical workshops: ‘ATHYS’ (spatial hydrology workshop) and ‘Hydrosphere tracers’ (workshop promoting the use of analytical techniques for tracing transfers or hydrological processes).

HydroSciences Montpellier is highly involved in research-oriented training and education. The training courses provided by the laboratory (‘Water’ Master’s degree, ‘Health Engineering’ Masters degree, ‘Water Sciences and Technologies’ engineering degree of Polytech/Montpellier) attract French and foreign students alike (especially from developing countries). The UMR is also involved from the Bachelor’s to the PhD levels.

The laboratory is a member of the Observatoire de recherche méditerranéen de l’environnement (OREME), an Observatory for Science of the Universe (OSU). Its research is also supported by major technical facilities such as the large regional technical platform for the analysis of trace elements in the environment (GPTR AETE) and the collective laboratory for the analysis of stable isotopes in water (LAMA).

One of HydroSciences’ strengths is its involvement in many national and international projects, its extensive network of collaboration with research laboratories and institutions worldwide, in developed and developing countries, thus giving it a high level of international recognition.

HSM also works with public partners such as the Regional Directorate for the Environment, the French Agency for Food, Environmental and Occupational Health Safety, local authorities (communities of municipalities, joint basin organizations), private consultancy and engineering companies (SDEI, Bio-U, SOMEZ, etc.). HSM has also filed several patents (especially in metrology) and has developed software tools for professionals (‘progiciels’, especially based on data management). One of HSM’s fields of excellence—study of organic contaminants—is the focus of a training and research chair, in partnership with the company Veolia, devoted to ‘Risk analysis related to emerging contaminants in the aquatic environment’. Moreover, HSM is involved in the ‘Water’ (global scope) and ‘Local vulnerability and risk management’ competitiveness clusters (‘Pôle EAU” and “Pôle Risques”).
Water management and adaptation to climate change—multidisciplinary research

The joint research unit Water Resource Management, Actors and Uses (G-EAU – AgroParisTech, CIRAD, IRD, IRSTEA, Montpellier SupAgro) conducts interdisciplinary research on water management. It brings together expertise in earth sciences (hydrology, hydraulics) engineering (automation, fluid mechanics, structural mechanics), life science (agronomy) and social science (economy, sociology, political science). It also includes methodological expertise for interdisciplinary research. Priority is given to research in Europe and Africa, with a special focus on the Mediterranean Basin.

This expertise is encompassed within nine teams, that address issues regarding adaptive water and aquatic environment management, focused on specific topics:

1. Hydraulic management, optimization and supervision of water transfers
2. Optimization of irrigation management and technology
3. Controversies and public actions
4. Innovation and change in irrigated agriculture
5. Tools and governance of water and sanitation
6. Combined water-society dynamics
7. Water management participation
8. Experimental analysis of sociohydrological dynamics and regulations

The teams address climate change adaptation issues from several angles.

- The unit analysed possibilities of adaptation of Seine Basin reservoirs upstream from Paris, for instance.
- It also studies the impact of hydraulic projects in Sub-Saharan Africa, such as the expansion of irrigation in the Upper Niger Basin.
- Climate change is also considered in terms of the generated vulnerability. The unit is modelling this and assessing the adaptation capacity of individuals and institutions. Several projects have focused on flooding and water shortages in Europe (France, Spain) and North Africa (Tunisia, Morocco).

The unit also focuses on the unintended impacts of adaptations to change in coastal areas.

Methodologically, the unit is working on the implementation of participatory approaches regarding integrated natural resource management in Africa (AFROMAISON project). This research focuses specifically on uncertainties associated with global change and how this process is perceived.

Finally, adaptation is approached through technological and organizational innovations. The unit is thus assessing highly efficient water use technologies (e.g. optimization of irrigation management under climatic constraints) and possibilities for tapping new resources such as wastewater (e.g. Water4Crops project).

ClimAware: reservoir management and adaptation to climate change

The ClimAware project (2010-2013), funded by IWRM-NET (Integrated Water Resource Management—Towards a European exchange network to improve the dissemination of research results on integrated water resource management), aimed to develop adaptation strategies to mitigate climate change impacts through regional case studies in three areas related to water:

- Hydromorphology in the Eder catchment basin, Germany (Kassel University, Germany)
- Irrigation in the Pouilles region, Italy (CIHEAM-IAM at Bari, Italy),
- and reservoir management in the Seine Basin, France (UMR G-EAU).

An integrated European-scale model was developed for combined analyses at two study scales (Kassel University).

The case study on the Seine Basin concerned major socioeconomic issues in the Paris region, it focused on the adaptation of reservoir management, with two main objectives, i.e. minimum flow and flood management. Four large reservoirs with a total capacity of 800 million m³ managed by the Établissement Public Territorial de Bassin (EPTB) Seine Grands Lacs, the project partner, regulate the upstream section of the Seine River and its three major tributaries (Aube, Yonne and Marne).

A hydrological modelling chain integrating reservoir management was developed to simulate the hydrological functioning of the basin. The parameters were calibrated according to real conditions (climate observations and management over the 1958-2009 period). The modelling chain was then forced with data from seven climate models under present (1961-1991) and future (2046-2061) climate scenarios. Adaptation scenarios regarding annual filling curves and real-time reservoir management were drawn up and their performances were tested under present and future climatic conditions, and then compared with those of the current management scheme.

The results showed that climate change could have a significant impact on low flows regardless of the selected management strategy for the four reservoir lakes in the basin.

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Impact of climate change at Paris.

Mean daily discharges for seven present time (PST; 1961-1991) and future time (FUT; 2046-2061) climate scenarios. Naturalised (blue) and unaltered (red) flows according to the current lake management scheme.
Wastewater reuse for irrigation

Wastewater reuse helps address water resource quantity and/or quality problems that are increasing due to population growth, urbanization, global warming and environmental (refilling rivers or lakes) or recreational (swimming pools, water parks, watering sports fields, etc.) water uses. Wastewater reuse is substantial in semiarid and arid regions (southwestern USA, Australia, Near East, Middle East, Mediterranean countries) and has been growing in recent years in Spain, Italy, Cyprus and Malta. It remains moderate in Greece and is negligible in other southern European countries (Portugal, France, former Yugoslav Republic, Albania, Bulgaria).

This practice should be promoted by enhancing the assessment of societal, technological, sanitary, agricultural and environmental risks, identifying current constraints, and developing decision support tools to guide public and project developer arbitration. UMR EMMAH conducted a review of around 600 articles on this topic and identified some recycling success and constraint factors in association with Suez-Environnement, TNO (a Dutch applied research organization, the Netherlands), Polytechnic University of Valencia (Spain) and UMR Environnement et Grandes Cultures (INRA, AgroParisTech). In collaboration with Veolia Water Systems Iberica and the group Economia del Agua de l’Universitat de Valencia in Spain, it submitted to Climate-KIC (Knowledge and Innovation Community, a network devoted to climate change) a project to assess the economic viability and competitiveness of agricultural waste recycling, identify market opportunities and define win-win strategies.

The research unit is also conducting studies on the environmental fate (soil, water, plant, atmosphere) of enteric viruses in wastewater. The collaborations combine quantitative microbial risk assessment with (in future) an economic analysis. Several research programmes on these issues are ongoing or pending funding (by CNRS-INSU, the French National Research Agency, Agropolis Fondation, Campus France). They bring together various partners, including Suez-Environnement, the Centre National de Référence des virus entériques, the Agence nationale de sécurité sanitaire de l’alimentation, de l’environnement et du travail (ANSES), the Laboratory for Molecular Biology of Pathogens (Technion, Israel), and research units, including G-EAU, the Division of Applied Mathematics and Informatics (AgroParisTech, INRA), D3E/NRE, etc.

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Main teams

| UMR GRED Governance, Risk, Environment, Development (IRD/UPVM) | 53 scientists |
| UMR HSM HydroSciences Montpellier (IRD/UM/CNRS) | 90 scientists |
| UMR LAMETA Laboratoire Montpelliérain d’Économie Théorique et Appliquée (INRA/Montpellier SupAgro/UM/CNRS) | 53 scientists |
| UMR TETIS Spatial Information and Analysis for Territories and Ecosystems (CIRAD/AgroParisTech/IRSTEA) | 42 scientists |
| UR D3E/NRE Nouvelles Ressources en Eau et Économie (BRGM) | 16 scientists |
| UR Green Management of Renewable Resources and Environment (CIRAD) | 18 scientists |
| UR LG/EI Laboratoire de Génie de l’Environnement Industriel (EMA) | 30 scientists |

Impacts of global change on water and adaptation in the Mediterranean environment

The joint research unit Modelling Agricultural and Hydrological Systems in the Mediterranean Environment (UMR EMMAH – INRA, UAPV) brings together staff from INRA Avignon, and the Université d’Avignon et des Pays de Vaucluse.

The research is focused on:
- the impact of global change on water resources (in quantitative and qualitative terms),
- and adaptation to global change.

The unit’s studies are based on observation of instrumented sites, experiments carried out in controlled or semi-controlled conditions (especially in laboratories), and on methodological development to gain insight into and model the functioning of Mediterranean ecosystems.

EMMAH brings together a range of expertise that makes effective use of in studies on landscape changes on a regional scale (especially land use patterns) and on water transfers in the aquifer, deep unsaturated zone, soil, plant and atmosphere continuum. It also studies the impact of biogeochemical reactivity on water quality, the environmental fate of human pathogens, and crop functioning according to climatic conditions.
Climate change, Earth geodynamics and surface manifestations—risk analysis and management

The joint research unit Geosciences Montpellier (UMR GM – CNRS, UM) has developed a global approach to Earth dynamics and surface manifestations, while taking couplings between the various layers (including the hydrosphere) into account.

The aim is to gain further insight into the dynamic processes involved at different scales and to take societal expectations into account, 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 waste, etc.)
- natural hazards (earthquakes, tsunamis, gravity hazards, floods, etc.)
- environmental and climatic changes with a high anthropogenic impact (coastline changes, coastal saline intrusion).

Five research teams (Mantle & Interface, Lithosphere Dynamics, Risks, Basins, and Porous Environment Transfers) conduct studies in three main scientific fields: geodynamics, reservoirs and risks. Of particular interest, the Risk and Climate subtheme is focused on climate change issues:

- heavy rainfall forecasting
- paleoclimates, extreme events and coastal system dynamics
- hydromorphodynamic modelling and coastal hazards.

In the Mediterranean Basin, UMR GM coordinates two experimental Systèmes d’Observation et d’Expérimentation au long terme pour la Recherche en Environnement (SOERE H+) research sites in Larzac (France) and Mallorca (Spain). The unit is also a member of OREME for which it conducts different observation tasks. It is also involved in GPTR AETE*, and hosts some equipment of the national platforms of the CNRS National Institute of Sciences of the Universe (INSU), including an absolute gravimeter and a scanning electron microscope for electron backscatter diffraction analysis (SEM-EBSD).

GM is also part of a large-scale national and international cooperation network that includes countries and programmes from Europe (HORIZON 2020 programme), the Mediterranean region (North Africa, Middle East), and elsewhere in the world (Taiwan, Japan, India, Australia, New Zealand, Iran, Brazil, Mexico and USA).

GM also collaborates with the private sector, especially via the creation of business start-ups by PhD students and for the funding of research contracts and theses. It belongs to the Geosciences Cluster, which was launched in 2011, involving key companies from L-R Region (Geoter, Cenote, imaGeau, Schlumberger, Fugro, Antea, Areva, Lafarge) and R&D and training agencies (GM, BRGM, EMA, CEFREM, HSM research units).

The R&D service of this unit addresses societal demands associated with increased water needs by developing the yet relatively untapped potential of natural water resources (complex aquifers) and unconventional water resources (treated wastewater, surface water, rainwater, etc.). Groundwater and aquifers—from hydrogeological and economic standpoints—is therefore the general focus of study of the D3E/NRE research unit.

Note however that, through a scientific programme on economic aspects of the environment and risks, the unit's economists also intend to conduct research topics such as natural risks or contaminated sites and soils (e.g. former industrial wastelands) in R&D, public policy support or international projects.

The water management issue is still the key overall focus of the unit's research, regardless of whether it is assessed from an environmental or natural risk standpoint.

Mainstreaming hydrogeological and socioeconomic issues to enhance management of growing water needs

The main missions of the research unit Nouvelles Ressources en Eau et Économie de l’Eau, Environment and Ecotechnologies division (UR D3E/NRE – BRGM) are to:

- study optimal groundwater management conditions (active management), especially for complex aquifers (karsts, crystalline rocks, volcanic environments) in situations when they are subjected to increased constraints (climate change, anthropogenic pressure, socioeconomic change, urbanization, etc.)
- develop suitable economic approaches to fulfil emerging needs regarding integrated management of water resources, aquatic environments and risks.

The scientific research and public service support activities of this unit are aimed at:

- developing innovative methods to study and assess—regarding their structure and functioning—the potential of karstic aquifers, crystalline aquifers, volcanic environments, thermomineral and mineral water springs
- characterizing the distribution of hydrodynamic properties of complex aquifers, including coastal aquifers, in order to develop active water resource management methods through multidisciplinary (geology, hydrology, geophysics, geochemistry and economy) approaches
- developing prospective approaches and methods to assess the economic value of environmental resources, to model various water demands, to analyse economic and institutional water resource access regulation mechanisms and assess the economic vulnerability of users to global change
- finally, developing modelling and decision support tools to manage these aquifers and predict the impact of global change (climatic and anthropogenic) on different scales, while integrating physical and socioeconomic issues.

The R&D service of this unit addresses societal demands associated with increased water needs by developing the yet relatively untapped potential of natural water resources (complex aquifers) and unconventional water resources (treated wastewater, surface water, rainwater, etc.). Groundwater and aquifers—from hydrogeological and economic standpoints—is therefore the general focus of study of the D3E/NRE research unit.

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The water management issue is still the key overall focus of the unit's research, regardless of whether it is assessed from an environmental or natural risk standpoint.
The research project ‘Multiuse management of Mediterranean karstic aquifers—Lez River, its watershed and catchment area’ (LEZ-GMU), coordinated by the French Geological Survey (BRGM), involved a partnership with UR D3E/URMNE, UMR HSM, G-EAU, TETIS, the European Centre for Research and Advanced Training in Scientific Computation (CERFACS) and Biotope, the ecological engineering consultant. This project was funded by Montpellier Agglomération, the Conseil Général de l’Hérault, the Agence de l’Eau Rhône Méditerrannée Corse and BRGM.

The aim of this project was to improve knowledge on the functioning of the Lez hydro-system (Hérault, France) and the quality of the resource in an active management and global change setting. Hydrogeological models to reproduce the Lez catchment hydrodynamic were built for this project. They facilitated studies on the impact of global change on groundwater resources. Nine climate scenarios from the CERFACS SCRATCH 2010 project (fine-scale climate projections for France in the 21st century) were used. These scenarios indicated an increase in temperature and a slight decrease in rainfall by 2050.

The performance of the karstic system was assessed for different extents of pumping with or without climate change. The findings indicated that climate change would result in an average 30% decrease in the annual recharge. This reduction would mainly occur in the autumn and spring periods and, to a lesser extent in winter. It would be observed through a decrease in the piezometry within the aquifer and result in a slight increase in the duration of the dry period in the Lez spring (+30 days on average compared to the reference period). The extraction scenarios showed a risk of greater water table depletion, but they also highlighted the possibility—while taking the uncertainties inherent to this type of approach into consideration—of increasing the current extraction volume, while maintaining a monthly average piezometric level above pump elevation.

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Analysis and management of pollutant flows and natural and technological risks

The Laboratoire de Génie de l’Environnement Industriel (UR LGEI – EMA) is one of the three laboratories of the École des Mines d’Alès (EMA), which in turn depends on the French Ministry of Industry.

LGEI focuses on resource management, including ecosystems, hydrosystems, anthropogenic systems, as well as raw materials, i.e. fossil and mineral resources. These resources should be utilized in rational and responsible ways to ensure the sustainability of ecosystems and the production capacity of humankind.

To meet these challenges, LGEI has developed a multidisciplinary approach on the following topics:
- assessment of the chemical and ecological quality of water and effluents; development of treatment systems; integrated management of pollutant flows (industrial environments, water resources) according to a ‘territorial ecology’ type of approach
- understanding and spatializing hydrological processes in catchment basins; understanding and modelling karstic or fractured aquifers for sustainable water resource management
- finally, natural and technological hazard analysis and management.

LGEI’s research activities are focused mainly on water resource management in connection with anthropogenic and climatic forcing. To address the societal demand (catchment basin managers, water agencies), the unit conducts studies on different types of contamination (persistent pollutants, toxins, algal blooms) in an effort to gain further insight into the status (chemical and ecological) of water bodies and their potential change patterns.

LGEI intends to develop integrated systems (sensors, sensor networks, data processing, modelling) and design decision support tools for different stakeholders (local authorities, companies in charge of sanitation or drinking water purification).

Regarding hydrosystem research, LGEI’s expertise is focused mainly on statistical modelling using formal neural networks in order to develop models for nonlinear and nonstationary systems. This choice raises questions regarding the validity of the models—built solely using data—when considering future changes that could arise as a result of climate change and extreme events. LGEI’s teams therefore carefully validate their models testing their performances with regard to the most intense events in the database (floods, drought).

See an example of a project conducted by UR LGEI on page 38.
Understanding plant responses to water stress to enhance performance in a climate change setting

Because of global change and the growing world demand for food, it is crucial to clearly understand how plants take up and utilize soil water and especially how cereal crops tolerate and react to water stress. These issues are studied through two research projects conducted by UMR B&PMP (see page 81).

The HydroRoot project aims to boost our fundamental understanding of root water transport. This will provide an integrated view of roots by taking the hydraulic properties of tissues and the root architecture into account, and by explaining how these components are molecularly controlled by physiological and environmental parameters. Through the strong physiological and genetic components of this project, this type of research could also have an impact on plant improvement programmes geared towards generating plants featuring optimised water use and stress responses.

Leaf rolling resulting from leaf epidermal contractile cell movements is an adaptive response to water deficit that occurs in many cereals. The aim of the LeafRoll project is to identify molecular mechanisms responsible for turgor and contractility variations in these cells by focusing specifically on transmembrane ion fluxes.

Molecular, physiological and agronomic analyses will be conducted on a panel of wheat cultivars showing various degrees of drought tolerance and on lines with modified expression of genes coding for ion transport systems. The studies will assess the role of these genes in leaf rolling and wheat productivity under water deficit conditions.

Greater representation of these phenomena in crop models enables better ex ante quantification of the potential of innovative techniques designed to enhance adaptation to future climate change. These studies are currently being carried out as part of the Agroecology-Based Aggradation-Conservation Agriculture (ABACO) and Environmental and Social Changes in Africa: Past, Present and Future (ESCAPE) projects. The EU-funded ABACO project aims to evaluate and implement conservation agriculture and agroecology based technical solutions that are also designed to reduce soil degradation and food insecurity. The ANR-funded ESCAPE project assesses the vulnerability of rural societies in sub-Saharan African regions to climate and environmental changes, while studying adaptation strategies to reduce this vulnerability.

The AIDA research unit is contributing to this project particularly by assessing the potential impact of future climate change on cropping systems. These projects are being carried out in countries such as Burkina Faso, Madagascar and Senegal, and the scientific questions to which AIDA teams are proposing answers (via an in silico test on technical and organizational changes) are, for instance, “Could economic risks for farms be reduced through crop insurance assistance based on meteorological analyses?”

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EcoAdapt project—climate change adaptation for local development

The EcoAdapt project has been funded for a 4-year period (beginning in January 2012) by the European Commission’s 7th Framework Programme to promote integrated collaboration between science and civil society to benefit ecosystems and inhabitants in three areas in Latin America. EcoAdapt hopes to show that scientists working together with civil society organizations (CSOs) can help design strong socially and technically based strategies for adaptation to climate change. CSOs provide knowledge through their work in the field and with local communities, while researchers provide knowledge acquired through their social and biophysical science research.

This work of combining different types of knowledge and collectively generating new knowledge is the real challenge addressed by EcoAdapt to support communities living in the project’s focus areas: Jujuy Model Forest in Argentina, Chiquitano Model Forest in Bolivia, and Alto Malleco Model Forest in Chile.

EcoAdapt considers that adaptation to climate change cannot be done individually, so collective efforts are needed to bring together organizations with complementary skills and fields of activity. The project consortium includes five CSOs and four research partners, including UR GREEN and UMR ART-Dev. Local stakeholders involved in the project are from model forest platforms (universities, national agencies, producers’ associations, community councils, private operators, etc.). Internationally, the project also has connections with the Latin American network of climate change offices (RIOCC) and with the Ibero-American Model Forest Network (IAMFN).

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Socioecosystem adaptation and transformation

Since 1994, the research unit Management of Renewable Resources and Environment (UR GREEN – CIRAD) has been investigating—in a systemic and interdisciplinary way—the role of ecosystems and the environment as a development sustainability factor. The unit provides knowledge, methods and tools to gain insight into ecological and social systems (i.e. socioecosystems [SES]). It focuses on different resources (water, forests, land, fisheries, etc.), which it studies on different scales—from village to region and sometimes to the country level, from areas delineated by social dynamics (pioneer front areas) to ecosystems (watersheds, forest ecosystems, etc.). It spurs cross-disciplinary analyses on biodiversity, land, land-use changes, arbitration between conservation and usage, as well as access and types of appropriation of natural renewable resources.

The unit conducts research on all continents in association with many scientific communities in developed and developing countries. Although its headquarters are in Montpellier (France), the team is highly involved in studies in West Africa, the Indian Ocean region, Southeast Asia, and more recently in Central America and Brazil.

One of the unit’s research priorities concerns adaptation and transformation. The aim is to determine how a society in its environment, i.e. an SES, perceives given disturbances. This involves studying, through a set of concepts and tools, how the society prepares and reacts.

GREEN’s research includes analyses and factors involved in modifying nature-society interactions within SES—changes in viewpoints and/or knowledge and/or practices, power games, network mobilization, socioeconomic and environmental processes. ■■■
Spatialization of environmental knowledge— for monitoring tropical areas vulnerable to global change

Founded in 2011, the joint research unit L’espace au service du développement (UMR ESPACE-DEV – IRD, UM, UR, UAG) conducts research (fundamental, technological and applied) on decision processes in favour of sustainable development in the developing world, at local, regional and global scales. By focusing on environmental monitoring and renewable resource management, the UMR investigates issues regarding the spatialization of environmental knowledge. The aim is to provide decision support in peripheral tropical regions that are vulnerable to global change.

UMR ESPACE-DEV has broad ranging skills and knowledge in research, training, expertise and service.

The unit consists of three research units:
- The Spatial Observation of the Environment (OSE) team conducts research ranging from satellite data management to the analysis of data flows and their salient features, with the aim of highlighting the environmental dynamics. From Earth observation data, the main activity of the OSE team is to contribute to gaining insight into interactions that regulate tropical systems, especially so-called terrestrial, oceanic and anthropogenic ‘tropical landscapes’, as well as physical, biological and human processes that they host.
- The Integrated Approach to Environments and Societies (AIMS) team studies the dynamics, functioning and co-viability of systems (ecosystems and sociosystems) in fragilized environments (islands, coasts, forests, oases, etc.) under the stress of global change. It focuses on fragmentation processes and on the vulnerability and viability of territories. The AIMS team implements remote sensing, direct field observations and stakeholder surveys in its research.
- The Modelling, Knowledge Engineering and Spatial Data Analysis (MICADO) team is specialized in knowledge modelling and digital and symbolic data in the environment field. The data is derived especially from remote sensing and in situ observations.

The following five themes are investigated in a cross-disciplinary manner by the three teams:
- ontology of spatiotemporal systems
- integrated study of the continent-coast-ocean continuum
- observatory of environmental, territorial and landscape changes
- environment, societies and sanitary hazards
- co-viability of social and ecological systems.

See an example of a project conducted by UMR ESPACE-DEV on page 65.
Spatial information for the monitoring and analysis of territories and ecosystems

The structure of the joint research unit Spatial Information and Analysis for Territories and Ecosystems (TETIS – CIRAD, AgroParisTech, IRSTEA) includes two scientific dimensions, with one being thematic (territories and environment) and the other methodological (remote sensing and spatial information). These two priority areas define the unit’s research field—spatial information—and its mandate is outlined as, “the production of knowledge, tools and methods to gain greater insight into nature/society dynamics and interactions and to support stakeholders in the management of their territories and renewable natural resources (land, water, forests, biodiversity).”

The unit implements an integrated approach regarding the spatial information chain, from its acquisition to treatment, including its management and use by stakeholders. Research is focused on agriculture, the environment, resources, territories, health, etc. On this basis, the unit devotes a major share of its activities to education, training, expertise and public policy support.

The TETIS research unit is organised in four research teams: ATTOS, AMoS, SISO and UsIG:

- Data acquisition and remote sensing (ATTOS). Developing tools and methods for acquiring spatial data through satellite and airborne (drones, planes) remote sensing, and for extracting bio-physical information from remotely-sensed data;
- Spatial analysis and modelling (AMoS). Focus on analyzing and modelling spatial structures and temporal dynamics of agro-environmental systems, developing spatial indicators for characterizing these systems, and evaluating uncertainties related to the data and models used;
- Spatial Information Systems: (SISO). Design and implementation of information systems to address environmental and landscape management related issues, including developing methods for information extraction from spatio-temporal data;
- Uses of spatial information for multi-scale development (UsIG). Assessing and improving the relevance of geo information according to stakeholder needs, developing methods for turning data into useful and used information, monitoring and evaluating the use of this information and its impact on actors, management and territorial governance.

The research is supported by the Montpellier-based Remote Sensing Centre and the EQUIPEX-GEOSUD (Geoinformation for Sustainable Development) project. Through this project, the Remote Sensing Centre provides access to researchers and innovative satellite data companies, calculation resources, specialized software (image processing spatial analysis, geographical information, statistics, etc.), training facilities and hosting capabilities.

See an example of a project conducted by UMR TETIS on page 74.
Changes in governance and territorial and resource management in response to global change

The joint research unit Governance, Risk, Environment, Development (UMR GRED — IRD, UPVM) focuses on relationships that societies overall, as well as individuals, have with the environment. It strives to address the following dual-sided question: how do new constraints and vulnerabilities modify the governance and management of territories and resources?

Biodiversity conservation and rural system dynamics is the first line of research at GRED. Agricultural societies are hampered by the fragilization of ecosystems and conservation injunctions associated with the globalization of issues. These policies are nevertheless undergoing drastic changes. They are no longer considered independently of development and, moreover, biodiversity and climate change issues tend to overlap, which is a source of complementarities as well as contradictions. This pattern is illustrated by measures regarding the mitigation of impacts or adaptation to climate change with, for instance, carbon sequestration negotiations being focused at the tropical forest level. The result is that these new policies orient the representation of the forest and affect the vulnerability of communities and the ecosystem.

The second line of research at GRED concerns the governance and management of resources and territories. These concepts are priorities for development policies and a strategic social issue, as illustrated by the conflicts and discrimination associated with territorial resource access. In this setting, special attention is paid to individual and collective strategies of the stakeholders involved. Being constrained by existing institutional frameworks, they adapt, circumvent or intervene to develop them. The question of governance scales thus seems crucial, along with the redistribution of decision-making powers following the emergence of new territories or international regimes. This multiplicity of scales and stakeholders leads to the emergence of hybrid governance strategies and institutional pluralism situations, both of which are drivers of complementarities or —conversely—conflicts.

The risks and vulnerability of societies and territories is the last line of research of GRED teams. So far, public efforts to strengthen resilience have been focused on risk prevention through the setting up of material and territorial infrastructures. They have recently turned towards supporting adaptation and resilience phenomenon in order to weigh the risks. However, the questions of the role of sociocultural factors in the vulnerability and that of the adaptation of social and cognitive structures have yet to be addressed. The aim now is to explain these interrelationships and the case of coastal and island areas is specifically targeted from this standpoint.

▼ Decentralized resource governance.
A training session as part of a community management study programme, bringing together teachers, researchers, students and members of a farmers’ association. Maps and diagrams are used for mediation between stakeholder groups.
The Environmental Services and Uses of Rural Areas project (ANR SERENA) implemented by the research units GRED, ART-Dev, GREEN and METAFORT (AgroParisTech, IRSTEA, INRA, VetAgroSup) between 2009 and 2013 focused on issues related to the emergence of the ‘environmental service’ or ‘ecosystem service’ (ES) concept and its inclusion in public policy.

The ES concept takes the productive function of ecosystems into account (e.g. carbon sequestration) as well as so-called cultural functions. The latter refer to educational and recreational roles of protected areas as well as the unique relationship between some societies and their environment. This identity aspect confers a heritage value to some practices or threatened natural landscapes and objects.

‘Payment for environmental services’ (PES) instruments illustrate this type of representation of nature-society relationships. Although the genealogy of the two concepts (ES and PES) was originally distinct, biodiversity conservation stakeholders now put them both simultaneously forward as a justification for economic incentives, nature preservation cost compensation and protected area funding. The role of these tools is to promote services provided by environment managers. Contributions are thus requested from resource users and ES beneficiaries.

A comparison of three countries revealed the extent of dissemination of the concept and the marked differences in its application.

- In Costa Rica, a country that has played a major role, the ES concept circulated through a forest policy launched in 1996. It reclassified as ‘PES’ a previous policy of financial support to forest properties that was partly funded by public subsidies backed by a tax on petroleum products and, more recently, on water.

- In Madagascar, the concept was gradually introduced via international cooperation from the year 2000, with the aim of boosting public awareness on conservation and providing sustainable funding for New Protected Areas and community management of forests. Stakeholders of these projects then focused on carbon markets, biodiversity, water and tourism.

- In France, the ES concept has yet to gain wide popularity. In conservation and biodiversity areas, it is currently being introduced through a biodiversity law. In agricultural policies, it is economic incentives, via regulation services rendered by farmers, which attract stakeholders’ attention regarding the new European policy.

Application of the ES concept and its links with international issues (climate change, biodiversity conservation, sustainable water management, ecotourism) has been promoted by the environmental and forestry sectors in international arenas. PES are being developed in Costa Rica on a national scale, and in Madagascar on a more local scale (REDD+ pilot programmes, local water platforms, and conservation contracts drawn up by NGOs). Generally, the agricultural sector—and more generally rural development policies—have not yet appropriated this concept to a sufficient extent to be able to renew their practices and intervention tools. Some existing initiatives (ecotourism, environmental certifications) sometimes include the ES concept, but this is often just empty rhetoric used to justify their legitimacy.

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Climate change—a new constraint for stakeholders, resources and territories in development

The joint research unit Actors, Resources and Territories in Development (UMR ART-Dev – CNRS, UPVM, CIRAD, UPVD, UM) develops research on the reconfiguration of territories from economic, political and social standpoints, while highlighting relationships between globalization and local dynamics. Its main research themes concern rural and urban territorial trajectories, the natural resource governance question, and other issues regarding mobility and circulation processes in the globalization setting. These themes are studied on the basis of territorial scales and public policies. The unit works on several continents in many geographical and political settings with marked differences in terms of choices and levels of development. It is striving to promote this wealth through comparative approaches.

Climate change—a factor responsible for environmental disturbances as well as socioeconomic and political tension—is a rising cross-cutting theme within the unit (‘Of lands and waters’, EcoAdapt and BLUEGRASS projects). The research teams are primarily seeking to understand and analyse these impacts by combining analyses on local, national and international scales. Climate change also places new constraints on natural resource management, including the risk of the emergence of conflicts regarding the distribution and appropriation of these resources.

Besides these efforts to characterize and analyse climate change impacts, the unit’s research also assesses various current political, institutional, regulatory, technical and behavioural options to address climate change challenges. They include climate change mitigation initiatives (human interventions to reduce sources of or increases in GHG sinks, as well as climate change adaptation strategies (modifications in natural and human systems).

Adaptation strategies may include setting up incentive economic mechanisms to encourage natural resource users to implement more sustainable practices. They thus accompany climate change policies (INVALUABLE and REDE CLIMAT projects). Research has also revealed that climate change adaptation is necessarily specific to the local setting and that there is no quick fix that could be universally applied anywhere and under any circumstances. As shown in the CIRCULEX project, the complementarity of the different types and levels of stakeholders (ranging from individuals to national and international decision-making bodies) is essential to ensure the proper design and success of these adaptation strategies and linkages between the different environmental issues (climate, biodiversity, water, desertification, etc.).

Of lands and waters

Around the globe smallholder farmers are coping with major disruptive changes that are unfolding simultaneously. Rapid changes in land tenure and water management practices are now overlapped with climate change processes. For instance, uncertainties regarding rainfall or the increased likelihood of extreme weather events coexist with other uncertainties on the future of land tenure or the maintenance of local water management customs. Hence, farmers’ strategies do not simply address climate change related problems, but rather a set of disturbances they are forced to cope with at once.

As the ‘Of lands and waters’ project specifically illustrates, and in which UMR ART-Dev participates, farmers develop their own strategies to manage these combined uncertainties. This project explores ways in which the relationship with land and water is affected by these global changes on very local to global scales. Based on eight case studies involving long-term field surveys in Kenya, Uganda, Mozambique, France, Spain, Nepal, Lebanon and the Palestinian Territories, this project assesses the experience of local agricultural stakeholders in order to gain insight into their perception of issues affecting them and the rationale behind their coping strategies. The project is also focused on processes that underlie these issues on regional, national and global scales.

This scientific research clearly differentiates locally developed strategies that are effective from those that, conversely, induce vulnerabilities. These latter strategies are quite logical from the standpoint of producers on the local level, but they could induce a vulnerability for farmers when they encounter stakeholders active at national or global levels, e.g. foreign investors or development support organizations.

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ACFAO: for sustainable forest management and climate change adaptation in Sudanian-Sahelian communities

The overall aim of the Forest and Adaptation to Climate Change in West Africa (ACFAO) project is to contribute to the development of ecosystem-based adaptation policies and projects to face climate change in the Sudanian-Sahelian region. This involves strengthening sustainable forest and landscape management and enhancing the coping capacities of the most vulnerable social groups, while improving their livelihoods, via ecosystem goods and services sustainably supplied by woodlands and parklands.

This project includes five main components:

- analysing forest and adaptation policies (and their linkages) by fostering the involvement of regional, subnational and national stakeholders in planning and discussions and identifying opportunities to influence these policies
- analysing the current and future vulnerability of communities living on pilot sites through a participatory, multiscale and integrative approach, while focusing on links between ecosystem dynamics and the reduction of this vulnerability
- formulating adaptation strategies that take ecosystem services into account and that mainstream local community strategies
- informing stakeholders involved in the project (policymakers, experts, practitioners and local operators) and building their capacities
- disseminating information and creating—within and outside of the countries involved in the project—networks of stakeholders concerned about climate change adaptation and ecosystem services in dryland regions.

This 4-year project with a €3.9 million budget, in which UR B&SEF (see page 35) participates, is coordinated by the Center for International Forestry Research (CIFOR), with cofunding from the French Global Environment Facility (FFEM) and various other sources.

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Sustainable development and management of resources from an economics standpoint

The Laboratoire Montpellierain d’Économie Théorique et Appliquée (UMR LAMETA – INRA, Montpellier SupAgro, UM, CNRS) is a general-interest economics research unit. It encompasses a broad range of theoretical and methodological frameworks—applied econometrics, behavioural economics, experimental economics, public economics, the history of economic thought and philosophy, microeconomics, socioeconomics and game theory.

The unit conducts a set of studies structured around several priority topics. The ‘Biodiversity, ecosystem services and natural resource’ priority line includes a broad range of research projects with a common thematic field—sustainable development and resource management. Most of these research studies concern quantitative and qualitative water management (watersheds and coastal areas), as well as agroenvironmental schemes, a conventional area of expertise and scientific collaboration in Montpellier. Several research programmes (ANR-MISÉEVA: French National Research Agency–Marine Inundation Hazard Exposure and Social, Economic and Environmental Vulnerability Assessment; LITEAU SOLTER, or Sustainable Coastal Management–Territorial Solidarity and Strategies for Coastal Flooding Resilience; Alternative Fondation de France) are focused on coastal hazards (erosion and coastal flooding) related to the sea level rise due to climate change. The aim of these studies is to inform and support public decisions on climate change adaptation policies (risk of inland and coastal flooding) and to identify awareness and training needs regarding governance.

Since 2014, several LAMETA researchers have been participating in a multidisciplinary ANR project entitled ‘Modelling to accompany stakeholders towards adaptation of forestry and agroforestry systems to global changes’ (MACACC, see page 77). This project aims to develop various global change adaptive management scenarios and to test producers’ capacities to adopt them in tropical and temperate regions worldwide.