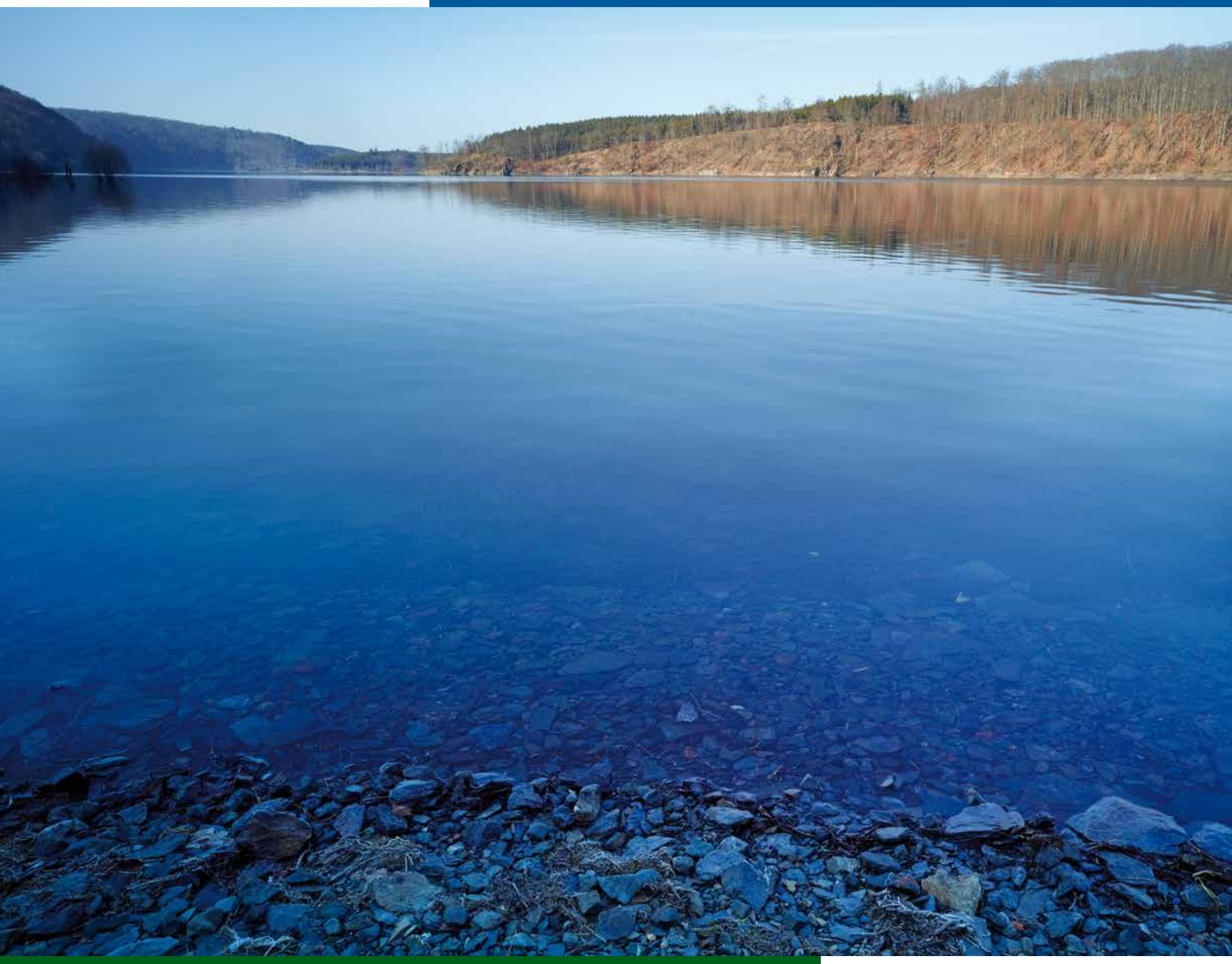
HELMHOLTZ
WATER NETWORK

Integrated research for addressing global water challenges



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Foreword

Prof. Jürgen Mlynek

Dear readers,
Global change – climate change, population growth and the more intensive use of land – is seriously affecting the very foundations of human life, including the availability and quality of water resources. Protecting mankind from the consequences of more frequent droughts and floods, and from pollutants in drinking water and irrigation water, while ensuring a sustainable approach to the management of water resources, are key challenges faced by the water sector in the 21st century. We need a profound understanding of our environmental system in order to safeguard the foundations of human life. Therefore it's necessary to describe the complex changes that have taken place in the water cycle, its interaction with soils, vegetation, the atmosphere and the anthroposphere – people and systems created or altered by people – optimally, influencing future developments and also being able to adapt to them.

In setting up the Helmholtz Water Network, the Helmholtz Association of German Research Centres has strategically positioned itself to tackle the water sector's most pressing issues for the future and, with a long-term approach to research, aims to find answers to the major challenges facing our society. The Helmholtz Water Network is the result of a more intensive thematic collaboration in the German research landscape and maximises synergies. On the one hand, universities are granted easier access to the infrastructures of the Helmholtz Association that are unique worldwide, while on the other hand, young researchers who are educated at the universities will become better acquainted at a younger age with the important issues faced by our society.

The Helmholtz Water Network is an example of how the German research landscape will continue to develop in the future, through long-term, subject-related research platforms and strategic partnerships between large-scale research institutes and universities. That is what makes us internationally competitive and what makes the Helmholtz Water Network one of the driving forces in water research in Germany, Europe and worldwide. With the Helmholtz Water Network, the Helmholtz Association is contributing to the protection and sustainable use of the foundations of human life on Earth.

I wish you an informative read.

Prof. Jürgen Mlynek
President of the Helmholtz Association of German Research Centres

I. Global water challenges and the role of science

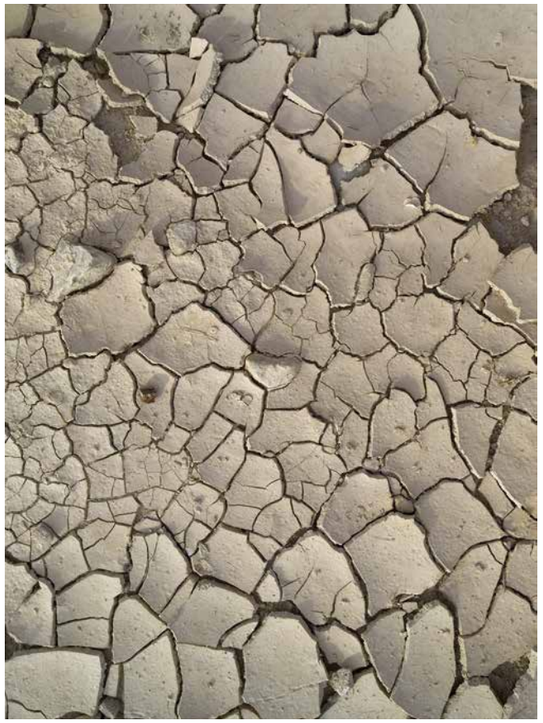
There is no life without water. An adequate water supply is essential for the health of humans and ecosystems as well as for the cultural and economic development of our society.

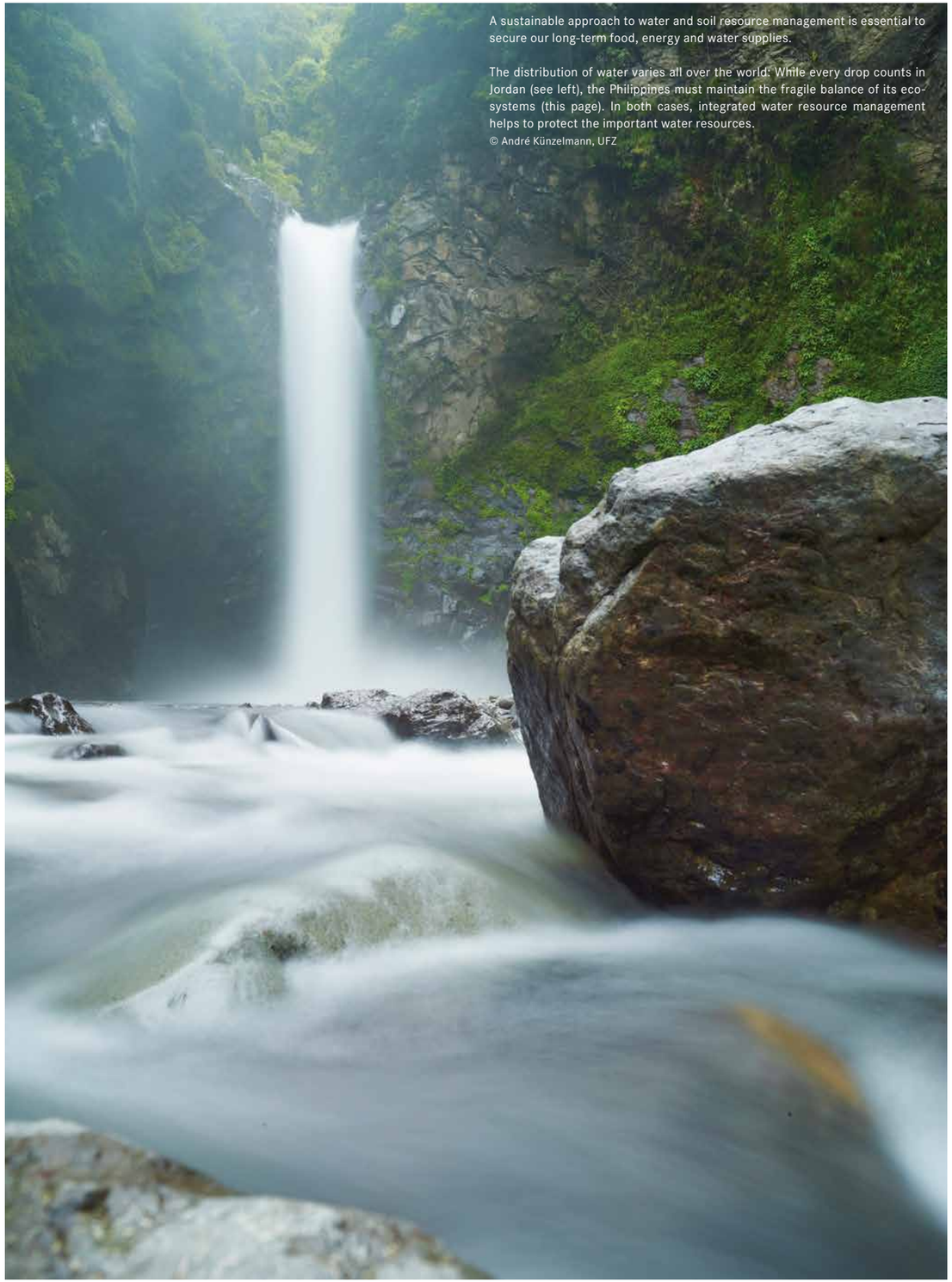
During these times of climate change, the resource that is the most essential for mankind and the environment is exposed, now more than ever, to a wide range of dynamic external influences. The change in land use resulting from the rising population and changing lifestyles is affecting the functionality and capacity of soil and ecosystems, which have a key influence on the quality and quantity of our water and are the basis for food production. Adapted water supply and disposal systems, water treatment technology and management strategies are needed for the rapidly growing megacities in emerging and developing countries.

In order to be able to assess the consequences for and changes to the environment and to be able to develop adaptation strategies, the main drivers and their effects must be identified and understood. A major challenge facing researchers is to measure all of the relevant complex aspects of the water cycle and their interaction with the environment. But measurements are not enough to provide us with information regarding the future development of our water resources. In order to realistically assess the present and future status of this essential resource, models are being developed that will allow us to gain a better understanding of the impact that global change is having upon it. This allows us to conclude that climate change has resulted in more frequent extreme weather conditions, such as droughts and floods, especially in regions that are already experiencing prevalent water shortages, such as the Mediterranean. In these areas the situation is becoming critical with regard to the available water resources and climate-related threats to the environment. This subsequently affects economic sectors that rely on a sufficient and regular availability of water, such as agriculture, industry and energy production.

To counter the increasing threat to human welfare posed by the effects of global change, we need to take an integrated approach to develop efficient and coordinated adaptation measures in the relevant sectors. Science has a major role to play here, as the previously relevant and historically proven knowledge is no longer sufficient as a basis for predicting future developments in times of global change, unexpected weather events and conditions that are becoming more and more extreme. Interdisciplinary cooperation across institutional boundaries is necessary in order to follow the long-term trends and developments of the complex networked environment.

Only then can we recognise signs of future changes, develop corresponding strategies to resolve imminent problems and subsequently implement them in the business sector and in politics.





A sustainable approach to water and soil resource management is essential to secure our long-term food, energy and water supplies.

The distribution of water varies all over the world: While every drop counts in Jordan (see left), the Philippines must maintain the fragile balance of its ecosystems (this page). In both cases, integrated water resource management helps to protect the important water resources.

II. The water research community in Germany and the Helmholtz Water Network

Against the backdrop of the challenges facing our society in the field of water and the resulting demands placed on scientific research, the question arises whether the water research community is adequately organised to fulfil its role. A compendium[1] published by the German Research Foundation (DFG) in 2003 concluded that the water research community in Germany is well-developed in terms of individual expertise, but that it is extremely dispersed and inadequately structured to meet the challenges of the future as one of the global research leaders in the field of water. An analysis on behalf of the Federal Ministry for Education and Research (BMBF) from 2010 – 2012 reflects this fragmentation of the water research community[2] in Germany, and comes to the conclusion that both universities and non-university research institutes possess a high research capacity, but lack the cross-institutional coordination of focal points as well as long-term agreements and strategies between the federal and the regional level.

The Helmholtz Association started to address this fragmentation in 2009. Its senate gave the Helmholtz Centre for Environmental Research (UFZ) the mandate of developing a concept to strengthen and improve the positioning of German water research. Within the German water research community the idea came up of achieving this by bundling the competences in interdisciplinary and cross-institutional Thematic Clusters and to create a platform to share ideas on new research methods and approaches: the Water Science Alliance. A white paper[3] was drawn up to develop the relevant subject-related focal points, with contributions from around 70 authors from all disciplines of water research from both within and outside the Helmholtz Association.

The Water Science Alliance initiative, supported by the BMBF and the Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and promoted by the UFZ between 2010 and 2013, was established as a community platform in spring 2013 in cooperation with the DFG's Senate Commission on Water Research. The central platform for the thematic development and networking of the community is the Water Research Horizon Conference (WRHC), held annually since 2010 and which is supplemented by the Online Portal for Water Research, a blog, workshops and round-table discussions.

The Helmholtz Association reacted to the major challenges facing water research outlined in the White Paper of the Water Science Alliance and to the fragmentation that was highlighted by the investigation on the water research community and procured funding accordingly (Joint Initiative for Research and Innovation, »portfolio funding«) from which the Helmholtz Water Network was developed. Complementary competences of the participating Helmholtz Centres are pooled in close cooperation with the universities. A first thematic clustering took place in 2010 between the UFZ and universities in Tübingen, Hohenheim and Stuttgart with the Water Earth System Science Cluster (WESS). More clusters have followed: The Helmholtz WasserZentrum München (HWZN), which is thematically closely related to WESS, brings together expertise from the German Research Center for Environmental Health in Munich (HMGU) and the universities in Bayreuth, Tübingen and the Technische Universität München (TU München), while the Center for Advanced Water Research (CAWR) links the research of the UFZ with the Technische Universität Dresden (TU Dresden).

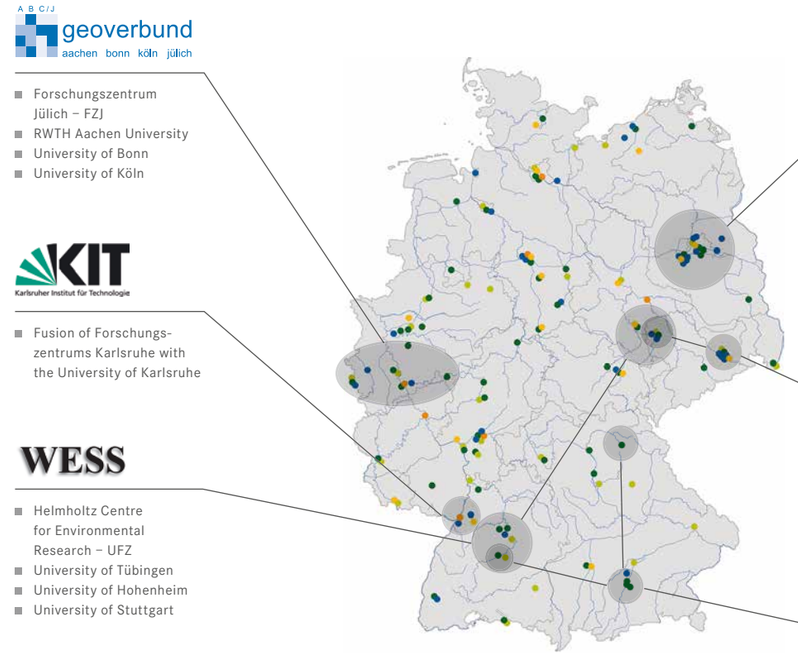
The establishment of the Helmholtz Water Network has strengthened the water research activities of the participating institutions by building on existing collaborative research alliances, such as the Geoverbund ABC / J (Forschungszentrum Jülich, universities in Cologne and Bonn, RWTH Aachen University) and Geo.X (German Research Centre for Geosciences – GFZ – at the University of Potsdam and others). At the Karlsruhe Institute of Technology (KIT), the first fusion of a university and a large-scale research institution in Germany, a water research coordination unit for the KIT was set up as part of the Helmholtz Water Network.

As part of the Helmholtz Association's third programme-oriented funding phase (PoF III, 2014 – 2018), the Helmholtz Water Network represents the cross programme activity »Water« and brings together the water research expertise from seven Helmholtz Centres in five programmes and two research areas, plus a Helmholtz Alliance and a Helmholtz Virtual Institute.
The Helmholtz Water Network can thus draw on the competences of a »water team« of 700 researchers (not including universities).

The Helmholtz Water Network aims to promote synergies between universities and non-university research institutes, to carry out collaborative projects, and to strengthen cooperations with leading international partners and the business sector. With its participation in or coordination of high-profile international activities, such as the World Water Quality Assessment initiated by the United Nations Environment Programme and the European Commission's European Topic Center on Inland, Coastal and Marine Waters, the Helmholtz Association is increasingly regarded as an important and influential actor within the national and international water research community.

The Helmholtz Water Network provides future opportunities for cross-institutional collaboration on joint research projects to tackle the major challenges in the field of water using the existing and prospective infrastructures of the Helmholtz Association.

This contributes to Germany's leading position in water research in Europe and internationally.



The map gives an overview of all publicly funded water research institutions in Germany.

The Helmholtz Water Network is strengthening the links between university and non-university research in the field of water. Clusters, both those previously established and those initiated by the Helmholtz Water Network, between Helmholtz centres and universities (highlighted in dark green) work thematically on the six major challenges in the water sector.

Publications

1 »Wasserforschung im Spannungsfeld zwischen Gegenwartsbewältigung und Zukunftssicherung«. (German only), DFG 2003, Wiley-Verlag

2 »Water Research in Germany – Research Fields, Centres, Competences«, UFZ, 2012

3 »Water Science Alliance White Paper – Priority Research Fields«, UFZ, 2010

http://www.helmholtz-wassernetzwerk.de
http://www.watersciencealliance.org
http://www.onlineportal-wasserforschung.de
http://www.geo-x.net
http://www.cawr.de
http://www.wasserzentrum-muenchen.de
http://www.wess.info
http://www.kit.edu
http://www.geoverbund-abcj.de

III. Research in the Helmholtz Water Network

The Helmholtz Water Network is playing a key role in addressing global water problems. This includes the further development of management strategies for extreme events, such as floods and droughts, strategies to manage pollutants in the water cycle that could threaten the health of the population and ecosystems, and the development of models that are capable of showing us the complex relationships and interactions of our ecosystem.

The network of seven Helmholtz centres and their key university partners is based on six thematic focal points, which are closely linked to the priority research fields identified by the Water Science Alliance, thus ensuring that they remain matters of long-term importance within the water research community. Based on the existing competences of the Helmholtz Water Network the following interdisciplinary research platforms have been established:

- Research platform 1
  Global change and hydrological extreme events:
  The impact of global change on water resources, hydrological extreme events, vulnerability, outreach and system solutions

- Research platform 2
  Urban water resources management (UWRM):
  Water in the urban system: Processes and solute dynamics, securing water quality in the long term, ecosystem services, floods in urban areas, the economics of water

- Research platform 3
  Integrated analysis of solute fluxes and processes in regional water cycles (SolFlux):
  Understanding the processes of terrestrial water fluxes, aqueous reaction rates, solute fluxes and turnover processes on catchment scale

- Research platform 4
  Integrated observation of the terrestrial water cycle:
  Development of new long-term observation and exploration technologies for the establishment of hydrological measuring networks for model development and validation, data management, integration and assimilation

- Research platform 5
  Integrated modelling and model benchmarking:
  Model concepts and model structures, model benchmarking, data integration and software development

- Research platform 6
  Complex water management in the Circum-Mediterranean region:
  Development of integrated monitoring concepts, modelling strategies and model parameterization for regions with water scarcity, sustainable management of water resources while taking into account socio-economic factors and the legal framework

The thematic focal points within the Helmholtz Water Network range from methodological challenges, such as the understanding of water and solute flows on a catchment scale, to integrated monitoring and research concepts and the development of corresponding models to process the monitored data, in order to provide integrated system solutions regarding water management and governance. The Helmholtz Water Network also focuses on issues regarding the global water situation, including the interconnections between water, energy and food security and the challenges that arise with rapid urbanisation and megacities. This is also closely linked to research into the risks of hydrological extreme events, such as floods and droughts, as well as the management of water resources in regions, where water is a scarce resource. Research here is concentrated on the Circum-Mediterranean region, including the Middle East.

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1 Global change and hydrological extreme events

Global change has many faces: Climate change, demographic transformation and globalisation are just a few of the factors impacting our environment, economy, politics and culture.

Environmental changes, such as increased population density, changes in land use and climate change, have serious consequences for mankind and ecosystems. Damage caused by extreme weather events, such as floods and droughts, have increased dramatically. The number of devastating flood disasters has doubled in the last 50 years, while the economic losses in the same time period have increased by a factor of five.

Many towns in the eastern Germany were flooded during the Elbe flood in summer 2013. The area around Elbe's confluence with the Saale was particularly badly affected (Barby in Sachsen-Anhalt). © André Künzelmann, UFZ

Eastern Germany was again affected in June 2013, for the second time in eleven years, by flooding which occurs statistically every 100 years in the region. Long-lasting periods of heavy rainfall combined with an extreme over-saturation of the soils led to the serious flooding in the Elbe and Danube catchment. Historic maximum water levels were recorded in both catchments, causing economic losses of more than 12 billion across different sectors.

Climate models forecast a global temperature increase of up to six degrees Celsius by 2050. Researchers at the University of Potsdam are currently studying the impact of such an increase in temperature will have on the intensity of precipitation. The first results found there to be a significant correlation between maximum daily temperatures and the maximum intensity of precipitation of small-scale thunderstorm events. The interdisciplinary team from GFZ, UFZ, KIT and the University of Potsdam are conducting joint research to better understand and quantify the influence that various factors of global change have on the risk of extreme hydrological events.

Researchers want to use this research platform in the future to develop and implement approaches that lead to the identification of the driving forces contributing to changes in the threat of and vulnerability to hydrological extremes.

Researchers from University of Potsdam are studying the connection between maximum daily temperatures and maximum intensity of precipitation of small-scale thunderstorm events as well as the impact on the human environment, the economy and ecosystems. © sborisov, Fotolia.com

In order to be better able to assess the causes and effects of extreme flooding in future, researchers of the GFZ and KIT are further developing an approach initiated by the international Integrated Research on Disaster Risk Initiative (IRDR) in order to analyse natural disasters in Germany like large-scale flood events. In the context of the research within the Center for Disaster Management and Risk Reduction Technology (CEDIM) i, the forensic analysis of flood disasters in Germany is being enhanced with the use of real-time components. The interdependence of the flood, technical systems and infrastructures, as well as social structures, is analysed in real-time. This will provide important disaster management information both during the extreme weather event and for subsequent recovery plans.

It is not only the damage caused by floods that has increased, prolonged dry periods and droughts have caused losses in agriculture and forestry in Germany and Europe amounting to billions of euros in the last 10 years. Water shortages, crop yield losses and severe forest fires have had a strong impact on the regions' ecosystems and economies.

Rising temperatures and a higher variability of precipitation cause losses in agriculture and forestry in Germany and Europe amounting to billions of euros. © gkuna, iStock.com

The highest temperatures of the last 500 years were recorded in Europe in the summer months of 2003, resulting in one of the most severe droughts in history in Central Europe. The losses in agriculture recorded in Germany alone amounted to over 1.5 billion.

In order to be able to react better in the future to droughts and water shortages, researchers from UFZ are using the mesoscale hydrological model (mHM) to create a high-resolution soil moisture map for Germany. mHM models hydrological processes and their interactions, taking into account the growth phase of the plants. The model calculates a soil moisture index, which shows whether or not a particular location is affected by drought. The model can be used to examine past and present droughts more closely with regard to their causes, their process and their impact. With the existing data the scientists provide a platform: the »drought monitor«, which is updated daily and is accessible to both the general public and stakeholders. With the further development of mHM, in future it will be possible to forecast droughts and to develop the necessary adaptation strategies, which can then be implemented in agriculture, for example.

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CEDIM (Center for Disaster Management and Risk Reduction Technology)

CEDIM is an interdisciplinary research centre of GFZ and KIT in the field of disaster management. Disasters are of particularly importance at CEDIM, along with the factors that caused them and their impact on nature and the human population. Research focuses on natural hazards, such as floods, droughts, storms, hail and earthquakes. Researchers from the fields of natural sciences, social sciences and engineering work together closely to address these challenges.

http://www.irdrinternational.org
http://www.cedim.de
http://www.ufz.de/mhm
http://www.ufz.de/droughtmonitor

© André Künzelmann, UFZ

2 Urban water resources management (UWRM)

Urbanisation is advancing rapidly across the world, increasing the pressure on the quality and quantity of the affected water resources.

More than 50 percent of the world's population currently lives in cities and this number is constantly rising. At the same time, medium-sized cities in the less developed regions of Europe are shrinking and their populations are aging, which poses challenges for the infrastructures and for water quality security. Urban regions take up water resources and couple substances, energy and water fluxes, which in turn causes water and environmental pollution through emissions. Due to the wide range of different substances and their various entry paths, plus their dynamics and feedback effects the entire system is very complex.

In order to gain a better understanding of the interaction between natural and urban waters, researchers at the Center for Advanced Water Research (CAWR) i have built up a long-term urban observatory covering the urban area of Dresden. The urban observatory analyses the turnover and transport processes of ecologically relevant wastewater and of rainwater compounds in urban drainage systems and watercourses. Researchers are also studying the effects that our ageing society has on the composition of the contaminants in wastewater in urban areas. An increased volume of medical residues entering the sewerage system, which ultimately flow, treated or untreated, into natural waters and therefore into our drinking water. This could pose a threat of unknown magnitude to the human population and to ecosystems through accumulation and long-term effects. Waste water management experts, biologists and hydrologists are working together in the urban observatory to investigate the dissemination and reproduction of antibiotic-resistant microorganisms which are deposited in the sewage sediments and in the biofilm formed along the side of the pipes of the sewerage system. The interrelationship between the quality and quantity of water resources also plays an important role in the research.

TU Dresden researchers taking samples from Dresden's sewerage system.
© Jürgen Loesel

In order to develop a holistic, integrated approach for problems of this kind in water resource management, researchers have to look beyond the boundaries of their field and work together with experts in engineering, the natural and social sciences, and with partners from the business sector and politics.

In the past few years, researchers from the UWRM research platform have accumulated extensive experience in this field by working on joint national and international projects. In the Western Bug catchment in the Ukraine, UFZ and TU Dresden researchers are working with the Dresden waste water treatment service and other local partners from the fields of politics, science and the water sector, as part of the International Water Research Alliance for Saxony (IWAS). The goal of the project was to investigate how an acceptable level of water quality can be achieved by identifying the investments urgently needed in the water sector and putting the appropriate incentive systems in place. Researchers from a wide range of disciplines gathered the necessary systems knowledge on the one hand and, on the other, developed an internationally used, web-based capacity development tool in the form of the interactive e-learning platform called »IWRM Education«. This is an integrated water resources management tool used as an advanced training platform for various target groups, from universities to public administration and decision-makers.

Researchers analyse the water quality in the Western Bug catchment in the Ukraine.
© Catalin Stephan, TU Dresden

In the field of adapted water supply and wastewater technologies that are being used in increasingly denser urban spaces, KIT researchers are developing less space-consuming processing technologies for the treatment of domestic and industrial wastewater. Researchers are testing the use of particulate biofilm aggregates to treat municipal wastewater. New processes to eliminate nitrogen are also being investigated, such as deammonification. The large-scale application of the process is currently being tested as it is very attractive from an economic point of view (no additional source of carbon is required, savings in aeration energy, less sewage sludge). Another objective is to design the processes involved in the treatment of wastewater energy self-sufficient, and even supply energy in the form of heating and electricity.

Deammonification reactor for treatment of process water in the main wastewater treatment plant in Ingolstadt. © N. Wagner, KIT

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CAWR (Center for Advanced Water Research)

CAWR is a strategic cooperation of the UFZ and the TU Dresden and pools the water-related expertise of both institutions. More than 500 scientists are conducting joint research in the field »Integrated Water Resources Management in the context of global change«. As a joint centre between a university and a non-university research institute with a focus on inter- and transdisciplinary water research, CAWR pursues national and international research, as well as education and training, and the transfer of knowledge.

http://www.cawr.de
http://www.iwas-initiative.de
http://www.iwrm-education.de

© Thomas Wöhling, University of Tübingen

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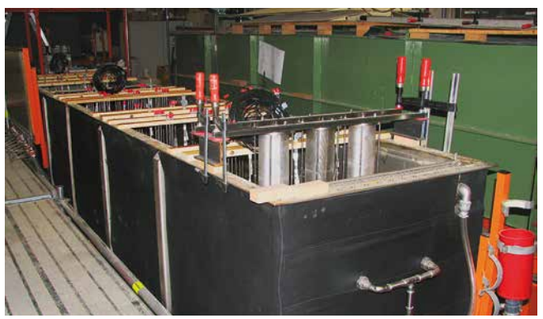
Integrated analysis of solute fluxes and processes in regional water cycles (SolFlux)

Climate change, changes in land use and the rising number and volume of chemical substances emitted into the environment significantly alter the matter fluxes and turnovers of substances in the atmosphere, in the ground and in waters, as well as in the biosphere.

One of the key impacts on the quality of water is the use of agricultural chemicals on land used for agricultural purposes, which are then transported through the ground and into the unsaturated zone, the groundwater and the surface water. Water is a carrier and solvent of many substances, about whose interactions, degradation products and long-term behaviour in the biogeosphere is scarcely understood. While the processes are partly comprehended in a laboratory, the question as to what happens to the wide range of substances on the larger scale relevant to water management remains largely unanswered. Furthermore, climate changes and urbanisation are also altering the entry paths and mechanisms.

The Helmholtz WasserZentrum München (HWZM), which is an alliance of researchers from the HMGU and TU München, and from the universities in Bayreuth and Tübingen, are investigating the effects of nutrients and pollutants flashing in the ecosystem and the associated processes caused by extreme rainfall events. As field research of pollutants entering the ecosystem and the associated processes is difficult to conduct and to control, HWZM researchers are analysing how pulses of pollutants enter and decompose in an »indoor aquifer«, a body of groundwater in a laboratory designed to replicate natural conditions.

The objective is to understand the hydrological, geochemical and ecological processes that control the degradation of pulsed pollutant inputs, using isotope chemical and molecular biological methods in high spatial and temporal resolution. The main focus of the research is on one of the most widespread pollutants found in groundwater: toluene. Aromatic hydrocarbons, such as toluene, pose a threat to water quality, are harmful to human health and adversely affect reproduction.



Inputs of harmful substances and their degradation speeds in groundwater are being analysed by researchers in the artificial indoor aquifer at the Helmholtz WasserZentrum München (HWZM). © Tillmann Lüders, HMGU

The quantity and concentration of emerging compounds in our waters, such as pharmaceuticals, pesticides and fragrances, has increased since the 1990s. The long-term effects of these emerging compounds and how they may impact human health and the environment has yet to be researched sufficiently. Residues of »old« inputs of persistent pollutants, such as pesticides used in the 1990s (e.g. atrazine) or the predecessors of modern flame retardants (PCBs – polychlorinated biphenyls) can still be found in our water and soils today. The WESS research cluster (Water & Earth Systems Science), which comprises the UFZ and universities in Tübingen, Stuttgart and Hohenheim and is collaborating with the HWZM, considers the environmental system as a natural »reactor«. In the Neckar and Bode catchments, researchers are examining the relevant processes that are important for the transport, retention and degradation of nutrients, pollutants and trace substances on a regional scale. In order to determine the degradation potential of emerging compounds in surface waters, researchers from the WESS cluster have developed a special sampling method (»Lagrangian Sampling«), which can be used to track and analyse defined water units at consecutive river sections. This method makes it possible to assess the degradation potential of different substances in the water. This approach can be used to detect that certain substances, such as the epilepsy drug carbamazepine or chlorinated flame retardants, are only degraded in rivers to a certain extent and therefore may accumulate in river water.

Researchers from the WESS research cluster study the exchange processes and transposition rates of solutes in the hyporheic zone using hydrological tracer substances in the Bode catchment. © Hermann Rügner, University of Tübingen

Research into the degradation potential of different substances is closely connected to the study of the exchange of substances between surface water and groundwater. In order to more closely examine the exchange processes and turnover rates of the dissolved substances in this transition region, the hyporheic zone, the water fluxes between river and groundwater were determined using specific tracer substances (»reactive tracers«). The results of the studies show that important transposition processes take place in the hyporheic zone and provide information on the retention and degradation of a wide range of trace substances in the water cycle.

The capillary fringe is another highly active area for the (bio)chemical degradation of organic substances in soils. Researchers from the KIT, UFZ, universities in Tübingen and Stuttgart, and other research institutes are investigating the behaviour of substances and their biodegradability in saturated and unsaturated soils within the DFG research group 831 »Dynamic Capillary Fringes«.

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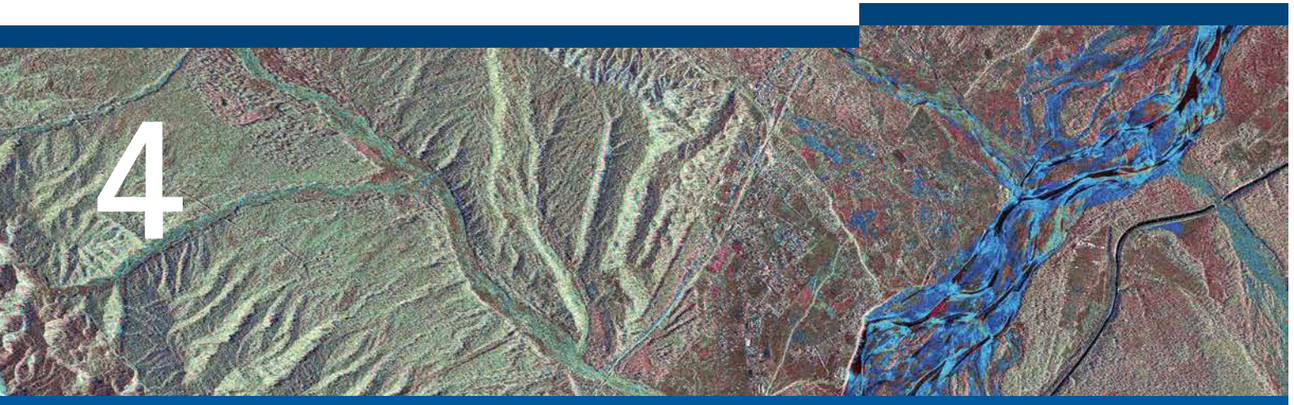
SOLUTIONS (SOLUTIONS for present and future emerging pollutants in land and water resources management)

In the EU project SOLUTIONS, researchers from UFZ are working with a large number of European partners to develop tools and models, in order to assess the wide variety of chemicals present in four European river catchments and the risk they pose to humans and the environment. The focus is on identifying dangerous pollutants and developing solutions to reduce the risks. The research covers both: the pollutants that entered our water in the past and are still having an impact on its quality as well as the »emerging« pollutants that are now being inputted by the agriculture, medicine, cosmetics and manufacturing industries. Future scenarios help to develop approaches for management strategies and the control of the input of pollutants through regulation.

As part of the EU project SOLUTIONS, researchers take and analyse samples of organisms, fish, mussels, biofilm, phytoplankton and aquatic plants while on a research expedition on the Danube. © André Künzelmann, UFZ

http://www.wasserzentrum-muenchen.de
http://www.wess.info
http://www.solutions-project.eu



© DLR

4 Integrated observation of the terrestrial water cycle

The changes to the environmental system that society will have to face in the coming decades are determined by the interactions between land, water, atmosphere and human activity. Researchers from the Helmholtz Water Network are developing methods to be able to identify these effectively and forecast them more precisely.

Climate change affects precipitation, which in turn affects the run-off in rivers. Varying amounts of water and their dynamics can change ecological systems and this can affect water quality. Long-term, system-oriented research and monitoring programmes are important to understand such changes and their interactions. A better understanding of the environmental system can help to protect the aquatic ecosystem and to develop sustainable water management strategies. Long-term, cross-compartment (soil, water, vegetation, atmosphere) and cross-scale observations are essential to identify long-term processes and feedback mechanisms. The observation data is transferred to corresponding models. In order to get maximum use from the data recorded and to achieve a better understanding of the system as a result and to be able to forecast future changes to the environmental system, the recording of data and the development of models must be closely coordinated with each other. It is therefore necessary to develop new and improve existing concepts and technologies for collecting and analysing above-ground and underground processes in combination with the development of models.

The TERENO pre-alpine hydrometeorological test site in the Ammergau Alps: measuring energy flow using the eddy covariance technique. © Harald Kunstmann, KIT

In order to be able to identify and record the most relevant processes, improved measuring concepts and technologies are required. The TERENO observatories (Terrestrial Environmental Observatories), which have been operating since 2008, and other Helmholtz infrastructures (see Chapter V – Infrastructures), form an important basis of research for the Helmholtz Water Network. Furthermore, to identify spatial and temporal change processes, variables such as water levels, soil moisture or the condition of vegetation, have to be comprehensively recorded in the highest possible spatial and temporal resolution.

The Helmholtz Alliance »Remote Sensing and Earth System Dynamics«, which comprises the Helmholtz Centres DLR, UFZ, FZJ, GFZ, HMGU, KIT, AWI and GEOMAR, as well as the TU München and the University of Potsdam, and other national and international partners, offers new opportunities in this context for the Helmholtz Water Network. Researchers from the centres are working together in developing innovative satellite products and methods of using them, which can record the dynamic processes of the hydrosphere in much greater quality than previously and therefore contribute to generating new knowledge for water research.

Researchers calibrate cosmic ray sensors in the Eifel-Rur observatory (TERENO) to measure the soil moisture content. © Heye Bogena, FZJ

In order to validate remote sensing data with ground data (»ground truth«), researchers from the KIT, GFZ, UFZ, FZJ, HZG, DLR, HMGU, AWI and GEOMAR Helmholtz Centres are conducting research in various regions of the world within the ACROSS research infrastructure (Advanced Remote Sensing Validation and Test Facilties). Information about soil moisture is recorded using sensors in the ground (soil moisture networks) and non-invasively via cosmic ray neutron probes, whereby the strength of the ray becomes weaker in soil with high moisture. Soil moisture is of key importance in soil-plant-atmosphere systems, which are being researched in cooperation with TERENO at the Collaborative Research Centre Transregio 32 by researchers from universities in Bonn, Cologne and Aachen, and Forschungszentrum Jülich.

Geophysical and soil moisture measurements in the Attert basin in Luxembourg as part of the DFG research group CAOS. © Nicolas Allroggen, Universität Potsdam

The DFG research group CAOS (Catchments as Organised Systems) is examining how the organisation of landscapes controls the interaction between spatially distributed hydrological processes and integral runoff. Researchers from KIT, GFZ, UFZ, the University of Potsdam and other research institutes are combining monitoring and exploration technology from the fields of soil physics, soil ecology, geophysics, remote sensing and (tracer) hydrology to take multi-scale measurements in the Attert catchment in Luxembourg. The results are being used to develop a new process-based model system for mesoscale catchments, for which the Helmholtz infrastructures are an important basis.

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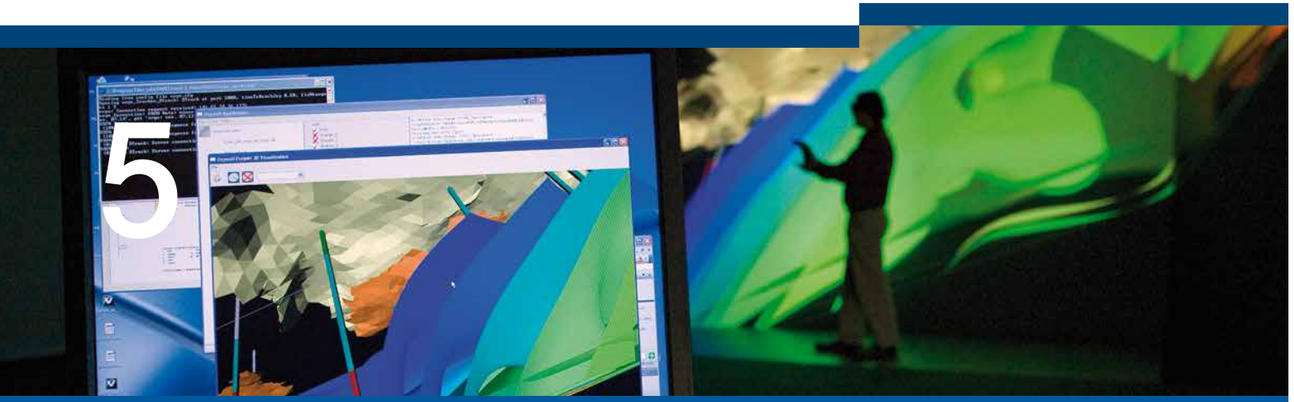
COSYNA (Coastal Observing System for Northern and Arctic Seas)

COSYNA

COSYNA is the HZG's coastal observation system. It records the environmental condition of the North Sea using extensive monitoring systems. Observation stations installed in the coastal region or mobile, automated stations, as well as satellite measurements, are constantly providing data for models. Within the Helmholtz Water Network, COSYNA is used to gain a better understanding of the impact that terrestrial water and solute fluxes have on the coastal regions. Pesticides and fertilisers used in agriculture, for example, have a strong impact on ecosystems. A collaborative »twinning« project with two PhD students each from the UFZ and HZG was initiated to more closely examine the interactions between land and coast.

http://www.tereno.net
http://www.hgf-eda.de
http://www.caos-project.de
http://www.cosyna.de



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5 Integrated modelling and model benchmarking

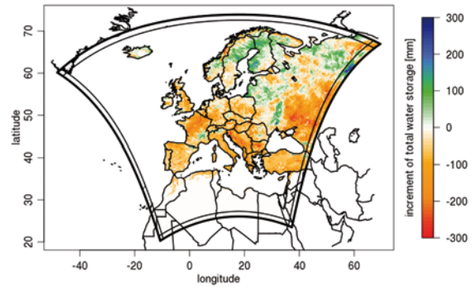
A broad spectrum of several models describes specific hydrological processes, solute fluxes and storage systems on different scales, compartments and with varying complexities. In order to understand the extensive interconnections within the environmental system, it is necessary to further develop the »one problem, one model« method.

Due to the dynamic changes to the environmental system and our society, hydrological modelling now faces a huge number of new unresolved challenges. In order to tackle these challenges, adequate and reliable models that are capable of simulating the interacting systems within the water cycle are required for different spatial and temporal scales. Therefore flexible model structures are essential, in order to be able to integrate the relevant processes into the model for all compartments (e. g. underground, land surface, atmosphere). Integrated system models are capable of reproducing the complex interactions between the different environmental compartments and processes. To ensure a realistic simulation of environmental processes, the models and the data recorded in experiments and long-term observations have to be compared and closely coordinated with each other.

Three groups from the Helmholtz Water Network are taking three different approaches for analysing and modelling the complex interactions between the hydrological processes on the land's surface and those in the atmosphere. The researchers share their thoughts and experiences to compare the three different approaches. The basis of the research at UFZ is the mesoscale hydrological model (mHM), which models different processes, such as evaporation, soil moisture, discharge and groundwater runoff, as well as their interactions. The stand-out feature of mHM is its »Multiscale Parameter Regionalisation« approach: Regional properties, such as soil structures, vegetation and geological properties, are linked to model parameters using transfer functions, which are transferred to coarse scales using specific scaling rules. In this way a consistent and robust model formulation across different scales is ensured. The mHM model can therefore be used for catchments with scarce or no hydrological data. These model properties are very important as a basis for deriving management decisions for hydrological extreme events, such as floods or droughts, particularly if there are few or no high-resolution measurements.

In the future UFZ researchers will couple the Multiscale Parameter Regionalisation approach with other models and further develop it for other models. The groundwater component of mHM is currently being replaced by a more complex hydrogeological model, in order to be able to provide answers to groundwater management issues in the future. Furthermore, researchers are working on implementing the approach in a mesoscale solute transportation model, a mesoscale isotopic model and an energy transportation model.

Researchers from the Geoverbund ABC / J (University of Bonn, University of Cologne, RWTH Aachen University, FZJ) have pooled their competences at the HPSC-TerrSys centre of excellence (Centre for High-Performance Scientific Computing in Terrestrial Systems) and are using the coupled models ParFlow-CLM + COSMO to investigate how models can be used to adequately calculate and simulate the hydrological interactions between atmosphere and land surface and the effects on exchange processes between groundwater and surface water. In order to facilitate an integrated study of water resources on a continental scale, researchers are implementing coupled hydrological models and land-surface models to complete water and energy cycles across the pan-European continent. The simulation results help, by taking advantage of new possibilities in the multiscale assimilation of remote sensing data i, to gain a better understanding of the interactions between water, energy and matter cycles from the underground up into the atmosphere.



Changes in integrated terrestrial water storage in Europe from 2002–2004. Significant simulated changes can be seen primarily in Central Europe due to the heatwave in 2003. © Stefan Kollet, FZJ

KIT researchers are using the high-resolution regional climate model ECHAM-MM5, coupled with the spatially distributed water balance model WaSiM, as a basis for their studies. In addition to assessing the effects of global climate change on water availability, the full coupled model systems also allow researchers to gain a better understanding of the cross-scale and cross-compartment effects that large-scale changes to land use have on the water balance.

Benchmarking tests enable the comparison of different types of models created by model developers from all over the world, in order to test and improve the functionality and efficiency of the models and, if required, coupling them with each other. As part of the model comparison initiative HM Intercomp (Hydrologic Model InterComparison), a number of international research groups are putting this idea into practice. The Helmholtz Water Network is also involved in the initiative (UFZ, FZJ and the University of Cologne). The researchers are analysing the efficiency of their models with regard to specific issues and different scales. Researchers use the benchmarking projects to test the results produced by their models, which are based on various different approaches, in simple reference cases. The comparison of results also enables the identification of the optimal model structures under specific conditions and helps to improve the forecasting quality of the model systems. The inclusion of uncertainties, which can be integrated into the model like climate projections using input variables, and also uncertainties from the model structures, are also taken into account by analysing the model results.

In order to gain a better understanding of the processes and interactions within the water cycle, model results were simulated in the VISLab visualisation centre.
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DFG research group 2131 Data Assimilation for Improved Characterization of Fluxes across Compartmental Interfaces

The DFG research group 2131 is examining how complex, dynamic simulation models for water and energy flows can be combined with the development and testing of integrated data assimilation techniques for the groundwater compartment through to the atmosphere. Researchers from universities in Bonn and Tübingen, from FZJ, UFZ and KIT and from other research institutes have been using remote sensing data since 2013 to develop the robust models that can show the interactions between land surface and atmosphere accurately and to optimise forecasting for energy and water fluxes. The basis for the physical-mathematical model is monitoring and observation data that is constantly being collected in the Neckar catchment by satellites, rain radars and other instruments.

http://www.ufz.de/mhm
http://www.hpsc-terrsys.de
https://svn.ufz.de/hydrobench
http://www2.meteo.uni-bonn.de/for2131/doku.php

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© ZAIAG

Complex water management in the Circum-Mediterranean region

One of the regions most strongly affected by global change worldwide is the Circum-Mediterranean region. An extremely rapidly growing population is leading to an increased demand for water, energy and food.

Climate models predict a heavy decrease in rainfall and a significant increase in air temperatures. This will severely intensify the current water crisis in Mediterranean countries.

In order to tackle the challenges faced in this particularly badly affected region, researchers from the Helmholtz Water Network are teaming up to strengthen their network of expertise in the research field of water scarcity problems. UFZ, KIT and GFZ researchers, plus partners from Israel, Jordan and the Palestinian Territories, are working together in the Helmholtz Virtual Institute DESERVE (Dead Sea Research Venue) in the fields of water, climate and environmental risks.

The intensive use of above and below-ground water resources in the Dead Sea region has brought along many changes: Falling groundwater levels, the pollution of the remaining water resources with pollutants from industrial and domestic wastewater, salinization and the Dead Sea's dramatic drop in water level are exerting pressure on the ecosystem and the growing population. To record all the relevant data surrounding water cycle variables in the catchment areas of the River Jordan and the Dead Sea, a cross-border, long-term monitoring network is currently being set up within DESERVE. It is recording meteorological parameters, such as air temperature, air humidity, rainfall, wind and solar radiation, and collects data from discharge and groundwater gauging stations. Temporary measurements and intensive field campaigns are embedded into this long-term monitoring network to gain a better understanding of the processes in the water cycle, as well as their complexity and variability. The combined approach of taking measurements over a long period of time and analysing processes is the basis for a long-term assessment of water availability in the Dead Sea region.

The foundations for collaborative research work in the semi-arid region were already laid in 2006 by researchers from KIT and UFZ, and other partners from universities, research institutes, industry and other relevant institutions for decision-making in Germany and in the Dead Sea's three adjacent countries: Israel, Jordan and the Palestinian Territories. As part of the BMBF-funded project SMART (Sustainable Management of Available Water Resources with Innovative Technologies), adapted water management strategies have been developed and are still being implemented in the region today, while taking into account legal, political and socio-economic factors, in order to sustainably increase the volume of water available in the Lower Jordan Valley, while at the same time improving water quality.

Meteorological measuring tower in the west of Madaba (Jordan). The Dead Sea is in the background. Researchers have been measuring wind speed, wind direction, air temperature, relative humidity, short-wave and long-wave net solar radiation, air pressure, rainfall, soil heat flux and soil moisture since March 2014.
© Friederike Lott, KIT

As every drop of water counts, the reuse of treated wastewater can significantly contribute to relieving the strain on the dwindling groundwater resources. A research and test facility to analyse treated wastewater and flood water and to work on capacity development measures was set up in a municipality close to the Jordanian capital Amman. The pilot facility enables the examination of the quality of the wastewater after it has been through the treatment stages the development of the optimal filter systems for treated wastewater, and the analysis of the stability of the treatment systems in the desert-like conditions of the region. Cost-benefit analyses are also conducted and provide a robust basis for decision-makers. With the involvement of development banks in the third phase of the project, decentralised wastewater treatment plants will be installed for larger areas and provide additional water resources for reuse. In order to coordinate approaches from science, water policy and implementation strategies in the region in the long term, the National Implementation Committee for Effective Decentralized Wastewater Management in Jordan (NICE) i was set up in 2012.

Research and demonstration facility in Fuheis (Jordan) to analyse treated wastewater and flood water, and to work on capacity development measures.
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NICE (National Implementation Committee for Effective Decentralized Wastewater Management in Jordan)

The SMART project's NICE implementation office at the Jordanian Ministry of Water and Irrigation in Amman supports the development of infrastructure for decentralised wastewater management. In collaboration with Jordanian stakeholders from eight different ministries and institutions, implementation strategies are being developed that take into account the interests of all of the region's important decision-making bodies (ministries, NGOs, universities, local authorities). Stakeholders and networks, such as the German Water Partnership (GWP), play an active role in creating the optimal conditions for establishing a decentralised wastewater management system and ensuring its long-term development with the help of capacity development measures.

http://www.deserve-vi.net
http://www.iwrm-smart2.org
http://www.nice-jordan.org
http://www.germanwaterpartnership.de

IV. Shaping the future: a vision for the international water-related research

Prof. Georg Teutsch is Scientific Director at the Helmholtz Centre for Environmental Research – UFZ, Vice President and research coordinator for the field of »Earth and Environment« at the Helmholtz Association.

Prof. Alexander Zehnder is former Chairman of the Council of the Swiss Federal Institute of Technology (ETH) in Zurich. Today he is Director of the Water Research Institute of the University of Alberta in Edmonton, Canada, as well as founder and director of Triple Z GmbH.

An interview of Tilo Arnhold, UFZ

Which great challenges are going to be important in the future for research especially in the field of water on an international level?

Prof. Teutsch We have to differentiate between the Central European region with temperate climate, well-developed infrastructure and relatively regulated structures on the one hand, and regions with poor infrastructures on the other. Water quality is our main concern in Central Europe. In an international context, the problem of quality is joined by the problem of quantity. Water scarcity is a serious problem in many regions and it will significantly affect food security. It is not possible to supply a world population of more than nine billion with clean drinking water and sufficient food if we maintain current food practices.

Prof. Zehnder Another aspects we need to consider are extreme weather events. These are always connected to water – either too much or too little water. Climate change is intensifying the situation. Floods, storms and droughts are the consequences. The climate debate is also closely linked to water.

Does this very global topic offer opportunities to collaborate with other actors in the international water sector and to work together in tackling the world's water problems?

Prof. Teutsch We know very much about individual scientific issues, have a good understanding of processes and have developed excellent technology. But we are not as good at dealing with greater societal issues. Extreme weather events often reveal how difficult it is to forecast them. The complex issue of water poses a particularly large challenge in this respect. Let's take a flood as an example: This is directly related to soil properties, weather forecasting, monitoring, land use, heavy metals and much more. A network can bring together the relevant actors. For a long time in Europe our research work has focussed around the European region. The German water research system, for example, is well-financed and has excellent researchers, but there has always been a lack of incentives for researchers to take an interest in major issues outside Europe that require a complex approach. Nothing will happen without the right incentives. That's why we need initiatives like this.

Prof. Zehnder There is a simple answer to the question of where water problems are being dealt with efficiently. It is in countries with good research systems, where engineers and scientists have been able to work together successfully. These are regions with policies capable of managing water correctly. There isn't a single well-developed country that is not able to manage its own water resources; on the other hand there isn't a single poorly developed country that manages water well.

So there is an opportunity here to export to the rest of the world?

Prof. Zehnder Technology and expertise can certainly be exported. But the profit margins are very small; everyone in the water sector is fighting for survival.

Prof. Teutsch If you have a look at the market, including the environmental technology sector, it's all about water supply and disposal, distribution systems, energy, etc. That's where the sector is developed. But I think the really successful export could be the methods developed as part of the EU Water Framework Directive. A transfer of technology would be unpatentable of course. But there is huge scope for a transfer of knowledge from these methods that is highly sought-after all over the world.

What expectations do you have of the Helmholtz Water Network?

Prof. Zehnder The idea was to provide the researchers with the opportunity to work together and benefit from their joint expertise. I think the past years have shown how great the potential is. The results have improved by several orders of magnitude since the network was set up. It is scientifically more interesting and relevant to work on projects that you have devised and developed together. That is the strength of the network, of course, and it is also the strength of the Helmholtz Association, that it can support and initiate such projects and tackle national issues.

Prof. Teutsch It's possible to say that the Helmholtz Water Network was the starting point – not least due to the support of Prof. Zehnder as member of the senate. But we knew from the very start that we didn't want to found THE Helmholtz Water Institute, which would control the system centrally. But rather to build up a research platform that needs to be supported by the community. The foundations are in place, but now it's time for it to be tested in practice, and I'm optimistic about that.

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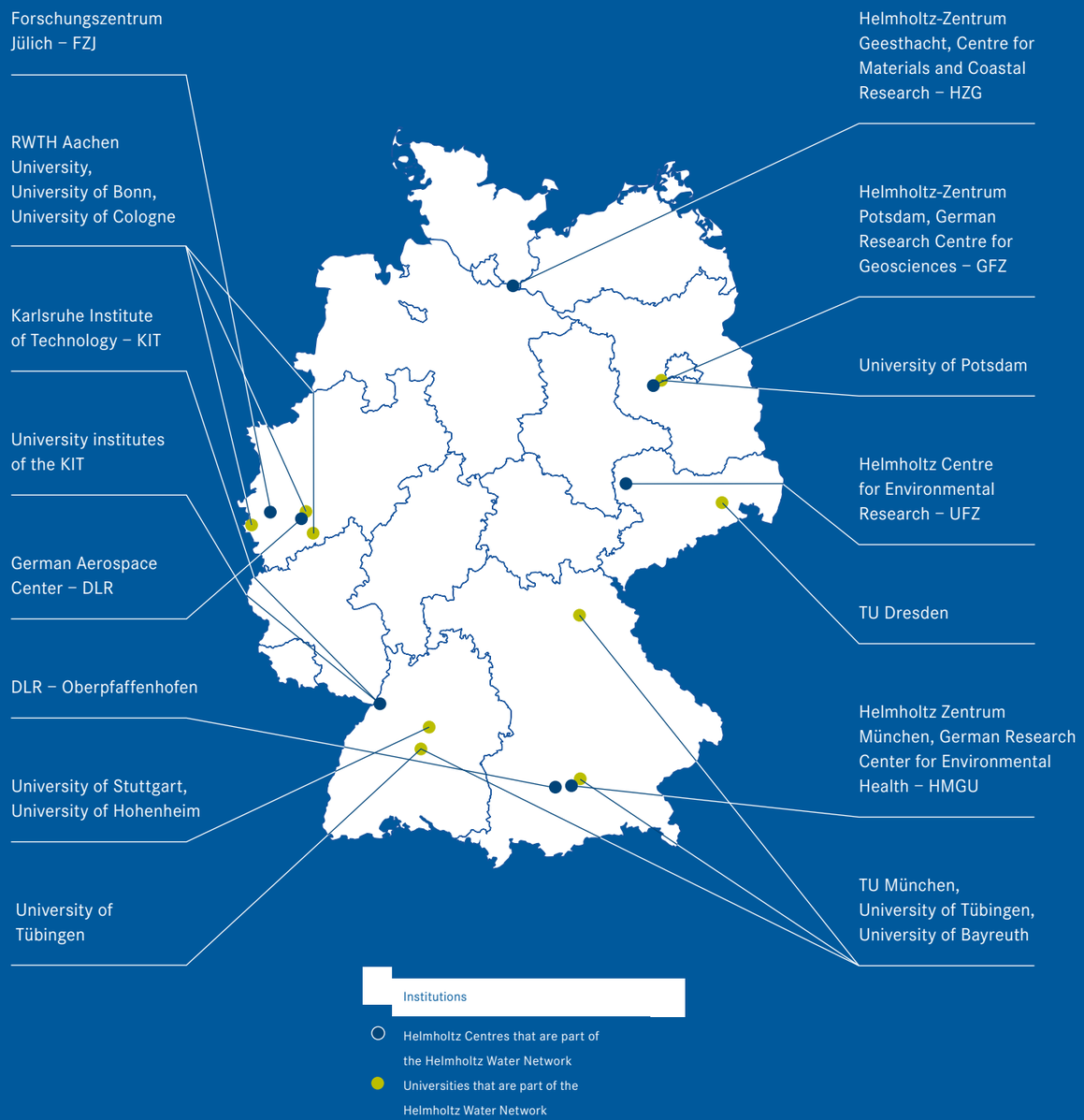
V. Institutional capacities of the participating centres



German Aerospace Center – DLR

- **Focal points within the Helmholtz Water Network:** Development of innovative satellite products
- **Competences in the water sector:** Synthetic aperture radar (SAR), modelling and inversion of soil moisture from SAR data, aircraft-mounted and satellite SAR systems

Forschungszentrum Jülich – FZJ

- **Focal points within the Helmholtz Water Network:** Soil-water modelling
- **Competences in the water sector:** Key technologies for energy and environmental research, bioeconomy research, modelling of complex systems, environmental research across different scales
- **University key partners within the Helmholtz Water Network:** RWTH Aachen University, University of Cologne, University of Bonn

Helmholtz Zentrum München, German Research Center for Environmental Health – HMGU

- **Focal points within the Helmholtz Water Network:** Groundwater and water quality
- **Competences in the water sector:** Groundwater resources, hydrological and geochemical processes, environmental microbiology, groundwater ecology, ecosystem services, sustainable use of resources, environmental and health protection, quality of drinking water
- **Key university partners within the Helmholtz Water Network:** University of Tübingen, University of Bayreuth, TU München

Helmholtz Zentrum Geesthacht, Centre for Materials and Coastal Research – HZG

- **Focal points within the Helmholtz Water Network:** Matter Fluxes and cycles of land and coastal waters
- **Competences in the water sector:** In situ monitoring systems, behaviour and effects of chemicals at the transitional zone between land and coastal waters, eutrophication of coastal waters, modelling of distribution pathways

Helmholtz Centre Potsdam, German Research Centre for Geosciences – GFZ

- **Focal points within the Helmholtz Water Network:** Monitoring, hydrological processes and extreme hydrological events
- **Competences in the water sector:** Multiscale observation methods, hydrological processes from the land surface to deep underground, analysis of extreme hydrological events, flooding risks and vulnerability assessments in the light of global change.
- **Key university partners within the Helmholtz Water Network:** University of Potsdam

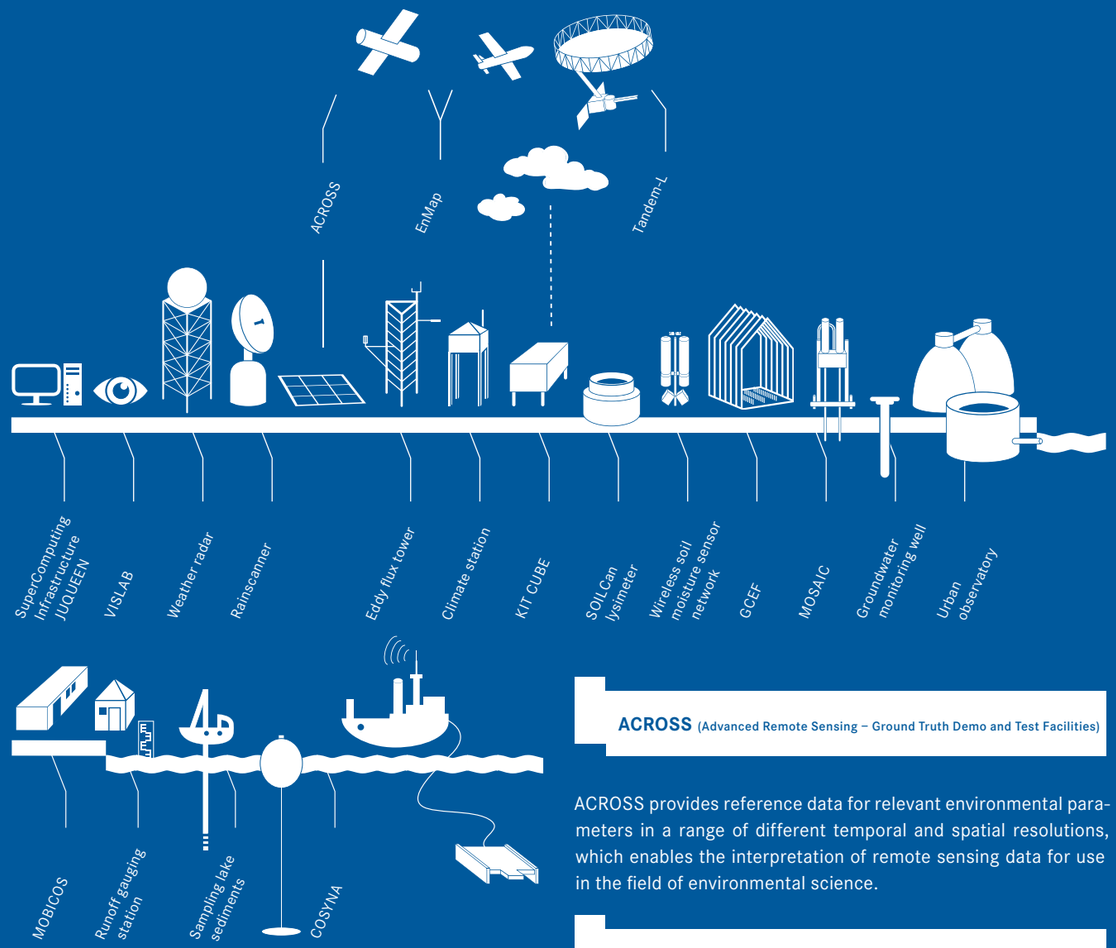
Helmholtz Centre for Environmental Research – UFZ

- **Focal points within the Helmholtz Water Network:** Sustainable management of water resources, model development and water scarcity
- **Competences in the water sector:** Investigation of the water cycle, relationships between humans and the environment, ecology, water quality, soil and land use, biodiversity, impact of climate change and possible adaptation strategies, environmental technology and biotechnology, behaviour of chemicals in the environment and their impact on human health, modelling and social science issues
- **Key university partners within the Helmholtz Water Network:** TU Dresden, University of Tübingen, University of Stuttgart, University of Hohenheim

Karlsruhe Institute of Technology – KIT

- **Focal points within the Helmholtz Water Network:** Technical water systems, hydrological processes, atmosphere and climate
- **Competences in the water sector:** Water technology (water treatment), research into processes of water and material dynamics in natural systems, atmospheric water cycle, model development and modelling (experimental, numeric, in situ), water resource management and measures, water technology (water treatment, disposal and treatment of wastewater)
- **Key university partners within the Helmholtz Water Network:** University institutes of the KIT

Infrastructures



The Helmholtz infrastructures are an important component of the research within the Helmholtz Water Network. The infrastructures are used to collect data on and to observe and analyse processes within the water cycle and the terrestrial system in laboratories, out in the environment and from space. The recorded data is used for modelling the current and future state of the environmental system.

ACROSS (Advanced Remote Sensing – Ground Truth Demo and Test Facilities)

ACROSS provides reference data for relevant environmental parameters in a range of different temporal and spatial resolutions, which enables the interpretation of remote sensing data for use in the field of environmental science.

COSYNA (Coastal Observing System for Northern and Arctic Seas)

COSYNA is a long-term observatory and coastal observation system for the German part of the North Sea. The comprehensive monitoring systems help to observe and analyse the environmental conditions of the North Sea. A large number of observation stations installed in the coastal region and mobile automated stations, as well as satellites, also provide an ongoing supply of data for models.

EnMap (Environmental Mapping and Analysis Program)

EnMap will be the first German hyperspectral Earth observation mission in orbit. Quantitative surface parameters can be derived from the EnMAP spectral recordings to describe the condition of and changes to terrestrial and aquatic ecosystems.

GCEF (Global Change Experimental Facility)

GCEF is an outdoor test facility in Bad Lauchstädt, where climatic conditions expected in the future can be generated on large plots of land. The facility primarily simulates the increased temperatures and seasonal reduced rainfall (mostly in summer) for the region of central Germany.

JUQUEEN (Jülich Blue Gene / Q Supercomputing Platform)

JUQUEEN is part of the Supercomputing Center Jülich and currently the fastest high-performance computer in Europe. Capable of around six quadrillion floating point operations per second, the supercomputer can run highly complex models from the fields of climatology, neutron research, nanomaterials and neurology.

KITcube (Overall monitoring system for probing the atmosphere)

KITcube is an overall monitoring system for the experimental exploration of the atmosphere. Tools for the ground-based remote sensing of the atmosphere (radar and lidar) and devices for in situ measurements (e. g. turbulence, radiation) allow for the spatially and temporally complete capturing of all relevant processes and meteorological parameters in a cubic volume of atmosphere with a side length of 10 km.

MOBICOS (Mobile Aquatic Mesocosms)

MOBICOS are eight mobile containers stationed in or close to water, in which studies and experiments can be carried out in nature-like conditions in the Elbe and Bode catchments. This infrastructure is the interface between laboratory and field experiments.

MOSAIC (Model Driven Site Assessment, Information and Control)

MOSAIC is a platform for model-assisted geohydrological exploration of the area close to the surface using new, minimally invasive methods. The combined technologies used in MOSAIC enable a high-resolution exploration of complex underground structures.

Tandem-L

Tandem-L is a proposal for a highly innovative satellite mission for the global observation of dynamic processes on the Earth's surface. The satellites can supply urgently needed information on the biosphere, geosphere, cryosphere and hydrosphere to solve the most pressing scientific issues.

TERENO (Terrestrial Environmental Observatories)

TERENO is a network of observatories for the integrated observation of the Earth in especially climate-sensitive regions of Germany (north-eastern lowlands, Harz mountains / central lowlands, Eifel / the Lower Rhine valley, Bavarian Alps / Prealps). TERENO researchers are investigating global change's long-term impact at regional scale on terrestrial environmental systems and its social and economic consequences.

Dresden Urban Observatory

The urban observatory for long-term observations in the city area of Dresden examines the interactions between natural, artificial and urban waters. Researchers are analysing the turnover and transportation processes of ecologically relevant substances contained in wastewater and rainwater in urban drainage systems and watercourses.

VISLAB (Visualisierung der terrestrischen Umwelt)

VISLAB is a visualisation centre that enables the 3D visualisation of data obtained from measurements and numeric simulations. Geoscientific model results can then be visualized, which will improve dialogue between researchers and decision-makers.

Facts and figures

The Helmholtz Water Network is a strategic initiative of the Helmholtz Centres involved in water research and their key partner universities. It pools the competences from two water-related research fields (Earth and Environment, and Aeronautics, Space and Transport) and five research programmes, plus a Helmholtz Alliance (Remote Sensing and Earth System Dynamics) and a Helmholtz Virtual Institute (DESERVE). The Helmholtz Water Network also promotes collaborative work between universities and non-university institutions in thematic research platforms. By utilising the infrastructures available at the Helmholtz Association for the experimental examination and long-term monitoring of environmental processes, the Helmholtz Association is playing a key part in tackling global water problems with the Helmholtz Water Network.

Research fields involved in the Helmholtz Water Network in PoF III

- Earth and Environment
- Aeronautics, Space and Transport

Research programmes involved in the Helmholtz Water Network in PoF III

- Geosystem: The Changing Earth
- Marine, Coastal and Polar Systems
- Atmosphere and Climate
- Terrestrial Environment
- Space

The Helmholtz Alliance and Helmholtz Virtual Institute involved in the Helmholtz Water Network

- Remote Sensing and Earth System Dynamics
- DESERVE

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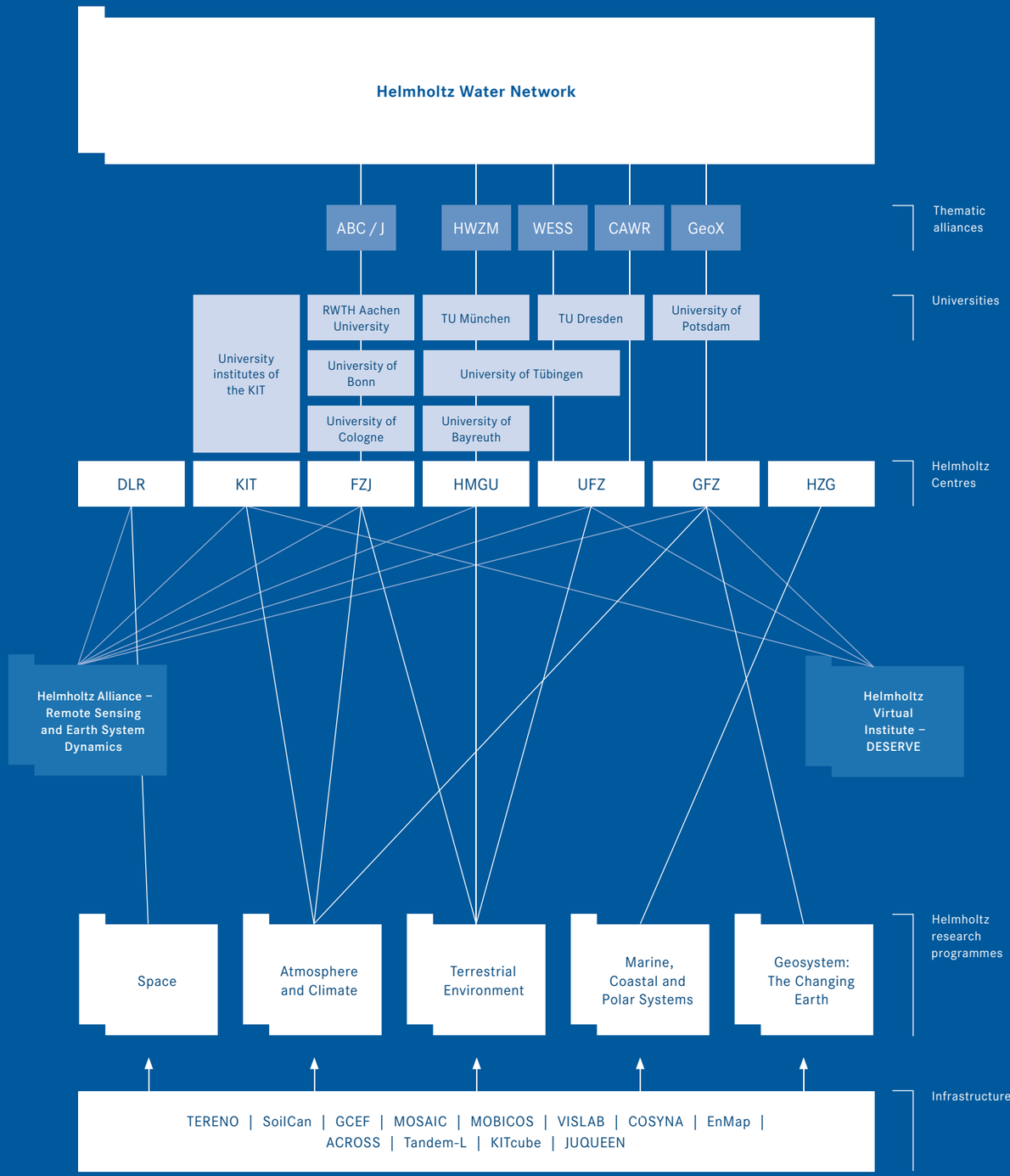

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