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Briefing

Water Safety and Security for People and the Environment

Research on a Key Resource of the 21st Century

Water security

Drought and heat stress, floods and heavy rainfall: Climate change is already having a significant impact on the water cycle. Both sudden water surplus and prolonged periods of scarcity, sometimes combined with heat waves, become more severe and less predictable. In countries of the Global South, it is already evident that this uncertain supply can hinder social and economic development. However, in the future, industrialized nations will also have to adjust to fluctuating water availability – and consequently the competing needs of people and nature, industry, and agriculture. Water is the key resource of the 21st century.

The breadth of our expertise on the subject of water is unique in the German scientific landscape, as our centers cover the entire water cycle with their research focuses – from the global terrestrial water cycle to the molecular level. Now, we are consolidating these competencies and resources in the initiative "Water safety and security for people and the environment in the 21st century." This initiative will develop strategies, systems, and technologies for improved water management.

The Key Resource for Nature, People, and Industry

Globally, water is increasingly becoming a crucial resource: it not only serves as drinking water but also irrigates fields and supplies factories, power plants, and green spaces. With the energy transition, demand for water will rise even further – for example, through the thermal use of water as a heat and cold storage medium or in hydrogen production. At the same time, climate change is significantly affecting water resources and leading to shortages, raising questions about which users should be prioritized: settlements? farmers? factories?

Additionally, enough water must remain within the environment to keep ecological systems intact. To sustainably supply both people and nature, water must not only be available in sufficient quantities but also in the required quality. In this regard, Germany has significant catching up to do: pollution of water bodies and groundwater with harmful substances remains too high. Moreover, our rivers and lakes are predominantly in moderate to bad ecological condition, leading to a disproportionately high loss of biodiversity.

Aerial view of the Rappbode reservoir system in the Harz region. The drinking water reservoir is part of the TERENO project in the Bode catchment area (Image: André Künzelmann/UFZ).

National and International Efforts

In light of increasingly scarce water resources, the German Federal Cabinet adopted the first-ever National Water Strategy in March 2023. This strategy identifies ten key areas where significant research is currently needed. The Helmholtz research campaign "Water Security for People and the Environment" addresses seven of these:

- Protection and restoration of the natural water cycle
- Promotion of climate-adapted, water-conserving land use
- Minimization of pollutant inputs into water bodies
- Climate-resilient expansion of water infrastructure
- Integration of water, energy, and material cycles
- Enhanced protection of oceans from land-based pollution
- Sustainable safeguarding of global water resources

The urgency to protect, conserve and substainably manage water resources has also been recognized by the European Parliament and the United Nations. The recently published study "Closing the Loops" by the European Parliamentary Research Service (EPRS) highlights the need to close water cycles and use water resources more sustainably and in a more environmentally friendly way. Additionally, the United Nations Sustainable Development Goal (SDG) 6 emphasizes the importance of universal access to clean water and basic sanitation.

Image: Phil Dera/Helmholtz

"Water affects nearly every aspect of our lives – from our health and reliable supply to the question of how and where we will live in the future. Research in this area means taking responsibility for the future: for stable ecosystems, a resilient economy, and a livable society. At Helmholtz, we combine interdisciplinary expertise, comprehensive data, and innovative technologies to address this complex issue in a holistic way."

Martin Keller
President of the Helmholtz Association

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What is Helmholtz's Contribution?

We develop solutions for improved water management while ensuring that this valuable resource can be used more sustainably in important areas of life and the economy. Our solutions can be applied not only in highly developed countries like Germany but also in Global South countries, where water supply shortages already play a significant role today. To ensure these solutions function optimally, however, we need to gain an even better understanding of the water cycle as a whole.

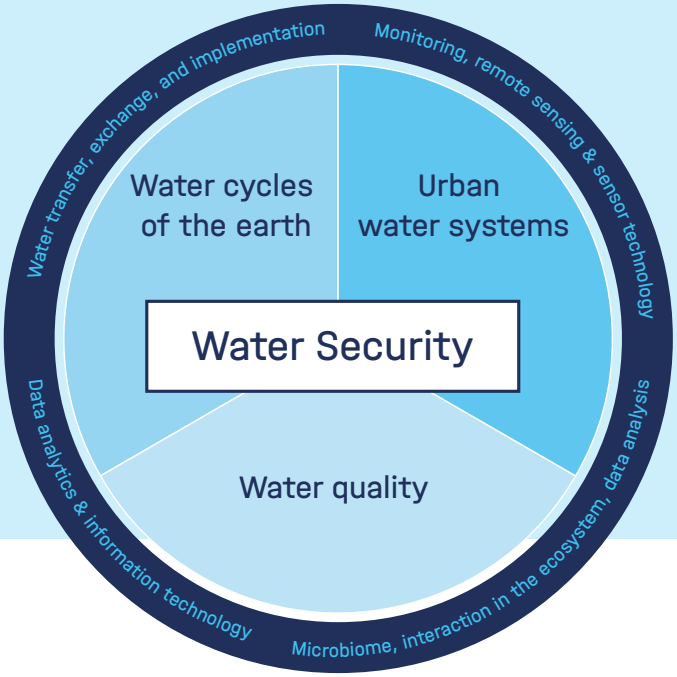
In various model regions, we therefore study both natural and stressed water cycles. With this knowledge, we develop intelligent information systems, management concepts, purification technologies, and early warning systems. We use numerous innovative research approaches for this, including novel digital simulations, networked monitoring, even via satellite, and AI-supported high-throughput methods, such as for water sample analysis.

Our research aims to significantly improve the ecological state of our rivers, lakes, and groundwater. To achieve this, we work closely with key stakeholders and maintain active dialogue with representatives from conservation, agriculture, industry, water supply, and urban development, as well as involving citizens through citizen science projects.

All these activities are united under the Helmholtz initiative "Water Security for People and the Environment in the 21st Century." In this initiative, we bring together the knowledge, data, and high-performance equipment of our centers – offering a unique nationwide expertise.

13 Helmholtz research centers are involved in the initiative:

- Deutsches Elektronen-Synchrotron (DESY)
- Helmholtz Center Potsdam - GFZ German Research Center for Geosciences
- German Aerospace Center (DLR)
- Forschungszentrum Jülich
- GEOMAR Helmholtz Center for Ocean Research Kiel
- Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
- Helmholtz Center for Infection Research (HZI)
- Helmholtz-Zentrum Hereon
- Helmholtz Center for Environmental Research (UFZ)
- Karlsruhe Institute of Technology (KIT)
- Max Delbrück Center (MDC)
- Helmholtz Munich
- Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research (AWI)



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Water Security for People and the Environment

Integrated Water Resources Management (IWRM) in Central Asia: Model Region Mongolia (Image: Andrē Künzelmann/UFZ).

We consolidate our research activities into three core topics and three cross-cutting themes. In the core topics, we focus on generating new scientific knowledge, while in the cross-cutting themes, we develop innovative research methods. In all core projects, we work closely with practical applications. Our real-world laboratories, called "Solutions Labs", ensure this collaboration: we study water cycles in various model regions and test our innovative solutions there. At the same time, with the "Solutions Labs", we aim to promote both knowledge exchange and knowledge transfer with decision-makers from politics, business, and civil society.

1. Research Focus: Water Cycles of the Earth

Various gravimeters for determining changes in natural water storage at the TERENO observatory in northeastern Germany, "Serrahn" location (Image: Marvin Reich/GFZ).

We aim to better understand the factors influencing our water cycles by analyzing them in various model regions: on one hand, in natural catchment areas with little or no human intervention, and on the other hand, in regions with intensive use. We comprehensively monitor these areas, both from space using satellite technology and through underground measurements, to capture the complete water budget of an area and its fluctuations.
By comparing these findings with geological archives, we can also look back historically – over many thousands of years. From this data, we derive measures for improved water management that balance the needs of nature, drinking water supply, industry, and agriculture under the conditions of climate change, energy supply, and population growth.

2. Research Focus: Urban Blue-Green-Red Water Systems

Green roofs can retain rainwater and cool buildings through evaporation (Image: chuttersnap/Unsplash).

Cities consume particularly large amounts of water and are simultaneously more vulnerable to the impacts of climate change. In model districts, we are therefore studying how water and energy cycles can be managed more intelligently. To this end, we are designing concepts for a new form of urban planning: it combines the infrastructures of water (“blue”), urban greenery (“green”), and energy (“red”). For example, parks also serve as rainwater storage, green roofs and facades cool buildings, and wastewater provides them with heat. We are testing such solutions in various cities and at several Helmholtz locations. There, we also examine how effective these technologies are, which combinations prove to be useful, and how they can be applied to other cities.

3. Research Focus: Water Quality

Wastewater analyses provide early indications of changes in water quality (Image: Ivan Bandura/Unsplash).

Germany's rivers, lakes, and groundwater are still too heavily polluted with problematic substances, such as micro-pollutants and plastic particles that degrade very slowly, or pharmaceuticals and their residues, which are not yet fully filtered out of wastewater or retained in livestock farming. In addition, problematic substances, such as pesticides from fields or nutrients from fertilizers, are washed into the freshwater bodies from the soil and are subsequantially transported to coastal and marine waters. These pollutants pose risks to nature and our health, which is why they must be reduced as much as possible through source control, use related minimisation and treatment. To address this, we investigate how pollutants enter the water cycle and spread within it. We also study the toxicological effects of these substances and analyze how their introduction can be reduced or completely prevented in the future. For this, we are developing innovative purification technologies, such as those for micro-pollutants. Key partners for us in this effort are municipal companies responsible for drinking water supply and wastewater treatment.

1. Cross-Cutting Theme:
Microbiome, Ecosystem Interactions, Data Analysis

Our three "Solution Labs" investigate highly complex ecological systems with a multitude of influencing factors, such as climate, weather, temperature, evaporation, runoff and flow paths, water quality, and the content of algae and bacteria, as well as fluctuating demands and needs.

Our researchers must process and combine an extremely large number of data points. To support this, we are developing the necessary innovative high-throughput methods: these enable the simultaneous automated testing of thousands of water samples, for instance, to screen for genetic information (microbiome). The resulting datasets are analyzed using artificial intelligence, and we integrate them to better visualize interactions within an ecosystem – such as how water levels and microbial biodiversity in a reservoir affect drinking water quality.

Machine learning techniques like deep learning help us identify notable patterns and features within these vast datasets. These insights are used to develop predictive models and warning systems. Additionally, we utilize analysis methods from X-ray imaging to study novel membranes that could potentially filter valuable metals from wastewater in the future.

UFZ scientists are sampling small water bodies in agricultural landscapes across Germany. Their work provides important data for policymakers in discussions and decisions regarding pesticide limit values in agriculture (Image: Andrē Künzelmann/UFZ).

2. Cross-Cutting Theme:
Monitoring, Remote Sensing, and Sensors

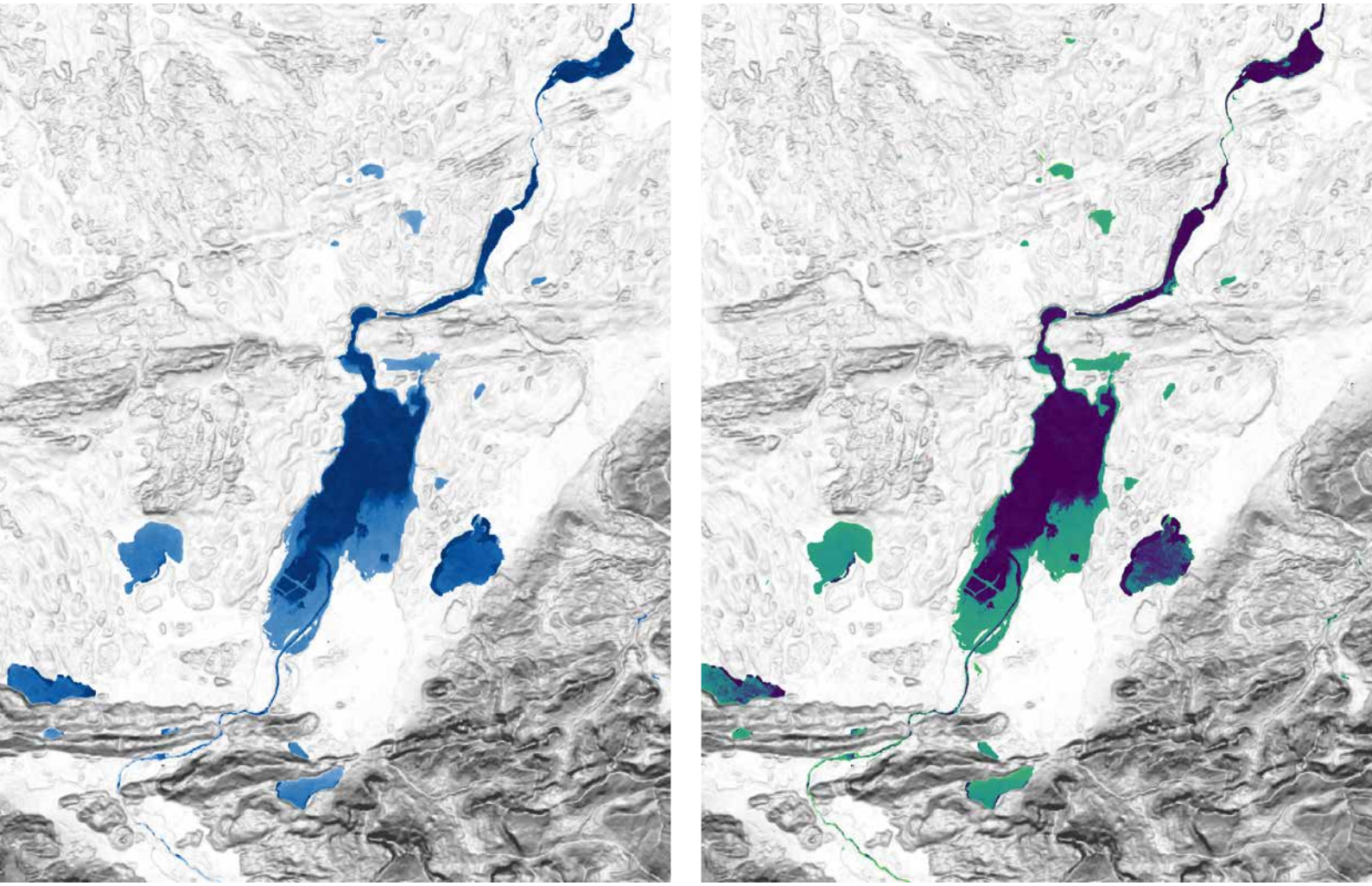
Factories, wastewater treatment plants, and fields: many different sources use water and release substances that can enter the water cycle. Water quality must therefore be regularly checked to prevent harm to the environment and human health. While point-source discharges, such as those from industry and settlements, are relatively easy to monitor, the diffuse entry of pollutants from agriculture is harder to detect with conventional monitoring programs.

We are developing novel monitoring systems to address this challenge. Using satellites, we monitor water bodies and detect, for example, turbidity, algal blooms, and pollution, even over large areas and extended time periods. Through remote sensing, we can also track the distribution and vitality of plants, algae, and other organisms – important indicators for assessing biodiversity and the ecological status of a body of water. In addition, we employ advanced sensors in soil and water: they monitor soil moisture in real-time and assess water quality by detecting phenomena like algal blooms and creating complete depth profiles of water quality in reservoirs.

Satellites from the GRACE missions document changes in the Earth's gravitational field, contributing to a better understanding of global water resources (Image: DLR).

3. Cross-Cutting Theme:
Data Analytics and Information Technology

We are developing digital models and solutions for the water sector: data collected by us is integrated into innovative water information systems, simulations and early warning systems. These systems allow authorities and companies to monitor and assess their water resources in real-time. Additionally, intelligently networked sensors raise alarms when shortages or contamination in the water cycle are imminent. In specialized simulations (digital twins), municipalities can also assess how to avoid and manage competition between drinking water supply and the water needs of industry and agriculture during supply crises. This makes the valuable resource of water more efficiently used, while also strengthening our supply systems to withstand crises. However, the digitalization of the water sector also brings risks regarding data protection and cybersecurity. We are therefore also addressing these aspects comprehensively.



Displayed are results from the "WaterDynamo" project of the German Remote Sensing Data Center (DFD), a DLR facility. WaterDynamo captures and analyzes spatiotemporal water dynamics using satellite remote sensing and advanced AI methods. The image shows Forggensee in Bavaria (Images: DLR-DFD; ESA).

Research vessel ALBIS on a sampling expedition on the Elbe (Image: André Künzelmann/UFZ).

Image: Sebastian Wiedling/UFZ

"We will establish three 'solution labs' in selected model regions in Germany that represent typical water security challenges for people and the environment. Together with decision-makers from politics, industry, and civil society, we are breaking new ground to translate the results of excellent research more quickly than before into urgently needed, implementable solutions."

Dietrich Borchardt
Hydrobiologist at UFZ and spokesperson for the initiative

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Helmholtz Association of
German Research Centers e.V.
Anna-Louisa-Karsch-Str. 2
10178 Berlin

Contact:

Nicolas Tellner
Manager Aeronautics, Space and Transport
Helmholtz Association
Tel. +49 30 206 329-669
nicolas.tellner@helmholtz.de

Dietrich Borchardt
Spokesperson for the Helmholtz Water Initiative
wasser@helmholtz-gemeinschaft.de

Annemarie Müller
Advisor to the Spokesperson and Coordinator
of the Helmholtz Water Initiative
wasser@helmholtz-gemeinschaft.de

More information at:
https://wasser.helmholtz.de/en/

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