EARTH WATER-ENERGY-FOOD NEXUS WORKSHOP:

“Assessment of the state of knowledge related to science, integrated observations, and governance in the W-E-F Nexus”

Fraunhofer IOSB
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Executive Summary

Background
The Future Earth Water-Energy-Food (W-E-F) cluster project and the Fraunhofer IOSB collaborated to hold a workshop in Karlsruhe, Germany on November 23-25, 2015. The workshop, entitled “Assessment of the state of knowledge related to science, integrated observations, and governance in the W-E-F Nexus,” constituted the second of four regional workshops planned as part of the Future Earth W-E-F cluster.

The workshop attracted 35 experts representing a broad spectrum of research, government, and international groups that work in the water, energy, and food sectors. Attendees included experts from industries in Germany, Belgium, Sweden, Japan and the USA, government experts from Germany, the European Space Agency and the UN, and academics from universities in Germany, the UK, USA and Australia.

The workshop took the form of a few overview talks followed by a series of panels. Each panel featured recognized experts who presented their perspectives on the panel theme followed by a discussion with the audience to broaden the insights and generate new ideas. The main source of recommendations came from the two breakout groups which dealt with the topics of observations/information and governance. This report provides a summary of the presentations, panels and ideas arising from the working groups. It also provides a preliminary assessment of ideas for addressing the needs of the Water-Energy-Food Nexus by using more advanced information systems and improved governance approaches.

Highlights, Conclusions and Outcomes
Various challenges and opportunities were identified related to science, integrated observations, governance and stakeholder engagement in the W-E-F Nexus.

Science issues associated with the W-E-F Nexus
The workshop discussed how the W-E-F Nexus should be defined including ways in which it should be categorized to enable a Nexus approach to both analysis and policy. The benefits and concerns for framing of the W-E-F Nexus in “security” terms were discussed. Approaching the Nexus from sectorial perspectives was felt to be useful for some studies but ultimately could be a limitation because it is seen as a contradiction in terms.

A number of scientific issues arising from trends in managing the Nexus or components of the Nexus were identified. There are many tradeoffs within and beyond the Nexus that must be assessed. Examples include environmental issues such as wetland preservation for biodiversity and flood reduction; implications of trends in foreign land ownership for developing countries to expand their W-E-F economy; climate change and its impacts on water, energy and food production and the interactions between these impacts that could lead to inadvertent amplifications; environmental tipping points related to water quality, pesticides and
biodiversity, the long term use of genetically modified organisms in agriculture, and tradeoffs between traditional energy and alternative energy. While the need to have knowledge related to these trends is clear, the research has not been undertaken to address the issues in ways that are best suited to answering the management questions. Research is also needed to develop the understanding, models and tools needed for evaluating current conditions and generating scenarios required for assessing future conditions. Models are appropriate tools for facilitating dialogues between scientists and W-E-F stakeholders, as well as providing the scientific community with feedback on the utility of their projections.

Addressing the complexity of Nexus topics is seen as a critical Nexus issue. System approaches can foster the understanding of the W-E-F Nexus and the diagnosis of complex problems within. Information needs of a systems approach to the W-E-F can be used to maximize the benefits from specific earth observations. Another question is related to the selection of boundaries for a system analysis. Promising ways forward can be the development of indices that represent critical linkages between the water, energy, and food systems. Scenarios can be another interesting approach to identify robust solutions that improve resilience rather than optimizing a single objective.

A number of innovative concepts and approaches that could serve as the theoretical basis for scientific research of the Nexus were presented during the workshop. These include political and other infrastructure that affect the structure of the W-E-F Nexus. Future research can address the question of how this infrastructure functions and how the possible constraints or opportunities it places on the W-E-F development in a given area can be documented. Further interesting nexus approaches are related to value chains and the concept of virtual water.

Potential funding options were also a point of concern. The EU Horizon 2020 program provides various opportunities for W-E-F studies. Although funding opportunities exist, they often require considerable creativity in searching out the best opportunity and developing a successful application for a given project concept.

**Integrated observations**

Integrated observations of the W-E-F Nexus can draw upon an array of emerging observational tools and concepts. However it is unclear which of these tools should be promoted in the W-E-F discussion and how they can be applied in the near term. Tools are required to integrate in-situ measurements with available data. Many users could benefit from local data transmitted by mobile phones but large information systems are not able to fully ingest and integrate this information with other data sources. For instance, NASA SERVIR system can provide larger data sets over the internet and GEONetcast can be applied in various contexts, as experiences in developing countries have shown, but they still have limited interfaces with mobile phones as data collectors/transmitters. An integrated data system (perhaps under GEO) could be a potential way forward to identify best practices for using Earth observations in the W-E-F Nexus.

Although there are many opportunities for using existing tools and data, research of the W-E-F Nexus also has challenges that require enhanced or specific data collection and innovative analysis techniques. For instance, better satellite data and analysis techniques are needed to distinguish irrigation areas in regions with fragmented agriculture. In particular, new tools and methods are needed to improve integration of information across the W-E-F Nexus. Value chain
mapping and monitoring systems are useful approaches to address the unique perspectives of the W-E-F Nexus.

There is also the need to be able to define and communicate the uncertainty or confidence in the data. There is the need to better define metadata and communicate the metadata to the user. Open and standardized metadata catalogues have been discussed as a promising approach. Systems approaches should be the basis for the design of data collection systems and setting research priorities. Synergies should be used in collecting the data (value of consolidating in a center) and evaluating the data that exist in different portals.

**Governance in the W-E-F Nexus**

Research on appropriate arrangements for W-E-F governance is required that address horizontal and vertical coordination. This requires community building to bring together scholars working on water, energy and food systems (comprising not only food production but also distribution and in particular food consumption) and those working on different levels from the local to the global. In general, the W-E-F Nexus can be an integral approach for improving the integration of capabilities and institutions in the water, energy and food sectors.

In addition, research on effective W-E-F governance instruments is required that applies a systemic approach by analyzing for example how various instruments can be combined and how their effectiveness depends on the context in which they are embedded and by developing appropriate performance measures. While instruments are available, it should be considered that they are not always neutral but can be chosen based upon particular interests. An assessment of effectiveness is needed for instruments at different levels. Various examples of potential instruments were discussed, such as Strategic Environmental Assessments, subsidies/taxes, restrictions on uses /spatial planning, pricing, self-regulation, and legislation, amongst others.

W-E-F governance research requires data on different levels of detail ranging from coarse to detailed data, depending on the research question. For instance, data on property and use rights could be particularly relevant to understanding W-E-F governance. Data on social impacts are also highly relevant, which can be gathered by making use of new information technologies (e.g., citizen science). Tracking implementation of policies with Earth System Observation is limited though, as one cannot track directly social and economic impact, but only secondary impacts.

**Stakeholder Engagement**

A number of challenges regarding the engagement of stakeholders were identified. In particular engagement with stakeholders such as policy-makers can be very challenging. There is a need to clarify who should be addressed as the “policy audience” for W-E-F discussions and which messages should be delivered. For example, the message could be connected to prevailing policy and practice (e.g. those working on IWRM). A dialogue with these stakeholders could also inform the W-E-F research agenda regarding knowledge and data gaps. Comparative analysis of completed studies could provide a fruitful approach for drawing lessons about the elements of successful W-E-F projects. This work would be accelerated by the development of an inventory.
of W-E-F studies from around the world. The inventory should describe the needs, the nature of the project and how its relevance to the W-E-F Nexus should be characterized.

Next Steps

The workshop concluded with a review of the actions to be taken in the near-term and the longer term. An inventory of ongoing and W-E-F-related “policy experiments” could be established. This could also support comparative case study analysis that apply a diagnostic approach and allows (further) development of governance tools.

In addition, there is the opportunity to engage in the implementation process of the Sustainable Development Goals (SDGs). Nexus indicators could be an innovative approach to analyze the interlinkages between SDGs. The Future Earth Sustainable Water Future Program (SWFP) could be used as a link to bring in a W-E-F Nexus focus into the World Water Development Report. Other future opportunities are joint publications and a potential proposal under the umbrella of the EU Horizon 2020 program.

The broad interest in the Nexus is leading to the development of opportunities for interested scientists to contribute. There is the opportunity to contribute to (shape) the W-E-F Nexus Knowledge-Action-Network to be implemented under the umbrella of Future Earth. The Scientific forum on "Understanding the Water-Energy-Food Nexus and its implications for governance" in Osnabrück (May 2016) – financially supported by the German Science Foundation (DFG) – might lead also to a proposal for a new nexus-specific research focus in Germany. Another possibility involves the establishment of a working group under the umbrella of the SWFP to develop an inventory of information that is supportive of W-E-F research and includes a means of accessing tools, synthesis of existing case studies, assessments of governance instruments among other things. The call for proposals made by the US National Science Foundation is also expected to launch a number of large studies to address key W-E-F Nexus issues. Some participants of the workshop contributed to the regional workshops of the cluster activity in Japan 2016 and all are invited to contribute to a workshop with W-E-F/ SDG focus later 2016.
Welcoming Remarks

Welcoming remarks and an introduction to the Fraunhofer Institute were offered by Kym Watson. Dr. Watson provided a description of core competencies of the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (IOSB) and their relevance to the topic of the workshop.

Overview of the Program and the Issues

GWSP and the Future Earth Sustainable Water Future Program

Prof. Claudia Pahl-Wostl provided an introduction to the Global Water System Project (GWSP) and the Future Earth Sustainable Water Future Program (SWFP). The GWSP was transformed into the SWFP at the end of 2015. The GWSP produced several accomplishments including the enlargement of a network of scientists, extending the dialogue about water and global change well beyond climate alone, and fostering several innovations (e.g., the nexus concept). The newly formed SWFP contains the thematic areas of “Global state of water”, “Governing the transition”, and “Water as a global agent”. Knowledge Production Centres (KPCs) will be established in different world regions that promote and coordinate international research activities in domains of specific importance for the SWFP. In addition, the KPCs aim at advancing the scientific understanding of the global water system by providing regional and thematic knowledge. The KPCs will manage and govern themselves, yet will develop research strategies and regional activities in accordance with the SWFP’s objectives. The next steps in 2016 will be the set up thematic working groups, water solution laboratories and regional centers. In addition, a scientific forum on "Understanding the Water-Energy-Food Nexus and its implications for governance" will be held in Osnabrück in June 2016, which is financially supported by the DFG.

The Future Earth W-E-F Project and the purpose of this workshop

An introduction to the Future Earth Water-Energy-Food (W-E-F) Nexus Project and the purpose of this workshop was also provided by Prof. Claudia Pahl-Wostl. Future Earth – the new interdisciplinary and solution-oriented Global Change Programme initiated by ICSU (International Council for Science) – identified the W-E-F Nexus as the first key focal challenge to
be addressed by the program Future Earth: “Deliver water, energy, and food for all, and manage the synergies and trade-offs among them, by understanding how these interactions are shaped by environmental, economic, social and political changes”. The nexus concept is based upon the insight that there is interconnection amongst and between global food, energy, water security and environmental sustainability. Addressing only one part may not lead to desirable and sustainable outcomes. Cooperation among scientists and policy makers are required to mediate trade-offs and explore synergies, helping reduce costs and increase benefits for humans and nature by integrated approach to the management of water, energy, food and the environment. Another issue is the fast degradation of natural ecosystems and their related services because of human activities. Thus the nexus concept supports an ecosystem integrated approach to better understand and to systematically analyze the complex interdependences of water, energy and food systems.

As a result of a proposal to the Belmont Forum by the Global Water System Project an interdisciplinary project was launched to address the use of Integrated Observations and Improved Governance for improving the sustainability of the W-E-F Nexus. There is a need for adequate, robust and reliable data and evidence-based analysis to identify and assess water, energy and food systems and the impact that any change in the system can have on the environment and livelihoods. This work area includes anything from earth observation data to rapid assessment tools, including satellite observations, and in situ measurements. Governance is at the heart of decision making and surrounds more than the need to exhibit transparency, efficiency, and public participation in decision making. Governance determines also if and when there are opportunities for developers, regulatory authorities and the public to interact in a balanced and respectful way. Broadly speaking, governance covers the way problems are tackled and opportunities created.

The Future Earth W-E-F Project will hold four regional workshops (this is the second) as the information gathering part of this project. Deliverables from the project for Future Earth will be:

- a set of research questions,
- a programme outline,
- a community of international experts,
- tools and techniques for using observations, physical sciences and social sciences to address the problems of the W-E-F with solutions-oriented research.

The first workshop took place in Washington, DC, USA on June 1-3, 2015 (Partner: Texas A&M University; 75 participants). The workshop contributed to the development of a W-E-F Community of Practice. In addition, US NSF may incorporate some workshop findings into its upcoming call for proposals. Recommendations from the workshop include the following (examples only):

- Undertake case studies to define the interconnectivity of W-E-F systems. In this regard, a suite of comparative case studies should be carried out with an emphasis on governance issues.
- Develop a shared platform with both national and international components for data to serve the three communities simultaneously.
The **second workshop** (this report) took place in Karlsruhe, Germany on November 23-25 2015 (Partner: Fraunhofer Institute; 35 participants). Priority Themes were:

- Information gaps related to energy security both in the fossil fuel and the renewable energy sectors
- Limits to the availability of water and land, water quality, and other factors that affect energy security
- Impacts of the use of foodstocks for energy production (biofuels)
- The role of renewable energy in the food sector
- Identification of data, information, and coordination gaps, as well as management and governance issues.

The **third workshop** will be organized in Japan in April 2016 (Partners: Japan Future Earth Node, RIHN). Priority Themes could be:

- Understanding the complexity of W-E-F Nexus system
- Methods of using W-E-F Nexus as a science-policy interface
- Interlinkages between land and sea under W-E-F Nexus framework
- Strategies for improving governance in the W-E-F Nexus
- Approaches to data collection, information and decision support on different spatial and temporal scale
- Assessing the requirements for water, land and energy for future food production

The **fourth workshop** will take place in Autumn 2016. The location needs to be determined. Priority themes could be:

- Articulate the role of Earth observations in informing Sustainable Development Goals related to water, energy, and food.
- Research agenda to support the monitoring of the relevant SDG indicators including modelling to improve predictions.
- Identify opportunities to use SDG targets for cross-sector collaboration for planning.
- Assess the degree to which the targets and goals provide opportunities for new integrated management of the sector at different scales.

**Governance Challenges of the W-E-F-Nexus**

Prof. Claudia Pahl-Wostl gave a presentation on the governance challenges related to the W-E-F Nexus. Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels of society (Rogers and Hall, 2003). Governance modes describe a certain logic of political steering, dominant forms of interactions and preferred instruments:

- Hierarchical governance mode – «Command and Control»
• Market-based governance mode
• Network governance mode

Prof. Pahl Wostl identified a number of governance failures causing problems for security in the W-E-F Nexus: (1) Inappropriate governance settings – fragmented, lack of horizontal and vertical coordination, sectoral fragmentation; (2) Lack of respect of good governance principles; (3) Lack of implementation of governance arrangements (capacity problems, lack of political will, asymmetric power structures); (4) Ignorance of importance of governance settings – focus on technical, natural science approaches to analyse problems and to identify solutions.

To illustrate the governance challenges in the W-E-F Nexus, a case-study of an intensive agricultural region in North-West Germany was provided. The intensification of agriculture and the increase of numbers of animals in this region resulted in environmental problems, which got obvious during the 1980s: Overspills of manure in combination with a limited absorption capacity of soils; emissions from animal housing systems and chemical fertilizers; potential hazards caused by animal diseases; potential conflicts regarding species-appropriate animal husbandry in relation to changing consumer demands and to sensitizing of the public (Mose et al. 2007). Claims for stronger regulation with stricter enforcement have started to replace efforts relying on voluntary agreements. However, the overall problem situation seems to be gridlocked with little prospects for fundamental change.

This case shows that abundance of data does not prevent coordination failures. In the end, the developments could have been foreseen (e.g. scenario analysis). A coordination of nexus issues is needed at level of policy development which also requires some flexibility during policy implementation. Prof. Pahl-Wostl suggests a greater emphasis on the process of governance reform rather than on idealized outcomes. Thus, governance reform processes can be a source of solutions, such as polycentric structures with improved, flexible coordination across sectoral and administrative boundaries. Another solution can be the implementation of an ecosystem services approach to make complex interdependencies and trade-offs explicit. Hybrid forms of governance (i.e., combinations of governance modes Markets, Bureaucratic Hierarchies, Networks) should be considered, as well as global networks to exchange experiences and lessons learned. These efforts should be guided by scientific assessments.

At the end of the talk, Prof. Pahl-Wostl posed a number of questions that need to be addressed regarding W-E-F Nexus governance:

- At which level – scale should the W-E-F Nexus be governed?
- How much should be coordinated during policy development and during policy implementation (adaptive management)?
- Which instruments are appropriate – being effective and flexible?
- Which kinds of indicators are most meaningful to support W-E-F governance at different levels?
- What are requirements for governance to make use of the potential of new information from Earth System Observations to support a sustainable management of the W-E-F Nexus?
- How to improve nexus governance in the Sustainable Development Goals (SDGs) implementation process?
Science Issues Associated with the W-E-F Nexus

Rick Lawford provided an introduction to some science issues associated with the W-E-F Nexus. At the beginning, Lawford presented some impressive examples of linkages between the water, energy and food sectors. Several trends can affect the future of the W-E-F Nexus, such as international commodity trades and speculation which can play a major role in the food system.

Rick Lawford (Morgan State University) introduced some science issues associated with the W-E-F Nexus that require substantive research. He noted that many of the needs for science, technology, observations, information systems, and understanding of systems for governance are related to the current structure and possible future structures for the food and energy industries. There is a great need for tools, techniques and models to enable the use of observations, and knowledge from the physical and social sciences to address current and future problems of the W-E-F with solutions-oriented research.

The future is filled with uncertainty in part because we do not fully understand the causes and consequences of some of the present trends in the W-E-F Nexus and its environment. Development of trends that could affect the future include:

- International commodity traders who through speculation may be having an increasing impact on the price of food.
- The continued difficulty in mobilizing the large food and energy production capacity of Africa in a way that brings maximum benefits to Africans.
- The drive for low carbon economies to combat climate change without understanding the consequences for regional energy and food production at the basin, nation and local scale.

Physical constraints on the system are also important. Water continues to be under stress in many parts of the world due to the depletion of aquifers and the pollution of surface waters. How these trends be reversed and how can new sources be developed given ever increasing demands for water for Irrigation and biofuels. (Some projections suggest that a requirement for 7% biofuels content in gasoline could lead to more water being used for biofuels than for entire food sector by 2050.) Science is needed to identify new sources be expanding waste water treatment and use and identifying and implementing technologies for fresh water harvesting through new deep aquifers and desalination. Science is needed to address and control the problems of nitrogen and phosphate in fertilizers which are leading to more algal blooms in receiving waters.

Climate Change and Variability introduce uncertainty and the risk of water scarcity into the management of the W-E-F Nexus. Climate extremes such as droughts are expected to increase in significance for the nexus under climate change. Adaptation strategies are needed to ensure food producers have flexibility to maintain high levels of production by increasing water use efficiency. Techniques to translate climate forecasts into risk assessments for water resource and W-E-F Nexus management. Earth observations have direct applicability to supporting seasonal prediction and climate monitoring. Society needs to be able to more effectively monitor variables sensitive to climate change such as soil moisture. During the next decade everyone will have the potential to be a data supplier thanks to big data, citizens' networks, and drones, amongst other technologies.
Another issue for the W-E-F is limited availability of new arable land. In addition to the encroachment of expanding urban areas on farmland, land ownership is changing in many parts of the world. Types of land acquisition that are likely to affect the nexus include:

1) Large national corporations buying land from small landholders in the same country.
2) International corporations buying land from small landholders or the governments of smaller countries.
3) Nations buying up land in other countries to secure their long-term food supply.

Coastal areas have great potential to produce food through harvesting of marine resources and aquaculture. However, issues of fish quality and environmental impacts need to be addressed.

Solutions to these and other problems will include standards to make the new wide diversity of data sources usable and to develop a W-E-F information system that produces products based on Earth observations and “observations of opportunity.” Open data and shared data products are a critical step to make sure all have access to the information needed for transparent, integrated, inclusive planning.

In this regard, a testbed project would be an excellent way to create a platform for testing ideas, data and information platforms and the potential benefits and needs of integrated planning.
Panels

Panel 1: Trends in the W-E-F issues

Chair: Annukka Lipponen (UNECE)

The panelists in this session included Wolfgang Grabs, Oliver Warweg, Jiaguo Qi, Bruce McComb, Dale Rothman, and Hong Yang.

Wolfgang Grabs: Understanding the Water – Energy – Food Nexus from a Water Perspective

Wolfgang Grabs of the German Federal Institute of Hydrology discussed trends in water and related issues. The W-E-F Nexus is a way to conceptualize the complex and interrelated nature of global resource systems in which user goals must be balanced while maintaining the integrity of ecosystems. Water systems themselves are multi-faceted and have many inter-related challenges.

The world water market is worth $463 billion per year and investments in water technology increase yearly. Water will be needed to meet the 60% increase in food demand expected by 2050 by FAO and the 50% increase in global energy consumption expected by 2035. Technology has a role to play in improving drinking water quality and sanitation services, and in reducing energy inputs for desalination and water treatment processes.

Wolfgang demonstrated the complexity of water issues with an overview of the Water Quantity-Quality Nexus from Near East and North Africa, where 5% of the world's population survives on less than 1% of the world's available water resources. Available water resources for different user communities must be determined based on economic, environmental, and societal sustainability considerations. Dynamic water resources assessment methods are needed to determine the variability of freshwater availability and water quality. Plans for adaptive water management should account for climate change and other local and regional anthropogenic influences.

Understanding the W-E-F Nexus is important for strengthening water resources management across sectors, institutions, and governments. The W-E-F Nexus could assist in addressing sectoral challenges and opportunities and different societal, economic, environmental, and political interests in a participatory, inclusive manner.

Oliver Warweg: Energy Issues for the W-E-F Nexus

Oliver Warweg of the Fraunhofer Institute discussed energy issues for the W-E-F Nexus with a specific focus on the impacts and challenges of renewable energies in Germany. He described the role of renewable energies as increasing the power produced and improving the ratio of fluctuating to controllable power. Oliver noted that grid stability requires a balance between electrical contributions and demand, and would require support for control- and reserve power.

The installed capacity for renewable energies in Germany is significant and growing. Forecast errors affect short-term operations and lead to requirements for an energy control reserve. Currently, renewable power generation in Germany is greater than the load, which has led to
proposals to decrease the number of coal, oil, and gas plants. Nuclear power plants are also being phased out. However, it may be necessary to increase storage to maintain system integrity. Furthermore, the current energy transportation system has a regional mismatch of generation and consumption so that the grids for both DC and AC power needs to be expanded.

Trading and marketing energy requires effective planning. Distribution is based on merit as well as marketing considerations. To be effective, marketing must be flexible and have access to stored energy. To facilitate distribution, grid expansion should include active distribution grids, smart meters, optimized local generation, and integration of market considerations. Power consumption will be organized through demand-side management with increasing flexibility, e-mobility, and greater reliance on local production and storage for individual consumption.

The effects of climate change (heat waves, droughts, extreme weather situations, floods, and increasing water temperatures) are expected to affect power production and distribution as well as the availability of commodities for power production. In summary, the increasing production of renewable energy will need to be based on suitable operations, grid availability and demand-side management to control the patterns of energy consumption.

**Jiaguo Qi: Food System in W-E-F Nexus**

Jiaguo Qi of Michigan State University described the role of the food system in the W-E-F Nexus. Changes in annual averages, seasonality, and extremes threaten food security and affect consumption patterns, which in turn drive changes in processing and production. Limited land available for food production also constrains food production.

Jiaguo explained that most of the frameworks proposed for the W-E-F Nexus are location-, community-, country-, and economy-specific, hence they are a challenge to generalize and often tend to be at the conceptual design stage and lack specificity. He discussed the lower Mekong Basin as an example, where food security is the primary issue. In spite of extensive coordination, moreover, an integrated regional or watershed approach does not exist.

Among food issues, food safety is most critical. Threats from chemicals and containments drive a demand for organic food production. Factors that are important in the Mekong Basin include management for crop production and research, climate change impacts on food security, and the food system's resilience.

A data platform is needed to support the development of strategies for resilience and food security. The future food system will need to include an early warning system, big data, system connections, and decision-support capabilities. Geospatial tools such as system mapping and spatial analysis are needed to evaluate climate change impacts. Soil research is needed to examine carbon sequestration and land degradation caused by urbanization. Human systems research is needed on how to motivate people to change. Biotechnology should improve crop productivity and thus contribute to food security. Concerns that need to be addressed include biodiversity losses due to agriculture, urbanization, and policy/institutions and their impacts on food security.

Capacity building will help disseminate technologies and adaptation strategies and the prevention of long-term soil degradation. Quantitative assessments of the effects of climate change on food systems in Southeast Asia are needed along with studies of food system evolution in changing rural-urban landscapes and food system transitions. Improved capabilities for disaster impact assessment with models and remote sensing are needed.
Trade-offs among and within food systems pose another challenge. Background information is needed to facilitate understanding of the Nexus at multiple scales, to prototype successful cases and scale them out and up and to ensure local food systems’ stability and long-term sustainability.

Bruce A. McCarl: Climate Change and Sectoral trends in the Water Energy Food Nexus

Bruce A. McCarl of Texas A&M University discussed climate change and sectoral trends in the W-E-F Nexus. 2014 was the warmest year since records began to be kept in 1880; 2015 was even warmer. Extreme events (temperature and precipitation) and variability have increased since about 1970. Precipitation varies with northern gains and subtropics drying.

Climate change impacts on water include drying in some areas and wetter conditions in others; melting glaciers; increased precipitation intensities; flooding and evaporation; changes in plant water demand; and decreased soil moisture. Climate change impacts food security by causing greater variations in yields, more pests, more frequent droughts, poleward shifts in vegetation zones, sea-level inundation, and land use changes. It impacts the energy sector through ozone depletion, increased cooling water requirements, and demands for more renewable energy. In spite of these trends, however, details about the onset and exact effects of climate change are often uncertain. To date, responses to climate change include developing more reliance on aquifers, reinforcing infrastructure, carbon markets, and new technologies.

In the southwest United States, agriculture is adapting to the changes that have occurred and will continue to adapt through land use, stocking rates, and governance. Adaptation is considered to be “natural” (actions in the ecosystem stimulated by species), “autonomous” (actions taken voluntarily by decision-makers), or “planned” (actions taken by governments to address needs judged unlikely to be met by others). The public sector should play a role in adaptation by providing information, shaping markets, developing technologies; and by acting directly by developing strategies, providing resources, carrying out projects, and enabling natural adaptation processes. The W-E-F Nexus is very vulnerable to climate change and this issue must be addressed on a priority basis by all sectors.

Dale Rothman: The Role of Scenarios in Exploring the Water-Energy-Food Nexus

Dale Rothman of the University of Denver discussed the role of scenarios in exploring the W-E-F Nexus. To develop scenarios one must assess “internal” (amenable to control by actors) and “external” (not amenable to control by the actors) factors and examine information in narratives and numbers. Consistency of assumptions about internal coherence in pathways and endpoints between stories and simulations should be sought. It is important to identify scenarios’ goals and ways to reach a systemic and holistic perspective in terms of key players, resources, interactions, uncertainties, and outcomes. Scenarios should support complementarity results because no scenario is automatically correct and all can be wrong. Scenarios should allow potential surprises to surface and address future as well as present problems.

Hong Yang: Trends in the W-E-F Nexus– An economic dimension

Hong Yang of the Swiss Federal Institute reviewed the W-E-F Nexus from an economic perspective. She presented an integrated analysis of the W-E-F Nexus and cost/benefit balances
in the context of climate change. If publications are used to determine issues, the issues (from largest to smallest) are as follows: Water-Energy Nexus: hydropower and energy generation (449 publications); Water-Food Nexus (153 publications); Energy-Food Nexus (144 publications); and water, energy, and food (119 publications). Only 37 publications deal with the W-E-F Nexus directly, and they do so only in a qualitative and conceptual way.

Economic studies addressing the Water-Energy Nexus focus on climate change impacts on water resources and consequences for hydropower generation, energy prices, desalination costs, and water management. Economic studies on the Water-Food Nexus deal with water pricing in irrigation, optimizing water allocation among W-E-F Nexus sectors, water use efficiency in agricultural production, drought impact on food production, opportunity cost of green and blue water use in agricultural production, and global/regional water savings associated with food trade/virtual water trade. The economic dimension of the Food-Energy Nexus focuses on biofuel based on global crude oil prices, the food price index, and the impact of biofuel on food prices at the country level.

Different market structures dominate in each sector of the W-E-F Nexus: energy (market operation, externality), land resource and food system (market operation, food security), and water resources (no real market, scarcity and variability). Gaps that need to be addressed include optimizing the use of water, energy, and food resources, investments, financing Nexus approaches, and the nature of externalities and public goods.

Approaches for the W-E-F Nexus analysis should consider using general equilibrium models and translating biophysical impacts into economic outcomes. They could also assess shocks to the system induced by climate change, policies and the price of commodities, and supply changes, among other factors.

Panel 2: Frameworks for understanding the W-E-F Nexus by sector

Chair: Jiaguo Qi

The panelists in this session included Holger Hoff, Ellie Biggs, Joseph Alcamo, Annukka Lipponen, and Antje Bruns.

Holger Hoff: SDGs - a framework for understanding and applying the nexus

Holger Hoff of the Stockholm Environment Institute deplored the lack of conceptual clarity in the W-E-F Nexus debate. He suggested using the nexus approach for SDG implementation to avoid silo thinking in the implementation of the SDGs related to energy, water and food. The nexus can provide a lens to look at the SDGs systematically and promote policy coherence.

A nexus approach can be applied to the SDG development goals to emphasize critical interlinkages and allow for their quantification (including their dynamics). The W-E-F approach should go beyond securities and also consider natural resources (i.e., water, land, energy; cf. SDGs 2, 6, 7, 15). Several inter-dependencies of natural resources exist, such as demands, uses, use efficiencies, degradation status, and scarcities. Figure 1 shows a W-E-F framework that includes natural resources.
Nexus principles comprise the utilization of synergies as well as the consideration of tradeoffs, externalities, and higher resource use efficiency (cf. SDG 8.4) for improved human securities while reducing pressure on natural resources and ecosystems. National governments need to be supported in applying nexus approach to SDG implementation. Designated national entry points (e.g. sustainability councils) and other institutions can play a key role in nexus operationalization. General inter-linkages among SDGs and targets and country-specific mapping and gap analyses can be starting points. A consortium of think tanks (under the IRF mandate) is also developing a nexus tool box for assessing (context-specific and quantitatively) critical interlinkages from biophysical, socio-economic and institutional perspective.

Participatory scenario development can be another critical tool that integrates stakeholder driven storylines with data and information from the nexus tool box, e.g. using WEAP & LEAP. A nexus typology for classifying countries and regions within global frameworks can be a helpful approach to assess the representativeness of case studies, scaling out and up, find region-specific patterns, and transfer best nexus practices. An initial synthesis from nexus case studies show that management of water, land, and energy takes place at different scales, which implies a need for addressing (beyond horizontal also) vertical nexus (across scales & levels) for policy coherence. In addition, times scales at which energy, water & food security deliver development vary, causing a need for addressing temporal nexus aspects also for policy coherence.

**Ellie Biggs: Sustainable Development and the Water-Energy-Food Nexus A perspective on livelihoods**

Ellie Biggs highlighted that that the nexus has an influential role in attaining human security. Limited research is currently linking nexus to sustainable livelihoods. ‘Environmental livelihood security’ refers to the challenges of maintaining global food security and universal access to freshwater and energy to sustain livelihoods and promote inclusive economic growth, whilst sustaining key environmental systems functionality, particularly under variable climatic regimes.

Ellie Biggs presented a framework to analyze the role of W-E-F issues on livelihoods. The framework assesses the environmental livelihood security of multi-scale systems. It uses
baseline spatial data for decision-making and considers livelihoods within the concepts of the nexus. In addition, the framework provides insight to future change through accounting for potential environmental and livelihood pressures and thus enables solutions for sustainable development. Ellie Biggs illustrated with examples from Southeast Asia and Oceania that the framework seems to be a promising approach.

**Joseph Alcamo: Applying systems thinking to nexus research**

Joseph Alcamo of the Center for Environmental Systems Research, University of Kassel, suggested a systems approach with emphasis on critical linkages. He explained the importance of critical linkages by pointing to the fact that in the end everything connected to everything else. Thus, it is critical to answer the questions: What are priority linkages? What are factors that should be investigated? Critical linkages are also important to build models for problem analysis and strategy development and to identify possible policy leverage points.

Non-linear feedbacks are still a construction side in large integrated assessment models. To identify critical linkages, he suggested a sequence of (1) participatory systems mapping (e.g., causal loop diagrams, systems dynamics diagrams and cognitive maps, amongst others), (2) scoring of critical linkages, and (3) development of integrated models.

Critical linkages can be determined for particular boundary conditions, such as spatial settings (e.g., local-regional-global), time periods / time horizons, and combination of issues. Systems mapping can be applied for problem scoping and identification of all linkages. Cross impact analysis supports the preliminary identification of critical linkages for specific conditions and policy leverage points. Finally, modelling and scenario analysis allows for detailed investigation of critical linkages for a range of conditions and policy leverage points.

**Annukka Lipponen: Assessment of the Water-Food-Energy-Ecosystems Nexus in Transboundary Basins: the framework**

Annukka Lipponen of the UNECE Water Convention secretariat reported on an assessment of W-E-F related challenges and governance issues in trans-boundary basins. Nexus assessments under the UNECE Water Convention are part of the 2013-2015 Programme of Work under the UNECE Water Convention (a global instrument), adopted by the Parties. A continuation to 2016-2018 has been endorsed that will involve more basin assessments.

A task force on the Water-Food-Energy-Ecosystems Nexus has been established to guide the work and to provide oversight. Its aims are to foster transboundary cooperation (intersectoral synergies & measures to reduce tensions) and assist countries (resource use optimization, capacity building). Assessments are prepared in close cooperation with and reviewed by the national administrations. A meeting of the Parties endorsed the methodology and general conclusions in November 2015.

The nexus assessment framework contains six steps (see Table 1). Annukka Lipponen illustrated the framework with results from three basins in which serious W-E-F governance deficits exist. As consequence, there are considerable problems in particular with hydropower and irrigation.
Annukka Lipponen drew a number of conclusions. First, many countries grapple with integration. IWRM is already challenging and the nexus approach even increases ambition. It is essential that intersectoral coordination and consultation, consideration of different interests and integrated planning are happening. Second, clear and accessible communication is needed to ensure attention to the conclusions of a nexus approach. Third, an active, sufficiently broad participation and commitment from the countries is necessary to shape the assessment process into a valuable exercise that focuses on relevant policy issues. Fourth, already the intersectoral-transboundary dialogue has value, but adequate data and support tools are necessary for a meaningful analysis. Fifth, the result of the nexus assessment may be controversial to a sector or a country, which requires proper design of the process and the institutional framework to ensure acceptance. Finally, the application of the nexus approach should build on the existing structures and processes: e.g. multisector structures and intersectoral processes (SEA etc.), amongst others.

### Antje Bruns: Political Infrastructures

Antje Bruns of the University of Trier argued for a central role of "political infrastructures." This refers to the political dimension of infrastructure and development. Infrastructures as socio-technical system structures form a major part of the material metabolism in societies. Infrastructures are central in establishing societal relations to nature and catalysts for environmental problems. A reshaping and reconfiguration of the linkages between consumption patterns, infrastructure, and the state of ecosystems is needed. This process should acknowledge the inherently political nature and implications of (networked) infrastructure. Infrastructure generally works at interfaces between nature and society, between provision and consumption, between different sectors (water, energy, food, transport...), between the urban and the rural, between distant places, between the past, present and the future.

Resource flows through cities are conducted by complex networked infrastructures which, in turn, have been designed, built, and operated in accordance with a particular set of technical modalities and governance routines. Antje Bruns suggested the identification of critical linkages in the W-E-F Nexus with infrastructure as an analytical entry point. Changes in one sector may

### Table 1: Nexus assessment framework

<table>
<thead>
<tr>
<th>Step</th>
<th>Location</th>
<th>Sectors</th>
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<tbody>
<tr>
<td>1</td>
<td>Identification of basin conditions, the socio economics</td>
<td>Desk study</td>
</tr>
<tr>
<td>2</td>
<td>Identification of key sectors and stakeholders</td>
<td>Desk study</td>
</tr>
<tr>
<td>3</td>
<td>Analysis of the key sectors</td>
<td>Desk study/ 1st Workshop</td>
</tr>
<tr>
<td>4</td>
<td>Identification of intersectoral issues</td>
<td>1st Workshop</td>
</tr>
<tr>
<td>5</td>
<td>Nexus dialogue and future developments</td>
<td>1st Workshop</td>
</tr>
<tr>
<td>6</td>
<td>Identification of opportunities for improvement</td>
<td>1st &amp; 2nd Workshop/D desk study</td>
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lead to changes in other sectors. For instance, droughts and low water levels have an effect on cooling water availability and hydropower generation. Energy shut downs affect efficiency and resilience of other sectors, such as water supply sector.

Antje Bruns highlighted the importance of the socio-political dimension of infrastructure. Securitization is an extreme form of politicisation. “Politicisation makes an issue relevant and involves responsibility, securitisation, on the contrary, involves the urgency of a threat, which legitimises actions outside the normal bounds of political procedure” (Sinha 2005, S. 320–321). Infrastructures have been for a long time invisible/absent from public debates (in the global north, though the situation in the global south is different in that respect). Infrastructures matter politically, both discursively and as a set of materials.

An agenda for studying the W-E-F-Nexus through an infrastructure lens requires the acknowledgement of the inherently political nature of infrastructures in the making of the water/energy/food metabolism. Critical links between infrastructures need to be identified and their cross-sectoral resilience assessed. This can lead to the identification of leverage points to reshape infrastructures and ultimately the societal metabolism.

Panel 3: The role of governance in the management of the W-E-F

Chair: Claudia Pahl-Wostl

The panelists in this session included Joyeeta Gupta, Aiko Endo, Ines Dombrowsky, Martin Keulertz, and Mathew Kurian.

The Panel elaborated on governance issues in the W-E-F Nexus by exploring the scope, present status and opportunities for improvement. Speakers were asked to address the following questions which were then further discussed in the governance break out group:

- What are governance challenges regarding a sustainable management of and enhancing resilience and security in the W-E-F Nexus?
- At which level could and should the W-E-F Nexus be governed?
- What are promising governance instruments to govern the W-E-F Nexus?
- To which extent is governance of the W-E-F Nexus limited by a lack of information?
- What are the requirements for governance to make use of the potential of new information from Earth System Observations to support a sustainable management of the W-E-F Nexus?

Joyeeta Gupta: Role of governance in Nexus

Joyeeta Gupta of the University of Amsterdam summarized governance approaches at different levels from the local to the global. Governance instruments at the global level include discourses (hegemonic, neo-liberal, goals (e.g. SDGs)), principles (e.g. Rio Principles), rules regarding public/merit goods/common heritage of humankind, human rights and ecosystem standards (e.g. 2 degree target), amongst others. Instruments at transboundary level can support equitable sharing of water resources. Instruments comprise standards, planned measures, no harm principle, and liability and compensation. Instruments at national level include the national level goals, targets, indicators, human rights, Social and Environment Impact Assessment and Payment for Ecosystem Services, amongst others. Instruments at project/local/household level
can relate to the governance of infrastructure, social and environmental management plans on food, energy and water nexus and livelihood approaches, amongst others.

Joyeeta Gupta emphasized the absence of systemic governance instruments as a major challenge. Furthermore, she highlighted that instruments are not politically neutral. Interests and preferred ideologies (e.g., neo-classical economic) may lead to the preference of some instruments over others.

**Aiko Endo: Methods of the Water-Energy-Food Nexus**

Aiko Endo’s presentation had a broader scope. She introduced the W-E-F project in the Asia-Pacific Ring of Fire coordinated by RIHN (Research Institute for Humanity and Nature). Case studies are quite local. She pointed to the potential of Earth System Observations and global models to put local studies in a global context. Case experience suggests the need to develop appropriate indicators and to provide policy options to local policy makers.

Aiko Endo discussed the pros and cons of qualitative methods for studying the nexus. For instance, a questionnaire survey allows for incorporating the local people's general outlook, collecting information to analyze W-E-F interlinkages when few data exist, and identifying key issues. An ontology offers a list of common conceptual terms that are understood among researchers and practitioners. An ontology can thereby help to assess whether the policy/plan would cover all disciplines including natural sciences, social sciences and the humanities, and sectors such as W-E-F. An integrated map provides an opportunity to share knowledge showing actual conditions at a spatial scale amongst stakeholders. However, drawbacks of these methods are that they are site-specific and that they allow only limited spatial and temporal applications. A physical model helps to understand the W-E-F Nexus system. However, the results of an integrated model simulation without social and local knowledge may lead people to misconstrue the model's results if the numbers from simulations are unrealistic for political, economic and other reasons.

**Ines Dombrowski: Reflections based on an ongoing DIE project**

Ines Dombrowski of the German Development Institute (DIE) presented a DIE project to study instruments implementing the W-E-F Nexus in two hydropower projects in Africa’s great lakes region. Dams on shared rivers create up- and downstream interdependencies. Thus, water for irrigation upstream reduces availability downstream and hydropower projects upstream affects hydropower projects, water use and ecology downstream. In addition, land-use changes (deforestation) upstream impairs downstream hydro power generation. The research questions in the project are: What are the interests of the W-E-F-sectors/actors and under which conditions may we expect coordination across sectors and borders? What are the role of River Basin Organizations and Regional Energy Organizations?

Ines Dombrowski concluded her talk with a number of hypotheses. First, some synergies can be found, but a number of goal conflicts between energy, water and environment sectors related to dams/hydropower are existing. Second, domestic regulation of dams/hydropower (hydrology, ESIA) plays an important role, however, may not necessarily take transboundary effects into account. Third, transboundary negative effects may potentially be further mitigated by interventions of international River Basin Organizations, however, impacts may be limited. Their effectiveness needs to be further explored. Fourth, downstream hydropower in addition to
upstream hydropower may motivate energy coordination across the cascade in Regional Energy Organizations (new actor!), but may be too narrowly focus on regulation of flow regime (the effectiveness needs to be further explored). Regional Energy Organizations could be interesting integrating actors. Finally with respect to data, the quantification of cross-sectoral (& transboundary) physical effects requires multiple data inputs. The role of big data needs to be explored and discussed (including economic valuation of effects).

**Martin Keulertz**

Martin Keulertz mentioned that the majority of analyses of the nexus have been difficult to translate into practice. In this vein, the nexus had become a vague concept which makes the concept itself difficult to communicate to those in charge of governing our natural resources: politicians and, increasingly, corporate managers. A useful start to look at the nexus is to first understand consumptive water use versus water withdrawals. Agriculture withdraws 70% of water, industry 20% and domestic water drawers around 10%. If we look at water consumption, domestic drawers consume 3%, industry 5% and agriculture/the food system champions the field with 92% of water consumption. This means that there are three supply chains that consume different amounts of water. The WASH (water and sanitation and health) supply chain merely consumes 3% because it can count on good technology to reuse water in most places around the world.

However, what all these three supply chains hardly take into account is the role of climate change. Climate change or more erratic rainfall or droughts exposes the vulnerability of the supply chains. They expose certain choking points where the three supply chains may get into conflict with each other. For example, hydraulic fracturing in the South-West of the United States may very well harm the interests of irrigation agriculture in some parts where the new oil and gas barons are active. China may face similar choke points with regard to coal extraction in the northern part of the country and its impact on the WASH supply chain. The three supply chains are governed differently. Only the WASH supply chain attaches a value/price to water. Both the energy and food supply chains give value to almost everything except for water. Water is the resource that is nowhere valued.

Martin Keulertz put an emphasis on corporate actors. Solutions would come from a financialization of water – accounting and pricing as solution. He thinks that water governance requires a greater financialisation of water. Only by understanding to give water a value, a supply chain managers in the headquarters of energy and food companies understands; financial managers in banks adhere to when assessing the funding of large-scale infrastructure such as power plants; and politicians understand when setting subsidies for farmers and the food industry. The value of water needs to be communicated, accounted and paid for from the farm to the consumer level. Of course, financialisation has its potential risks. Farmers and companies could cook the books; banks could pay lip service to water. It is indeed an uphill struggle but, according to Martin Keulertz, a necessary one to leap the nexus from a theoretical concept that fits all purposes to a basic framework that can influence those in charge of managing natural resources.
Panel 4: Land, Climate and Energy issues and their interlinkages

Chair: Kym Watson

The panelists in this session included Salman Siddiqui, Dirk Schwanenberg and Gerhard Rappold. This panel aimed at exploring the constraints that land, climate and energy impose on the W-E-F and identifying how an integrated approach to the W-E-F could change the nature of those constraints.

Salman Siddiqui: Where the crops meet water: mapping the irrigated and rainfed areas of Asia and Africa

IWMI (International Water Management Institute) is working on Global Irrigated Area mapping (GIAM). The availability of data at higher spatiotemporal resolution and greater computing power gives rise to an opportunity to update GIAM with new data and algorithms.

There are several research challenges presenting also opportunities: a) classifying high resolution pixels for fragmented agriculture, b) developing enhanced analytical tools (e.g. based on Fourier analysis) to better differentiate spectral signatures of irrigated and rainfed areas, c) improving performance of rapid, automated mapping techniques using coarse resolution satellite images, d) providing and applying ground truth data.

Irrigation is a crucial component in the water-energy-food nexus; it is already happening in Asia, and might happen soon in Africa. There is a compelling need for better irrigation monitoring systems for agriculture, water resources, and energy policies and investment plans in Asia and Africa. Technology advances, but significant gaps remain to map small scale irrigation using satellite images. Continuous monitoring and evaluation also requires consistency in data sources and mapping approach.

Dirk Schwanenberg: Constraints that Land, Climate and Energy impose on the W-E-F Nexus

Sustainability of projects and maintainability of tools is an important issue. The Netherlands Hydrological Instrument is sophisticated operational tool for integrated water management and policy analysis, but is only applicable to the Netherlands. In general, forecasting and decision support tools need extensive customization for data and models in close cooperation with the stakeholders. In developed countries there is a wide range of tool users and reliable data sources. In emerging and developing countries the most successful users are semi-private and private companies that are the problem owner. There is a strong research requirement for robust tools considering data and model uncertainty (e.g. weather prediction). The target is to provide multi-objective decision support.

Deltares is putting more research emphasis on the W-E-F Nexus. But is IWRM outdated? What is the relationship to the W-E-F Nexus? Many people have studied IWRM and cannot identify themselves readily with the Nexus. We need to gain acceptance by the end user for a nexus approach. Innovations will be technology driven and not primarily Nexus driven.
Gerhard Rappold: Realization of the Water Energy Food Nexus

The W-E-F Nexus approach is hard to sell. The Nexus should be seen as a building block for the SDGs. The development of a W-E-F Nexus approach must consider human needs. Its underlying governmental implementation should however be kept in sectors as a “super Ministry” would not work in practice. In the MENA Region, the League of Arab States has W-E-F Nexus activities supported by GIZ project work and has issued a draft roadmap of the Regional Dialogue on the Nexus Water, Energy and Food Security.

The significance of economic parameters is apparent in the case of solar power in Jordan: by switching from agricultural production to solar power production an operator can increase his earnings from 200€/year/1000m² to 1000€/year/1000m². The increased income can be spent on food imports instead of fossil fuel for energy generation. This shift also reduces ground water abstraction.

GIZ is applying a Nexus and livelihood approach for rural areas in India, combining the aspects of electricity supply, biofuel, irrigation and food production. Together with FAO and on behalf of BMZ, GIZ is a leading partner of the W-E-F Nexus High-Impact Opportunity in the UN Sustainable Energy for All (SE4ALL) initiative.

The overall goal is to contribute to the achievement of the SE4ALL objectives through better use of the W-E-F Nexus perspective and by fostering synergies between the different sectors. This will include the consideration of the W-E-F Nexus perspective at policy and implementation levels in order to ensure improved energy access and energy efficiency, as well as augmented use of renewable energies.

Knowledge management and dissemination of best practices is critical to promoting the W-E-F Nexus and engaging stakeholders. The portal http://www.water-energy-food.org/ has been launched by GIZ for this purpose. GIZ is also working on a Nexus Resource Platform to present regional nexus dialogues. Ideally, dialogues should lead to the development of policy recommendations and action plans. Outputs should be endorsed at regional and national level.

Panel 5: Earth Observations and Information Systems

Chair: Joseph Alcamo

The panelists in this session included Adrian Strauch, Heather Price, Richard Lawford, Chris Mannaerts, Anne Gobin, and Paul Philippe Mathieu.

Pierre-Philippe Mathieu: Earth Observation in the Digital Age

Pierre-Philippe Mathieu of ESA gave a comprehensive overview of Earth observations in the digital age. He noted new trends that affect the evolution of data systems, including “big data,” Earth observations, the Internet of Things, social media, crowdsourcing, and digital technologies and communities. These developments will all have an impact on managing the W-E-F Nexus. The majority of our food comes from 37% of our land but at the same time over 180,000 individuals migrate from rural areas to cities every day, contributing to food insecurity and variability in crop prices.
The UN has been discussing the data revolution in the context of sustainable development. The data revolution will be responsible for changes in data volumes, variety, velocity, and openness. New concepts and technologies such as citizen observatories, drones, and the Internet of Things accelerate these trends. Planet Pulse extracts information from these large data flows and provides insights from the community to the global scale. Mobile devices and open data policies greatly expand the public's access to this information.

Earth observations are also entering a new era. ESA is launching a Sentinel series that will provide global, high-resolution, sustained, high-quality data through open data archives. The Sentinel satellites are directly relevant to the W-E-F Nexus and will include Sentinel-1 (radar mission), Sentinel-2 (high-resolution optical mission), Sentinel-3 (medium-resolution imaging and altimetry mission), Sentinel-6 (altimetry mission), and a special multi-variate mission that will be directed at Essential Climate Variables.

The digital revolution will promote new approaches such as automated data-model workflows to help scientists focus on science rather than IT. Calculations will be carried out by software at the data archive. Some of the priorities for this new approach include open science and innovation, new economic models, the digital single market, and new interactions between consumers and data producers.

**Adrian Strauch: Wetlands and the W-E-F Nexus: The co-creation of satellite-based information and knowledge for enabling sustainable use of wetlands.**

Wetlands link water, energy, food, and the environment. Wetlands provide important ecosystem services that support water security (pollutant removal, flood protection) and enhance food security (rice production, firewood for cooking) and energy security (hydropower, water storage). He described the Satellite Wetlands Observation System (SWOS) project, which will use satellite data to provide a service to pinpoint wetland policy and monitoring needs; generate mapping products and indicators on wetland ecosystems; provide training courses; generate a knowledge base, toolbox, and infrastructure; and support informed conservation and restoration measures.

SWOS data systems are being developed through collaborative efforts with projects initiated by the Ramsar Convention on Wetlands. The system tailors products to user and policy needs and provides a wetland network and knowledge hub that will bring together expertise and knowledge from all relevant disciplines and sources. SWOS is also developing a mobile app that can be used as a platform for crowdsourcing. SWOS and GWOS wish to be partners in the W-E-F Nexus project and are interested in working on Nexus topics at different test sites.

**Heather Price: The Role of Geospatial Information for Assessing Environmental Livelihood Security in the South Pacific**

Heather Price presented a case study using the environmental livelihood security (ELS) framework. Her project is a concrete application of the ELS Nexus framework. The case study was carried out in the Ba river catchment in Fiji. The W-E-F issues faced by Ba communities arise primarily from floods, drought, dredging, land erosion, and mining. Based on a review of community experience to enrich stakeholder engagement, models were processed, missing datasets were identified and acquired, and results discussed with the community and other stakeholders.
Clean water is needed to ensure a healthy population. Data on the percentage of population with access to improved drinking water and sanitation were obtained from population surveys. Other health data were obtained from health centers and mobile phone data. Water data were obtained for water levels (in-situ monitoring), precipitation patterns (meteorological models), land use (high-resolution imagery from drones), and water quality (satellites) data. Future work will include the identification of appropriate ELS indicators in the Bac catchment and sourcing/commissioning datasets to provide indicator data and other case studies in the Mekong Basin, Cambodia, and the western Australian wheat belt.

**Rick Lawford: Satellite Observations in Support of the Water-Energy-Food Nexus**

Rick Lawford presented on NASA satellite observations and products in support of the W-E-F Nexus. NASA's applications division encourages the adoption of NASA data and tools by decision-makers and operational agencies in the areas of disasters, ecosystems, health, and water as well as other societal benefit areas including agriculture and energy. Data used in planning include precipitation measured with the Global Precipitation Measurement mission. Various missions enable the derivation of evapotranspiration and irrigation water use estimates and land use change assessments, like soil moisture data used in agricultural forecasting from the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) and NASA's Soil Moisture Active Passive (SMAP) missions and groundwater variations measured with the Gravity Recovery and Climate Experiment mission and MODIS and LANDSAT land surface data. In the future (and if approved), water levels will be measured by the Surface Water (SWOT) mission.

NASA has also developed the Global Agricultural Geo-monitoring Initiative to coordinate satellite monitoring observation systems in different regions of the world in order to enhance crop production projections and weather forecasting data thereby improving market information and transparency. NASA’s policy of free and open data access has expanded use of the data worldwide and generated large returns from its investment in EO missions. Together with USAID, NASA has established SERVIR hubs that make satellite data available on a regional basis. Hubs are located in Panama, Nepal, Kenya, and Vietnam; another hub will likely be established in West Africa in the near future.

**Chris Mannaerts: Use of near real time Earth Observation Data and open Tools for water - ENERGY - food NeXUS and security analysis**

Chris Mannaerts of the University of Twente gave an overview of the use of near-real time Earth observations and open tools for W-E-F Nexus security analysis. He focused on GEONETCast, a global data dissemination system of GEO that provides free near real-time environmental and Earth observation data and derived products to a worldwide user community using a telecommunication satellite-based data distribution system.

ITC supports GEONETCast with its ILWIS Open GEONETCast TOOLBOX v.3.72, which facilitates visualization and the processing of scientific satellite data. GEONETCAST carries satellite and in-situ data streams that support the W-E-F Nexus, including water security (precipitation, evapotranspiration, soil moisture, water quality); energy security (solar radiation, wind energy data); food security (land use/land change data); and agricultural and hydrological forecasts. Chris demonstrated a range of GEONETCast applications including the use of apps and products to provide water productivity estimates for cropland and support a water use monitoring system. He also showed how these toolboxes are being applied in Ethiopia to assess the number
of people at risk from drought and in China to assess Guanting reservoir riparian area emissions and their effects on air and water quality.

Chris concluded by noting that the W-E-F Nexus needs quantitative and timely open information globally, better resource use efficiency in all three sectors, and better couplings of water governance to agriculture, energy, and society. Earth observations provide "transparent" global data and geo-information for Nexus studies in real time if needed, enabling more assessments to be carried out using observational modeling. Chris also suggested that W-E-F Nexus studies should first engage in pilot projects where appropriate cross-sector data analysis and interaction can be readily achieved and evaluated.

**Anne Gobin: Earth Observation & information systems for the W-E-F Nexus**

Anne Gobin presented on Earth observation and information systems for the W-E-F Nexus based on her experience with the VITO system. She identified global trends affecting the Nexus including climate, resource availability, population pressure, and urbanization. To address W-E-F and Land Nexus issues, we must provide data at appropriate spatial scales and work with users to define the appropriate information and spatio-temporal scales. The system will need to be built on those needs to the extent they are matched with the scales at which the information can be supplied. New capabilities are emerging such as the Sentinel-2, which can provide data appropriate for agricultural monitoring.

VITO has developed a 17-year archive of globally harmonized vegetation products. Crop growth can be monitored using various tools. The choice of indicator is based on the needs of the stakeholder. Information is made available through web-based applications, information dashboards, and time series viewers. Anne noted that within the W-E-F Nexus, remote sensing has a critical role in delivering information from the field to global scale at different temporal resolutions. Remote sensing provides geospatially consistent and harmonized data, develops policy support, plans advice, and facilitates the assessment of W-E-F Nexus efficiencies. Challenges revolve around stakeholder interactions (user requirements) in terms of data processing and analysis and the exploration of options. This involves clarifying concepts such as land cover to use in monitoring by selecting the appropriate app, flexible approaches to monitoring, modeling, tool development, and big data management.

**Panel 6: Panel on Management and Capacity Development (Needs, Opportunities, Funding)**

*Chair: Jelena Stamenkovic*

The panelists in this session included Chris Mannaerts, Holm Voigt, Peter Viebahn, Albert Sodemann, and Pedro Sanz.

**Chris Mannaerts: Capacity development for water - ENERGY - food NeXUS and security analysis: people, systems & information**

At the beginning of his talk, Chris Mannaerts asked the question about who are the addressees of capacity development. The W-E-F Nexus requires integrative multidisciplinary science teamwork so that a range of stakeholder needs can be addressed. Social and political scientists...
are needed to deal with qualitative and quantitative data (e.g., census data). In addition, economic and law scientists are required to deal with economics, management, communication, and law issues. Natural scientists (physics, mathematics, hydrology, agriculture, natural resources, biogeochemistry, health, marine, geology, engineering) are also important to consider climate sciences, geospatial sciences, remote sensing, complex systems, amongst others. In the end, systems thinking and approaches can be the “glue” that helps to bind these different perspectives together.

Chris Mannaerts also differentiated the societal roles of stakeholders. First, there is a Research & Development (R&D) track that includes researchers, as mentioned in the previous paragraph, and system developers. In addition, there is a leadership track including decision and policy makers, and an expert track of professionals and operational scientists. These different tracks have specific training needs. The leadership track requires an introduction to concepts, strategies and benefits to allow integration of concepts into daily livelihood. The expert track demands more in-depth operational use and implementation of nexus concepts drawing upon existing system use and data management approaches. The R&D track requires integration of new science elements by system developers and researchers.

Chris Mannaerts proposed a number of curriculum elements for capacity building. These include system dynamics thinking and analysis approaches and geospatial concepts. In addition, the development of knowledge about the W-E-F system, understanding of human and climate interactions (connectivity), energy resources, water cycle/chain and agricultural production, as well as environment and ecosystems is required. Further important aspects for capacity building are the teaching of how to use data and information sources (incl. earth observations) and communication methods, skills and dissemination.

In conclusion, the W-E-F Nexus concept is already well known in “systems research” circles, but somewhat new in more “sectoral” disciplines where capacity development is needed. Spatial systems thinking approaches are essential for knowledge integration. Easy open access to resource data incl. satellite and in-situ data, combined with other data sets (e.g. social, economics) is also needed. Use of open source tools are recommended to foster rapid uptake of concepts and design of own nexus applications for land, water, energy. The goal should be to capacitate more people in Nexus W-E-F resource analysis and management - not only scientists, but also the application sector and public.

Holm Voigt: Thoughts on Capacity building in the W-E-F Nexus

Holm Voigt of the SWFP presented the Aral Sea catastrophe as a nexus example. Based upon experiences from an afforestation project, he highlighted the need to balance several aspects of nexus issues, such as the institutional framework, hydrology, economy, forestry and spatial assessments. Nexus research should also assess on the incentives of actors in problem situations. There is a need to develop the capacity to practically apply the nexus concept. Knowledge brokers can play a key role in this respect.

Peter Viebahn: Integrated energy and water resource planning to overcome challenges in MENA

Peter Viebahn of the Wuppertal Institute for Climate, Environment and Energy started his presentation by showing the need for an integrated water and energy resource planning in the
MENA region. There is a rapidly increasing water gap identified in most climate change scenarios for MENA, so that energy intensive water desalination will be of high importance in all countries in future. Additional electricity demand induced by the water sector is hardly considered yet in most scenarios although this might increase the electricity demand by almost 40%. The example illustrates core of the energy-water nexus in the MENA region, which can also be extended to an energy-water-food (-resource)-nexus. It is also a good example for illustrating the need of capacity building, as the lack of the additional electricity demand induced by the water sector also illustrates the insufficient collaboration between relevant stakeholder groups.

Peter Viebahn presented a participatory scenario building approach as a potential capacity building and policy integration instrument. Experiences from a GIZ consulting project in Tunisia was presented where different stakeholders were included in the scenario development project. Fifty stakeholders participated in the review and approval of core modelling issues. Scenarios were discussed and modified based upon stakeholder input, and a final electricity generation scenario (mix in 2030) was adopted. The chosen scenario became the basis of current Tunisia Energy Plan.

Peter Viebahn concluded with some comments on the needs and opportunities of a nexus approach in general and the presented participatory scenario building approach in particular. Thus, interdisciplinary research is needed to address interfaces of the water-energy nexus at different levels and to consider relevant stakeholders. The participatory approach that was presented resulted in substantial learning effects with respect to long-term and dynamic thinking as well as multi-criteria assessment. High acceptability of final "Tunisian scenario" was achieved, as stakeholders "made" it by themselves instead of relying on external consultants. Capacity building is necessary for science, as funding opportunities for methodology development and increased effort has to be offered. Capacity building in the policy sector is also required to allow for policy integration by building-up organizational structures and funding of applied research.

Albert Sodemann: High Potencial – Poor Performance: Nexus Based Regional Planning - Case of Colombia

Albert Sodemann presented various examples of nexus issues in the Colombian river systems. In addition, he highlighted conflicts between small-scale farming and large-scale capitalistic farming. There is an ancient clean indian technique to make fertile tropical moisty soil using charcoal (Terra Preta), but which is considered to be outmoded today. Instead, a plantation economy based on industrial agrochemical input with high environmental footprint is considered to be more competitive.

The W-E-F Nexus plays a key role in Colombia. For instance, 81% of energy production depends on hydropower. The impact of climate change caused a reorientation in public water management politics prioritizing energy security based on fossil fuel resources. There is a high potential of biomass energy production which is partially exploited for biofuels (ethanol, biodiesel) under protected market conditions (still at a very low level using sugar cane and oil palms, covering only 0.1 % of power demand). The government is investigating the use of fracking and ground sea exploitation of oil and gas deposits with high exposure to environmental risks.

Nexus governance is currently dominated by sectorial planning. Centralized decisions are made on mining which have gravely negative impacts on regional and local levels. Water management
is still at the beginning in Colombia. In addition, sustainability programs concerning food are missing completely.

Albert Sodemann made some final observations regarding the needs of capacity development. Capacity development is needed to acquire appropriate data that allows for focusing efforts and controlling outcomes. In addition, excellent educational programs concerning W-E-F topics are needed. Further needs are good management practices on all levels of governance and entrepreneurial craftsmanship, funds for enduring efforts, and local or regional pilot projects. Research and practice should start with comparatively simple approaches (fractal way) and form a strong international W-E-F-Nexus Network.

**Pedro Sanz: SPAIN – NAVARRA scenarios**

The SPAIN – NAVARRA scenarios aim at flash floods prevention and mitigation in mountainous forested areas, as well as scarcity and flood prevention and mitigation in flat farming areas. Further topics of the scenarios are related to water quality for urban uses, water cost for farming and industrial uses, and interbasin water transfer.

The Spain scenario showed the value of a nexus approach, as a way to improve scarcity and floods impact. Renewable (wind and solar) energy can be more widely integrated by water pump energy storage. Negative aspects are the competition between water, energy and food sectors, as well as the uncertain impacts of climate change. Governance and management require moving (1) from competition to collaboration, (2) from remediation to prevention, and (3) from average to focused solutions. Some example topics that require a nexus approach are water dams that are also used as energy stocks and irrigation resource, adverse phenomena prediction, and high definition local weather forecasts (Time and Space) instead global trends.

**Presentations**

**Science Session 1**

**Kym Watson: Overview of EU expert group study on the Junction Health, Environment and Bioeconomy**

Kym Watson gave an overview of the conclusions of an EU expert group study on the Junction Health, Environment and Bioeconomy. The task of this group was to identify emerging, but not necessarily widely recognized, trends, to assess implications for the three fields Health, Environment and Bioeconomy and to identify the most promising scientific and research areas. The major conclusions of interest to the W-E-F theme were that systemic challenges require systemic responses, which need to connect global and local level understanding and action, from planetary boundaries to local resilience. Furthermore the study emphasized the importance of institutional and behavioral changes.
**Dietmar Kraft: Funding opportunities in H2020 for topics related to the Water-Energy-Food Nexus**

Dietmar Kraft reported on funding opportunities in the EU Horizon 2020 (H2020) program for topics related to the Water-Energy-Food Nexus. H2020 has a strong emphasis on "innovation actions" – use existing knowledge for improved instruments and services. The W-E-F Nexus is not explicitly addressed but there are many related topics where a W-E-F focus would fit. Identifying such opportunities requires some exploration of program calls.

**Science Session 2**

**Holger Hoff: An analysis of the Nexus activities across the German Development Cooperation project portfolio**

Holger Hoff of SEI presented a nexus portfolio analysis, which is providing tentative answers to the following questions: (1) how can a nexus approach add value to ongoing or new GIZ projects?; (2) how feasible is the nexus approach in these projects?; (3) how relevant is the nexus approach in the German Development Cooperation? GIZ's portfolio of (3000+) projects were filtered and 450 GIZ (and BGR) projects finally entered the nexus analysis.

Initial results show that some patterns and priorities for applying a nexus approach emerge, related to project type, context and region. More in depth analysis of the „top 15“ projects shows that resource and human security problems are often aggravated by inefficient value chains. The nexus approach is already built into most projects, e.g. by considering multi-functional production systems, agro-forestry, ecosystem-based approaches, climate smart agriculture and payments for ecosystem services. Land management and rehabilitation are mentioned as objectives in most projects, while policy coherence is not mentioned in any of the “nexus priority” projects.

Next steps comprise a backward analysis for selected projects to check whether the project history suggests a nexus approach and a forward analysis to verify whether the project success justifies or depends on a nexus approach. Future steps will comprise the mainstreaming of the nexus approach into one specific GIZ project (climate adaptation in the MENA region), the identification of cross-sectoral regional and national institutions and governance structures, and development of policy guidelines for nexus mainstreaming into national policies. In addition, a nexus typology is developed based on project type, context etc. in order to standardize and contextualize the mainstreaming of a nexus approach and enable the transfer of best (nexus) practices between projects and regions.

**Hans-Peter Plag: The Food-Water-Energy Nexus: A Challenge for the European Network of Earth Observation Networks (ENEON)**

Hans-Peter Plag presented the membership, governance and components of the ENEON organization. Several global nexus challenges were presented to highlight the need for nexus research and action. The nexus perspective requires understanding of the interdependencies between energy usage and availability, population growth, global change, food security, water security, and the global boundaries.
Hans-Peter Plag presented ConnectinGEO Task 5.6: “Interdisciplinary Challenge: Food-Water-Energy Nexus”. ConnectinGEO aims at linking existing earth observation networks with the science and technology communities, the industry sector and the GEOSS and Copernicus stakeholders. The next steps will be the identification of key players in the EO world, developing a link to GEO activities (e.g., Integrated Global Water Cycle Observations Community of Practice, GEOGLAM, volunteers are welcome), populate the GEOSS Knowledge Base with relevant information, and carrying out gap analysis.

**Breakout Discussions**

Two breakout groups convened to discuss science issues with regard to (1) Observations and Science and (2) Governance and Management.

**Breakout Group 1: Observations and Science**

*Chair: Adrian Strauch*

The breakout group on Observations and Science was structured along a number of questions.

1) What scientific understanding is needed in order to allow society to address Water, Energy and Food in a more integrated way and to effectively communicate these connections to the public?

The breakout group discussed the need to focus on the users of earth observations and take full advantage of the infrastructure that is in place. In addition, a dialogue with the public on the need for services from the W-E-F is required as well.

In addition, the definition of value chain(s) and the types of information that needs to be included in the nexus is an important task. The value chain will depend on the sector, which needs to be defined for the nexus, and requires a definition of the source of value (e.g. science, economics, ...). There are different levels of usage depending on where people are in the value chain.

It has to be recognized that it is the information from the data that has value. The group also discussed the potential of research network data to be open and easily accessed and available as soon as possible. There is also the need to be able to define and communicate the uncertainty or confidence in the data (change of input conditions, boundary conditions, models, etc). In some cases different scenarios are needed to reflect changes in basic commodity prices (oil, food, etc). Best practices need to be developed to determine when it is appropriate to use a particular data set for a specific problem (i.e., best practices). Another opportunity relates to moving toward more dynamic system outputs that reflect the variations in the critical variables. There is the need to better define metadata and communicate the metadata to the user. The quality of the data that is communicated to the public should be improved. The purpose of the collection of the data should also be included in the metadata. The group discussed the need to advance the nexus understanding through systems approaches, which should be the basis for the design of data collection systems and setting research priorities.
2) What benefits could be derived from better integration of information in relation to...

i) Management of the Water-Energy-Food Nexus

A benefit can be the identification of resilient solutions by ensuring that the needs of all of the other resource sectors are met. Another benefit is the minimization of unintended impacts and more stability in the system. A better integration could furthermore help to make the connections with the environment and land issues more explicit.

ii) Management of water resources

Benefits can also be related to the integration of surface water and ground water as well as the integration of the freshwater and the marine water for aquaculture. The integration of different perspectives of the regional water cycle can support better management. Finally, the application of desalination for enhanced water supply can also benefit from a nexus approach.

3) What are the observational needs to allow this integration (i & ii)?

First, it has to be ensured that appropriate spatial scales are being compared (e.g., national versus regional). There is also a need to have techniques and a platform for ensuring scale compatibility. Data availability is a prerequisite which can be improved by the development of proxy observations where real observations are not available.

Geographical units need to be selected that are appropriate for the problem. Another requirement is the building of confidence in the data sets so that people will use it and increase the value of the information. An inventory of appropriate social data should be developed to find ways of combining physical and social (in particular with respect to qualitative) data. A profile of virtual water flows at national and other appropriate scales was also discussed as a promising approach.

4) In what ways would the increased accessibility of data and analysis tools improve the coordination of the W-E-F Nexus?

An increased accessibility of data and analysis tools would make the research more efficient. Data providers should provide data in standardized formats. It should be ensured that data are adequate to track the movement of water and energy between the nexus elements. Increased accessibility of data and analysis tools would also increase the understanding and communication between sectors (through use of models).

It should be ensured that data are made available so that they are used in the right way. This includes national access to data collected by private companies where the data are of national value. This would support transparency and credibility in decision making.

Another need is to fund the continuation of data collection and the maintenance of tools and experts who are needed to curate the service (e.g. EC projects). Regional discussion and coordination should be promoted to build a basis for joint ownership of the resource or asset.
5) How can existing EO data, activities, and initiatives be brought together to make best use of already existing resources in a solution oriented approach?

Open and standardized metadata catalogues have been discussed as a promising approach. It should be assured that data latency is defined in the metadata. Synergies should be used in collecting the data (value of consolidating in a center). There is also the need to evaluate the data that exist in different portals.

High performance data hubs are required to enable users to make use of the Copernicus data. In addition, users will need to become knowledgeable on mixing small and large data processing capabilities. The development of transparency platforms for renewable energy studies can be another valuable approach.

Several questions were not discussed in the breakout group, but are highly relevant as well:

- What additional data and model development is needed to support predictions and scenarios required to better manage the W-E-F?
- How can information be used to close the “productivity gap”?
- What information and technologies are needed to expand the use of renewables in farming operations?
- What changes are needed in the W-E-F components to more effectively manage the W-E-F in a way that minimizes its impacts on environmental quality and biodiversity? What information is need to monitor opportunities and progress in this area?
- What factors must be considered in recycling waste water from energy and food systems? What data are needed to facilitate this recycling?
- What research and information is needed to improve the viability of producing biofuels?

Breakout Group 2: Governance and Management

Chair: Joyeeta Gupta

The breakout group on Governance and Management was also structured by a number of questions:

1) What are governance challenges regarding a sustainable management of and enhancing resilience and security in the W-E-F Nexus?

A question that was posed by the group is related to which instruments for policy integration are effective? An assessment of effectiveness is needed for instruments at different levels. Examples of potential instruments were mentioned to be Strategic Environmental Assessments, subsidies/taxes, PES, restrictions on uses /spatial planning, pricing, self-regulation, legislation, corporate nexus responsibilities (SCR), government reorganization directives, extraction/user fees, bans on certain activities (prohibitions), standards (water quality), reporting requirements
Further research questions were posed and discussed by group members:

- Would merging of responsibilities of ministries / authorities support a Nexus perspective – implementation?
- How do we get different actors together (across levels and sectors) to start thinking in Nexus terms?
- Where and how is memory preserved in the political system (civil service versus politician) for continuation in policy? Long-term vs. short term.

2) **At which level could and should the W-E-F Nexus be governed?**

The following research questions were addressed:

- Which social contracts (e.g. human rights, constitutional rules) are required?
- Which kind of contractual law (transparency) is compatible with the nexus perspective?
- What could be the role of policy experiments to address this question?

3) **What could be governance arrangements to support nexus governance?**

The following more specific research questions were posed:

- What can be the role of polycentric governance and hybrid governance arrangements?
- What is the role of coordination networks versus fusion of ministries?
- What is the potential role of task-forces?

4) **What are promising policy instruments to govern the W-E-F Nexus?**

A list of promising instruments is provided above (see question no.1 that was discussed in this breakout group). The following research questions related to instruments were asked by the group:

- How can one overcome the lack of systemic instruments?
- How could PES be made more systemic?
- What could be the role of integrated assessment approaches like strategic environmental assessment?
- Should regulation be more stringent rather than providing economic incentives (stronger emphasis on hierarchical governance mode)?
- Could clearer reporting requirements be an effective instrument and which indicators would be the most appropriate to address the nexus?
- Could a “nexus seal” or “nexus certificate” be useful to support “nexus-friendly” products or self-marketing of corporate strategies?
5) To what extent is governance of the W-E-F Nexus limited by a lack of information -- Which data are required for W-E-F governance?

The group discussed that different levels of detail are needed ranging from coarse to detailed data, depending on the research question. The following research questions were defined:

- Does data/information on administrative structures and procedures support nexus thinking?
- What kind of data is required for evaluating policy experiments?

Data on property and use rights could be particularly relevant to understanding W-E-F governance. Data on social impacts are also highly relevant, which can be gathered by making use of new information technologies (e.g., citizen science). Tracking implementation of policies with Earth System Observation is limited though, as one cannot track social and economic impact, but only secondary impacts.

6) What is / could be the role of EO in W-E-F governance?

EO can support the monitoring of the physical manifestations of social processes (e.g. water use, land-use changes). A number of research questions were formulated by the breakout group:

- Is the anonymity and privacy of data a potentially relevant issue for using EO data for W-E-F governance?
- Could there be competing legal demands?
- What kinds of services/tools are needed to translate data to actionable knowledge?
- Could there be governance challenges arising from the use of ES data?
- Do data-producers and scholars self-censor their data and why?
- What could be potential critical issues that can result from a nexus approach?
- Does EO require data from governance? What are political processes that lead to the design and implementation of EO programs (design, funding)
- What is the role of EO in the SDGs?

Further governance related questions – issues

The group discussed the concepts of decision theaters and boundary organizations as a means to improve the science-policy interface. Another discussion point was related to different questions that might arise depending on the research approach, ranging from more “basic” to “action” research.
Reflections on the Workshop Results

Claudia Pahl-Wostl reflected upon a number of governance issues with a research/science focus that were discussed during the workshop. Research on appropriate arrangements for W-E-F governance is required that address horizontal and vertical coordination. This also includes effective W-E-F governance instruments that apply a systemic approach. The availability of more data/information from EO provides opportunities as well as challenges for W-E-F governance (see governance breakout group results). Community building is needed to bring together scholars working on water, energy and food systems (not only agriculture – production) and those working on different levels. Contested issues are the following:

- How to define the W-E-F Nexus? What are the categories that determine what enters into a nexus approach?
- Should the W-E-F Nexus be framed in “security” terms?
- Does it make sense to approach the nexus from a sectorial perspective? Would this be a contradiction in terms?

A number of questions were also posed with respect to messages for and from policy-making:

- Which "policy audience" – "stakeholder groups" do we want to address?
- Which messages do we have for these different audiences?
  Should there be a shift from "optimizing" a single objective to "multi-objective” optimization or even stronger towards resilience and robust approaches rather than optimal approaches?
- Is the W-E-F a perspective we want to promote? How to connect such a message to prevailing policy and practice (e.g. those working on IWRM)?
- What messages could come from policy/practice to inform the W-E-F research agenda? How do we become responsive to those?

Rick Lawford concluded with a lists of (1) issues that seem clear, (2) issues where clarification is needed, and (3) issues where action is needed.

Issues that seem clear

Oliver Warweg outlined the challenges of energy production through the use of value chain mapping and showed areas where different aspects are affect by climate events such as drought. We need to consider how these complexities in dealing with energy can be mapped to other problems associated with climate and the Nexus.

Wolfgang Grabs suggested that the W-E-F Nexus could be a good mechanism for improving the integration of capabilities and institutions in the water sector.

Salman Siddiqui demonstrated the need for better satellite data and analysis techniques to resolve irrigation areas versus non-irrigation areas in places where agriculture is fragmented.

Dieter Kraft demonstrated the benefits of the Horizons 2020 for W-E-F studies. Funding opportunities exist but it seems to require some creativity in searching out the best opportunity for a given project.
Joyeeta Gupta showed the complexity of issue related to the implementation of W-E-F approaches noting that while instruments were available they were not always neutral, suggesting that the formal implementation of the W-E-F may require some positive political intervention.

Heather Price described a project in Fiji dealing with Environmental Livelihood issues in the Fiji Islands; they planned use for EO in the analysis, and plans to extend the work to other areas.

Anne Gobin described Vito’s comprehensive activities and products for addressing W-E-F issues at a number of scales. She noted the importance and challenge of stakeholder interaction.

Gerhard Rappold noted the difficulty of defining the W-E-F Nexus and listed a wide range of GIZ projects that are being carried out and are relevant to the W-E-F considerations.

Ellie Biggs described the successful application of the multiscale Environmental Livelihood security model.

**Issues where clarification is needed**

Holger Hoff demonstrated that techniques exist for analyzing the profiles of funded research. How can these techniques be applied to the information needs of the Future Earth W-E-F project?

Pierre-Philippe Mathieu demonstrated an impressive array of observational tools and concepts which are emerging. However it is unclear which of these tools should be promoted in the W-E-F discussion and how they can be applied in the near term to our work?

Kym Watson described an EC study on the Junction of Health, Environment & Bioeconomy (JHEB). The report notes the need to develop urban farming, fish farming and saline farming amongst others. Which of these issues should the FE W-E-F take as a priority (if any).

Jiaguo Qi identified the need for systems approaches to understanding the W-E-F Nexus. What should be the boundaries for a system analysis?

Bruce McCarl showed the importance of climate change for the W-E-F. What priorities should be attached to the vulnerabilities in the W-E-F and how can these pressures be addressed?

Dale Rothman reviewed a methodology for developing scenarios. Are there areas in the W-E-F where this approach is needed in the near term?

Hong Yang showed different approaches to the W-E and W-F economic linkages; however, the approaches for analyzing linkages for water in the W-E-F are limited. Are there indices that could be developed to represent these relationships?

Aiko Endo demonstrated an elaborate analysis system applied to a complex governance issue in Obama, Japan. The system of ontology engineering supported by surveys seemed to result in good solutions for marine issues. How can this approach be tested in other areas for other W-E-F issues?

Ines Dombrowsky demonstrated that broader approaches to regulations are needed to deal with W-E-F issues than just general water issues, especially where transboundary basins are involved. What aspects of food and energy issues move in the physical environment and can these be measured?
Adrian Strauch described a system under development for monitoring wetlands. This system may provide some tools for the W-E-F Nexus activity but more importantly would provide an environmental stakeholder for the W-E-F project. What interest would GWOS sponsor such as Ramsar have in the W-E-F?

Rick Lawford presented an overview of NASA activities and products related to the W-E-F. How do users best integrate their in-situ measurements with these data and what services can NASA SERVIR provide on mobile phones?

Joe Alcamo described the systems approach for diagnosing complex problems and showed how this could be applied to the W-E-F. What benefits would there be in applying this approach to diagnosing the critical aspects of the W-E-F? The Earth Observations and Information Systems Panel also noted the need to address information needs of a systems approach to the W-E-F to maximize the benefits from specific observations.

Annukka Lipponen described the UNECE approach to Nexus Diagnostics. Is there a role for these types of analysis to serve as a basis for comparative studies for basins across the world?

Albert Sodemann outlined possible W-E-F developments in Columbia. How can we effectively work with governments setting up basin plans based on the W-E-F concept to assist in their planning and to develop a learning space to evaluate W-E-F concepts?

Antje Bruns addressed the political and other infrastructure that affects the structure of the W-E-F. How do we document this infrastructure and the possible constraints it would place on the W-E-F development in a given area?

The Earth Observations and Information Systems Panel identified the need to define value chain(s) and the types of information that needs to be included in the nexus. How do we go about it?

Chris Mannaerts presented GEONetcast which seems to have had great success in developing countries. We should encourage the transmission of relevant information on the W-E-F using this technique. What is the best way to go about this?

**Issues where action is needed**

Bettina Schmalzbauer reported on the German Earth Summit. There should be some German representation at that meeting to make connections with other relevant German Future Earth projects.

The TAMUS/Future Earth W-E-F workshop in DC offered participants an opportunity to join a Community of Practice. Are Karlsruhe participants interested in the same offer?

The concept of virtual water is receiving substantial attention (e.g. Hong Yang): we should scope out a study for using the concept to address the W-E-F Nexus.

There are many activities related to the W-E-F being undertaken. How can we develop an inventory of these activities and identify their clear relevance to the W-E-F?

The benefits that can be derived from better integration of information in relation to the W-E-F are manifold. These should be documented and used to inform the skeptics.

We need to launch a best practices project (perhaps under GEO) on the best practices for using Earth observations in the W-E-F.
Outlook

Claudia Pahl-Wostl presented some opportunities for follow-up activities. An inventory of ongoing and W-E-F-related "policy experiments" could be established. This could also support comparative case study analysis that apply a diagnostic approach and allows (further) development of governance tools. Funding is needed for these activities though.

In addition, there is the opportunity to engage in the SDG implementation. Nexus indicators could be an innovative approach to analyze the interlinkages between SDGs. The SWFP could be used as a link to bring in a W-E-F Nexus focus into the World Water Development Report. Other future opportunities are joint publications and a potential proposal under the umbrella of Horizon 2020.

There are also various opportunities to contribute to ongoing activities. There is the opportunity to contribute to (shape) the W-E-F Nexus Knowledge-Action-Network to be implemented under the umbrella of Future Earth. The Scientific forum on “Understanding the Water-Energy-Food Nexus and its implications for governance” in Osnabrück May 2016 – financially supported by DFG – might lead also to a proposal for a new nexus-specific research focus in Germany. Another opportunity is the set-up of a working group under the umbrella of the SWFP (e.g. inventory of tools, synthesis of existing case studies, assessment of governance instruments etc.). The call for proposals made by the US National Science Foundation is also expected to launch a number of large studies to address key W-E-F Nexus issues. Finally, all participants of the workshop are invited to contribute to the next workshops of the cluster activity (Japan 2016 and workshop with SDG focus later 2016).
References


Acronyms
BfG  German Federal Institute of Hydrology
BGR  Federal Institute for Geosciences and Natural Resources
BMZ  Federal Ministry for Economic Cooperation and Development
DIE  German Development Institute
DFG  German Science Foundation
ELS  Environmental Livelihood Security
ENEON European Network of Earth Observation Networks
EO   Earth Observation
ESA  European Space Agency
ESIA Environmental Social Impact Assessment
EU   European Union
FAO  UN Food and Agriculture Organization
GEO  Group on Earth Observations
GEOGLAM Group on Earth Observations Global Agricultural Monitoring Initiative
GEOSS Global Earth Observation System of Systems
GIAM Global Irrigated Area Mapping
GIZ  Deutsche Gesellschaft für Internationale Zusammenarbeit
GWOS Global Wetland Observing System
GWSP Global Water Systems Project
H2020 Horizon 2020
ICSU International Council for Science
IOSB Optronics, System Technologies and Image Exploitation
IWMI International water Management Institute
IWRM Integrated Water Resources Management
JHEB Junction of Health, Environment & Bioeconomy
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<tr>
<td>KPC</td>
<td>Knowledge Production Centres</td>
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<td>LEAP</td>
<td>Long range Energy Alternatives Planning System</td>
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<td>MENA</td>
<td>Middle East and North Africa</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>R&amp;D</td>
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<td>RIHN</td>
<td>Research Institute for Humanity and Nature</td>
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<td>SEA</td>
<td>Strategic environmental assessment</td>
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<td>Stockholm Environment Institute</td>
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<td>UNECE</td>
<td>United Nations Economic Commission for Europe</td>
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<tr>
<td>USAID</td>
<td>US Agency for International Development</td>
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<tr>
<td>VITO</td>
<td>Flemish Institute for Technological Research</td>
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<tr>
<td>WASH</td>
<td>Water and Sanitation and Health</td>
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<tr>
<td>WEAP</td>
<td>Water Evaluation and Planning System</td>
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<tr>
<td>W-E-F</td>
<td>Water-Energy-Food</td>
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Appendices

Appendix 1: Agenda

PRE-FINAL

AGENDA (Version: November 22, 2015)
FUTURE EARTH WATER-ENERGY-FOOD NEXUS WORKSHOP:
“Assessment of the state of knowledge related to science, integrated observations, and governance in the W-E-F Nexus”
Fraunhofer IOSB (Fraunhoferstraße 1, 76131 Karlsruhe, Germany)

NOVEMBER 23-25, 2015

This workshop is the second in a series being held by the Future Earth Project: "Integrated Observations and Improved Governance for the Water-Energy-Food (W-E-F) Nexus."

(Unless otherwise noted all sessions will be held in the Max-Syrbe-Saal on Level 2)

Monday, November 23, 2015

08:15-08:45: Registration (IOSB Foyer)

08:45-10:15: Introduction (Chair: Kym Watson) (Max-Syrbe-Saal)
- Welcoming remarks and Introduction to the Fraunhofer Institute (Kym Watson, others)
- Introduction to GWSP and the FE Sustainable Water Future Program (Claudia Pahl-Wostl)
- Introduction to the Future Earth W-E-F Project and the purpose of this workshop (Rick Lawford)

Overview of priority W-E-F Nexus issues:
- Governance Issues (Claudia Pahl-Wostl)
- Science Issues (Rick Lawford)

10:15-10:35: Break

10:35-12:15: Panel on Trends in the W-E-F issues (Chair: Annukka Lipponen)
This Panel will explore the potential issues for specific sectors when they engage in the W-E-F Nexus

- Each panel member will make a 10-minute introduction, after which the floor will open for targeted discussion.

12:15-13:00: Lunch (Provided by the workshop)

13:00 – 13:30: European activities related to the W-E-F Nexus
- Kym Watson: Overview of EU expert group study on the Junction Health, Environment and Bioeconomy
- Dietmar Kraft: Funding opportunities in H2020 for topics related to the Water-Energy-Food Nexus

13:30-15:15: Panel on Frameworks for understanding the W-E-F Nexus by sector (Chair: Jiaguo Qi)
This Panel will explore ways to portray the interlinkages and interactions in Nexus
- Each panel member will make a 10-minute introduction, after which the panel and the floor will open for targeted discussion.

15:15-15:35: Break

15:35-17:15: Panel on the role of governance in the management of the W-E-F (Chair: Claudia Pahl-Wostl)
This Panel will elaborate on governance issues in the W-E-F Nexus by exploring the scope, present status and opportunities for improvement.
- Panel members: 1) Joyeeta Gupta, 2) Aiko Endo, 3) Ines Dombrowsky, 4) Martin Keulertz, and 5) Mathew Kurian
- Each panel member will make a 10-minute statement, after which the panel and the floor will open for targeted discussion.

**Tuesday, November 24, 2015**

08:30-08:50: Summary from Day 1 (Rick Lawford) (Room: Max-Syrbe-Saal)
- Introduction to Future Earth (Bettina Schmalzbauer)

08:50-10:15: Panel on Land, Climate and Energy issues and their interlinkages (Chair: Kym Watson)
This panel will explore the constraints that land, climate and energy impose on the W-E-F and will identify how an integrated approach to the W-E-F could change the nature of those constraints.
- Each panel member will make a 10-minute statement, after which the floor will open for targeted discussion.

10:15-10:40: Break

10:40-12:30: Panel on Earth Observations and Information Systems (Chair: Joseph Alcamo)
This panel will explore the contributions of observations, models to the W-E-F Nexus.

- Panel members: 1) Pierre-Philippe Mathieu (ESA) 2) Adrian Strauch, 3) Heather Price, 4) Rick Lawford (NASA) 5) Chris Mannaerts and 6) Anne Gobin
- Each panel member will make a 10-minute statement, after which the floor will open for targeted discussion.

12:30-13:15: Lunch (Provided by the workshop)

13:15-14:00: Presentations:
- Pierre-Philippe Mathieu: The Role of Digital Technologies in facilitating the use of Earth Observations
- Holger Hoff: An analysis of the Nexus activities across the German Development Cooperation project portfolio
- Joan Masó: The Food-Water-Energy Nexus: A Challenge for the European Network of Earth Observation Networks (ENEON)

14:00-14:15: Introduction to Breakout Groups

14:15-16:45: Breakout Groups meet (Groups will take breaks on their own time)
Participants will have the options of joining the breakout group of their preference.
1. Observations and Science (Chair: Adrian Strauch; Rapporteur: Richard Lawford) (Room: Max-Syrbe-Saal)
2. Governance and Management (Chair: Joyeeta Gupta; Rapporteur: Johannes Halbe) (Room: Tagungsraum on the ground floor)
(Note – Breaks will be scheduled by the breakout group chairs)

16:45 – 17:30: Reports from the Breakout Groups:
Observations and Science: Adrian Strauch
Governance and Management: Joyeeta Gupta
Discussion

19:00 - : Workshop dinner at Marianne's Flammkuchen Restaurant (flat rate cost 20€ pp)

Wednesday, November 25, 2015

08:30-08:45: Summary from Day 2 (Claudia Pahl-Wostl) (Room: Max-Syrbe-Saal)

08:45-10:15: Panel on Management and Capacity Development (Needs, Opportunities, Funding) (Chair: Jelena Stamenkovic)

This panel will focus on successes and failures in past capacity building efforts with a view to identifying some basic recommendations related to capacity building for future W-E-F capacity building activities.

- Panel members: 1) Chris Mannaerts, 2) Holm Voigt, 3) Peter Viebahn, 4) Albert Sodemann, and 5) Pedro Sanz
- Each panel member will make a 10-minute statement, after which the floor will open for targeted discussion.

10:15-10:35: Break

10:35-11:45: Summary Discussion
11:45-12:00: Workshop Summary, Conclusions and Adjournment

12:00-13:00: Lunch (Provided by the workshop)

There will be space for up to five posters (Format A0 portrait). Posters will be viewed during breaks and before and after sessions.
### Appendix 2: List of Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
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<tbody>
<tr>
<td>Alcamo, Joseph</td>
<td>Center for Environmental Systems Research, University Kassel, Germany</td>
</tr>
<tr>
<td>Biggs, Eloise</td>
<td>University of Southampton, UK</td>
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<tr>
<td>Bruns, Antje</td>
<td>University of Trier, Germany</td>
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<td>Chaves, Fernando</td>
<td>Fraunhofer IOSB, Germany</td>
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<tr>
<td>Dombrowsky, Ines</td>
<td>German Development Institute</td>
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<tr>
<td>Endo, Aiko</td>
<td>Research Institute for Humanity and Nature (RIHN), Japan</td>
</tr>
<tr>
<td>Fink, Thomas</td>
<td>Wuppertal Institute for Climate, Environment and Energy, Germany</td>
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<tr>
<td>Gobin, Anne</td>
<td>Flemish Institute for Technological Research (VITO), Belgium</td>
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<tr>
<td>Grabs, Wolfgang</td>
<td>German Federal Institute of Hydrology (BfG), Germany</td>
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<tr>
<td>Gupta, Joyeeta</td>
<td>Institute for Social Science Research, University of Amsterdam, the Netherlands</td>
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<tr>
<td>Halbe, Johannes</td>
<td>Institute of Environmental Systems Research, University of Osnabrück, Germany</td>
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<tr>
<td>Hoff, Holger</td>
<td>Stockholm Environment Institute, Sweden / Potsdam Institute for Climate Impact Research, Germany</td>
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<tr>
<td>Hou, Michael Z.</td>
<td>Energie-Forschungszentrum Niedersachsen, Germany</td>
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<tr>
<td>Keulertz, Martin</td>
<td>Humboldt University of Berlin</td>
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<tr>
<td>Kraft, Dietmar</td>
<td>Forschungszentrum Jülich GmbH/Projektträger Jülich, Germany</td>
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<tr>
<td>Lawford, Rick</td>
<td>Morgan State University, USA</td>
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<td>Lipponen, Annukka</td>
<td>United Nations Economic Commission for Europe (UNECE), Switzerland</td>
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<tr>
<td>Mannaerts, Chris</td>
<td>Faculty of Geo-Information Science and Earth Observation, University of Twente, the Netherlands</td>
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<tr>
<td>Mathieu, Pierre-Philippe</td>
<td>European Space Agency (ESA), France</td>
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<td>McCarl, Bruce</td>
<td>Texas A &amp; M University, USA</td>
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<tr>
<td>Pahl-Wostl, Claudia</td>
<td>Institute of Environmental Systems Research, University of Osnabrück, Germany</td>
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<td>Price, Heather</td>
<td>University of Sterling, UK</td>
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<td>Qi, Jiaguo</td>
<td>Center for Global Change &amp; Earth Observations, Michigan State University, USA</td>
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<td>Rappold, Gerhard</td>
<td>Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Germany</td>
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<td>Rothman, Dale</td>
<td>University of Denver, USA</td>
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<td>Name</td>
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<tr>
<td>Schmalzbauer, Bettina</td>
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<td>Schwanenberg, Dirk</td>
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<td>Siddiqui, Salman</td>
<td>International Water Management Institution/CGIAR, Sri Lanka</td>
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<td>Voigt, Holm</td>
<td>University of Bonn / Global Water System Project, Germany</td>
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<td>Fraunhofer IOSB, Germany</td>
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<tr>
<td>Yang, Hong</td>
<td>Swiss Federal Institute for Aquatic Science and Technology (Eawag), Switzerland</td>
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