> Georesource Water – The Challenge of Global Change

Approaches and requirements for an integrated management of water resources in Germany

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> CONTENTS

SUMMARY

Freshwater (from now on simply referred to as "water") is a precious good. It is one of the essential georesources. The most obvious uses of water properly occur in private households: we do the laundry and dishes; we cook, drink and water the plants. The largest share of water is, however, used by agriculture and industry. In particular, considerable amounts of water are used for power plant cooling in energy production.

Groundwater accounts for about one third (30.1 percent) of global water resources, while only a small share is contained in lakes (0.26 percent), wetlands (0.03 percent) and rivers (0.006 percent). A much higher portion is trapped in ice and snow and is thus barely available for utilisation.

Global change and its impact on water resources

Climate change, the globalisation of markets, demographic change, rapid technological developments and changes in land use all represent different facets of what is usually referred to as global change. While the impact of global change on available water resources differs from region to region, it is clear that the demand for water as a georesource keeps increasing. Already today, we see cases of interregional competition and conflict related to water usage. For instance, rising global demand for foodstuffs also entails an increasing need for irrigation in agriculture. Moreover, global change and the transformation of river landscapes will probably lead to increasing problems with flooding.

For these reasons ensuring sufficient availability and quality of water, as well as meeting the related challenges of water and flood protection, are key societal objectives. In this context, innovative adaptation strategies and new technologies may not only lead to more sustainable forms of water and land management but might also create new economic opportunities in the global marketplace. Germany can make a particular contribution to solving global water problems through the development and export of technologies and best practices.

Water resources in Germany

Germany is rich in water resources. Although the overall amount of water is ample, there are German regions with low levels of water resources available for utilisation, as well as regions whose water resources undergo considerable annual fluctuation. In terms of water resources, Germany is facing the following – existing or expected – challenges.

Climate change and water balance

In Germany climate change can be documented empirically. Particularly marked climatic changes have been observed in Southwest Germany, the Alpine region, and Eastern Germany. For many rivers, gauging has shown significant changes in the water balance over the past one hundred years. Whereas a number of rivers in the Western and Southern parts of Germany have experienced increased flooding events, other rivers now have less water or even dry up occasionally. Some regions are also confronted with changing groundwater levels. In parts of Western Germany there has been a considerable rise in groundwater levels over the past twenty years, while levels have dropped in parts of Northern Germany (especially in Brandenburg). In the future, we can expect noticeable impacts on available water resources especially in those regions where the water balance is already strained e. g. the German Lowlands. For some regions, we can foresee shortages in water supply for agriculture, energy industry and ecology e. g. for purposes such as agricultural irrigation, cooling of power generation plants or the preservation of wetlands. Against this background, accurate quantifications of water balances and efficient forms of water resources management will gain further importance in the years to come.

Water utilisation and water efficiency in landscapes

In the first instance the availability of water is usually measured on a local or regional basis. At this scale the availability of water resources is largely dependant on factors such as vegetation coverage and the specific types of land use. As a result of the increasing integration of the world economy, however, a global perspective has become ever more relevant. The trade of goods and their transportation have direct impacts on a country's water resources ("virtual water trade"). For example, water consumption in arid countries could be reduced not only by means of improved forms of local management, but also by (partly) substituting the local production of water-intensive agricultural products for imports.

What is more, water does not respect political borders. River basins often stretch across several administrative boundaries or even countries. For this reason, the European Water Framework Directive demands modes of water resources management based at the river basin level. In addition, it explicitly stipulates standards as regards informing, consulting and actively involving the public. Implementing these additional requirements for water management confronts political, economic and scientific actors with a wide range of tasks that can only tackled through working together.

Water quality

Ensuring water quality (and thus the preservation of high-quality water resources) can be assumed to be one of the key challenges related to water management in Germany in years to come. Of particular concern is the input of substances to the water system. Further intensification of agricultural production as a result of global change will increase the input of pollutants (e. g. crop protection products and fertiliser residues) in Germany as well. Apart from the long present and well-known problematic substances (e. g. heavy metals, radioactive iodine, CO_2 and nitrate), a range of "new" substances is increasingly apparent globally and could therefore be detectable in German waters soon. This input of substances has a negative effect on water quality and this will, in turn, have impacts on both human health and the environment.

The use of the subsurface may also, however, have possible consequences for the natural water cycle and water quality. There are already complex demands made of the subsurface, which is, among other things, utilised for purposes such as the abstraction of drinking water and disposal of waste products.[1]

Regulatory and institutional approaches for sustainable water management

Over the last twenty years the concept of "Integrated Water Resources Management" (IWRM) has become a key part of the international agenda. Integrated water resources management is described as a process that allows for the development of water and land resources (as well as the natural resources connected to them) in a way that ensures a maximum of both economic benefit and societal welfare without impairing the (sustainable) viability of the ecosystems concerned.

Although there is a general awareness in Germany and elsewhere about the close interrelationships between water and land use, the tendency to consider water and land separately still prevails in science, public administration and the economy. In particular, departments responsible for environmental protection at both the national and state level have to tackle existing deficiencies and – if necessary and possible – implement shifts in policy. The acatech POSITION incorporates a number of approaches and outlines requirements for promoting sustainable water resources management in Germany. The following **recommendations** are made:

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1 Essentially, the discharge of polluting substances into the groundwater is illegal. Exceptions may however be permitted under certain conditions, e. g. for disposing or storing sewage resulting from mining under the condition that the intake capacity of surface waters has been exhausted (e. g. saline leaches resulting from the extraction or processing of potash salt).

Climate change and water balance

(1) Improve hydrological quantification and communicate uncertainties more clearly

(2) Improve the standard of knowledge on the past variability of the water balance

(3) Optimise water resources management and establish risk management

Water utilisation and water efficiency in landscapes

(4) Reassess water in landscapes

(5) Promote water efficiency in agriculture through targeted measures

(6) Explore the functionality and possible applications of soil additives

(7) Raise awareness of methods of sustainable water use in both the economic sector and the general public

Water quality

(8) Avoid the discharge of undesired substances into the water cycle and eliminate them from sewage

(9) Conceptualise risk assessments for mixed substances and trace elements

(10) Promote the multiple use of water

(11) Monitor and ensure the hygienic quality of raw water and drinking water

(12) Consider the effects of using the subsurface on water

Regulatory and institutional approaches for sustainable water management

(13) Manage natural resources in an integrated manner

(14) Better connect theory to practice through strengthening regional networks

(15) Develop satisfactory forms of communication between science, economy, politics and the public

Cross-cutting issues

(16) Introduce integrated monitoring and systematise monitoring programmes

(17) Strengthen interdisciplinary and application-oriented research

(18) Promote future-oriented technologies and improve framework conditions for innovation

PROJECT

The acatech POSITION PAPER is based upon the acatech STUDY *Georessource Wasser – Herausforderung Globaler Wandel. Beiträge zu einer integrierten Wasserressourcenbewirtschaftung in Deutschland (Hüttl and Bens 2012).*

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We commissioned 13 expert reports on individual topics, which were then published in the series acatech MATERIALS:

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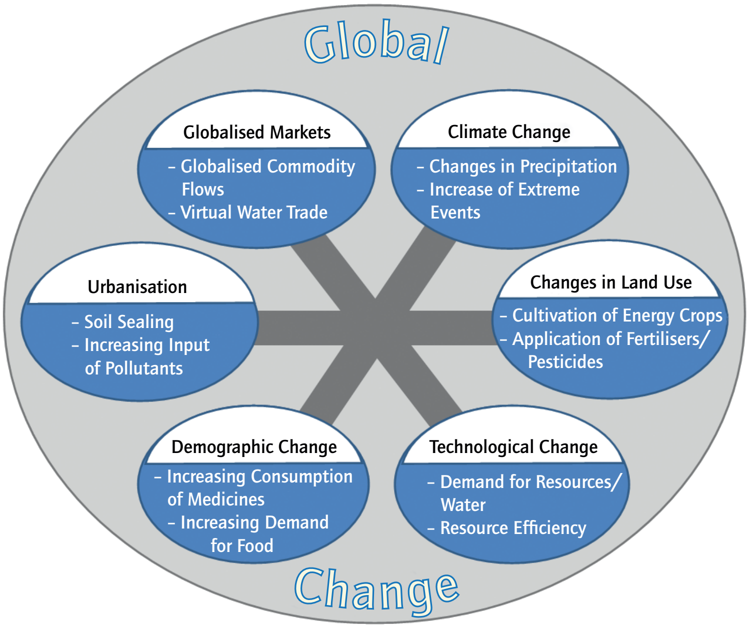
1 INTRODUCTION

Global change and regional water resources

"Flood of the century" in 2002, "record summer" in 2003, or the "warmest winter on record" in 2006/7 – we all have become familiar with these headlines. The year 2011 was also characterised by meteorological records. The spring of 2011 was the sunniest in Germany since meteorologists had begun systematically recording hours of sunshine in 1951. It was the second-warmest year since the first temperature measurements across Germany were performed in 1881 and the driest since 1893 (DWD 2011a). In contrast, the summer was very wet in the Eastern part of Germany. With 114 litres per square metre, precipitation exceeded the average rainfall of 78 litres per square metre by almost 50 per cent and in some places in Northeastern Germany, it was even three to four times above average (DWD 2011b).

These weather phenomena are – at least in part – attributed to climate change (Hüttl and Bens 2012). However, a more differentiated consideration reveals that climate is only one of the many factors impacting on society to have changed over the past decades and that will continue to change in the years to come (NKGCF 2008, DFG 2010; fig. 1). Economic change associated with the globalisation of markets is vast. Technologies open up possibilities to intervene in the "Earth System" that had hitherto been unthinkable (Hüttl 2011). The financial crisis has revealed the fragility of the economic and financial system in Europe and beyond. While the global population amounted to 2.5 billion people back in 1950, it has now reached approximately 7 billion (FAOStat 2011). In 2050 a global human population of 8 to 10.5 billion is predicted (WWAP 2009).

Figure 1: Facets of Global Change with Examples of Mediate and Immediate Impacts on Water Resources (Bücker et al. 2012)



Population growth and the increasing demand for natural resources such as land, water and raw materials are directly interlinked.

These transformations have massive impacts on the amount and quality of water resources worldwide. Water scarcity, erosion, flooding and deficient water quality are consequences of global change. One of the big societal challenges thus lies in achieving the sustainable[2] utilisation of water resources today and for future generations.

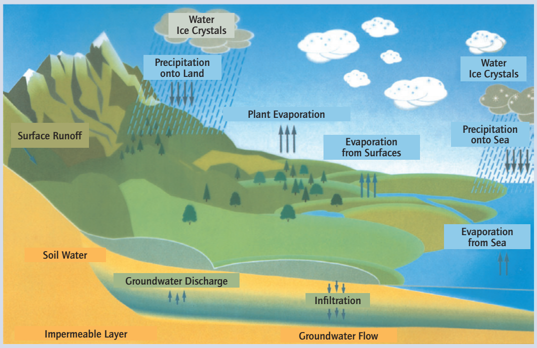
Focus region Germany

The most pressing water problems, which threaten the existence of peoples in particular places, currently exist outside Europe or will arise there in the future (WWAP 2009). Nevertheless, Europe can also expect to be confronted with water-related economic and ecological problems (EFA 2009). Global economic and demographic developments have consequences for regional flows of resources. Accordingly, the global demand for food and raw materials also results in economic transformation in Germany. Extensive change in agricultural practices such as the increasing cultivation of energy crops, as well as transformations in industrial production and energy (source) transitions have a direct impact on regional water resources (Cosgrove and Rijsberman 2000). In turn, as a traditional centre of technology and industry, Germany can contribute to solving global water problems by means of exporting technologies, methods and best practices.

With a potential water yield[3] of 188 billion cubic metres (30 year average), Germany is overall a water-rich country. The water yield comprises the amount of water that can be withdrawn from surface water and groundwater within a particular period of time (Strigel et al. 2010). In 2007 water withdrawal in Germany amounted to 32 billion cubic metres and thus remained below 20 per cent of the potential water yield (see table 1). Despite a generally sufficient water volume, there are German regions where utilisable water resources are small or water yields are subject to substantial seasonal fluctuations.

Georesource Water

Just like soil, land area, mineral raw materials and energy resources, freshwater (in the following simply referred to as "water") belongs to the georesources that are available in limited quantities and which are essential to human beings (DFG 2010). It is different from other georesources in that it is constantly in motion and – depending on climatic conditions – is very unevenly distributed in both spatial and temporal terms (EEA 2010).



Source: F&H München/Industrieverband Agrar (IVA)

2 In this context, the concept of sustainability comprises the three dimensions of ecology, economy and society and aims for the preservation of natural resources for future generations.

3 The amount of water that is available from surface water and groundwater within a particular period of time and can, therefore, be withdrawn without harming the ecosystem (see also glossary in the appendix).

Table 1: Withdrawal of Water According to Sector in Germany and Worldwide. Source FAO (2011)

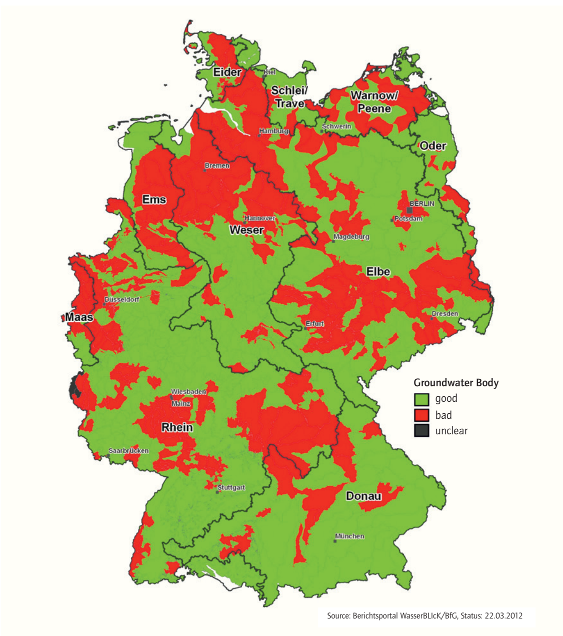
ANNUAL WATER WITHDRAWAL FROM NATURE (GROUNDWATER AND SURFACE WATER)			
In Germany (as of 2007)		Worldwide* (as of 2003)	
Sector	Water Withdrawal	Sector	Water Withdrawal
Households	15.9 %	Households	11 %
Industry	83.9 %	Industry	19 %
Agriculture	< 0.3 %	Agriculture	70 %
Total	32.2 bn. m³	Total	3.800 bn. m³

* Note: Calculated on the Basis of the Global Sum of All Water Withdrawals

Climate change (global warming) in Germany can be empirically validated. Between 1900 and 2000, the mean annual temperature rose by about 0.8 to 1.0 °C (Zebisch et al. 2005). Precipitation levels do, however, provide a more differentiated picture. From a long term perspective, it is not possible to detect any significant trends in terms of mean values or regional distribution. For the past 30 years, however, we can observe a marked increase in winter precipitation, while summer precipitation has not changed significantly (ibid.). Southwest Germany, the Alpine region and Eastern Germany are the regions affected by particularly pronounced climate change. We can expect strong impacts on the available water resources for the future especially for regions whose water balance is also already under pressure, most notably the lowlands of Eastern Germany (Grünewald 2010). Such change alters the ecological and economic conditions for water resources management, agriculture, forestry, inland navigation, environmental protection and nature conservation. For some regions, we can expect pressure on water supply for agriculture, ecological purposes and energy management (e. g. irrigation, cooling of power generating plants and the preservation of wetlands).

It can be assumed that the main problem for Germany in the future will be related to water quality rather than the amount of water available, since we can expect unexpected inputs of substances to impair the quality of water. In particular, the combination of climate change and the further intensification of agricultural production are likely to encourage greater use of plant protection products in the future. Moreover, demographic change in the form of an ageing population will lead to the rising consumption of pharmaceuticals and, consequently, this will increase the input of pollutants into both surface water and groundwater. For example, it is already evident that half of groundwater bodies will fail to meet the “good chemical status” by 2015 as stipulated in the European Water Framework Directive's implementation (BMU and UBA 2010; fig. 2). In contrast to surface waters, the particular challenge concerning groundwater lies in its spatial extension; it is practically impossible to intervene to achieve a quick improvement of water quality. Moreover, we can expect growing conflicts over the utilisation of the subsurface. Drinking water supply, utilisation for temporary storage or deposit, raw material extraction and supply for thermal energy have already become, to some extent at least, competing interests.

Figure 2: Probability of Achieving the Objective "Good Chemical Status" for Groundwater Bodies in Germany. Source: BMU and UBA (2010)



The challenge of sustainable water resources management

Many global water-related problems are management problems. By the same token, numerous conflicts of interest and use related to water resources exist due to ill-conceived decision-making structures or the fragmentation of resource management into different sectors (WWAP 2003, 2009). In Germany, for example, the pronounced subdivision of competences within the water sector and at the federal level has led to coordination problems within the various subsections (cf. Moss 2004, SRU 2007, Exner and Seemann 2011, Theesfeld and Schleyer 2011). There is also much room for improvement as regards the strategic alignment of, and coordination between, water-related sciences at the national level (DFG 2003). This applies to both basic and applied research (e. g. technology development) as well as to implementation into practice (cf. Schumann 2011). Essential information and data are sometimes difficult to access or remain confusing and somewhat difficult to understand (DFG 2003, BMU 2006). Frequently, recommendations are disseminated according to their disciplinary orientation and are not presented in terms accessible to a broader audience (cf. Hüttl and Bens 2012).

In 2003 the German Research Foundation published a memorandum on water research on the conflict between implementing policies orientated to present needs and safeguarding future conditions (DFG 2003). This provided an important foundation for the sustainable management of water from an academic perspective. Almost a decade later, it is fair to say that some of the goals mentioned have been met and others not (Hüttl and Bens 2012). With the aid of the *Water Science Alliance,* first steps towards an improved coordination of water research in Germany have been made (Water Science Alliance 2010). The *Global Change* research programme in Germany has also focused on the issue of water resources in numerous projects (e. g. Rieland 2004, Mahammadzadeh and Wiesweg 2010, Leibniz-Gemeinschaft 2011, NKGCF 2011, Grünewald et al. 2012).

In terms of the provision of essential public services, the issue of sustainable water resource management is of high socio-political relevance in Germany. There is therefore demand for further efforts to achieve integrated thinking on water resources as well as for interdisciplinary and intersectoral research and management. Furthermore, novel challenges are arising from rapid technological and socio-economic transformation.

Research question, working method and results of the project group

The project group "Georesource Water – The Challenge of Global Change" aimed to make a contribution to research and practice on sustainable water resources management in the context of global change. In doing so, it hoped to support knowledge transfer between academia, the economic sector and society. The emphasis was on the natural and technical sciences. Essential technology-centred questions were addressed in terms of the experiences, functions, risks and opportunities related to selected water technologies. Closely connected to these issues were questions about the framework conditions that may either promote or impair technological innovation in the water sector. From the plethora of water technologies, we have selected the ones that are particularly relevant for "global change". Moreover, the topics had to be addressed in a particularly innovative way, taking into account knowledge gaps and providing space for lively discussion (cf. Hüttl and Bens 2012). Since the geographical focus was Germany, the most important research fields in global terms were not addressed by the project whenever they were of less practical relevance to the German case (e. g. desalination of seawater).

The project group's work focused on reflecting upon, assessing and synthesising the findings of current research. In the spirit of searching for "new discoveries", a particular concern was to examine research which has received less attention. We made a conscious choice not to address those questions that had been the focus of earlier projects (e. g. land use changes: Hüttl et al. 2011, infrastructure management: Hillenbrand et al. 2010, flooding: Merz et al. 2011). On the basis of external reports from experts, workshops and discussions with key actors in industry and research, the group identified topics which were seen to have a high relevance for the future. We pursued an integrated approach, one which brought together a range of (water-)issues and identified information and knowledge gaps.

The spatial focus was on Germany, though the project considered global repercussions and German contributions to the alleviation of water problems worldwide. Thus the project concentrated first on "sensitive regions" in Germany, i. e. regions where problems in the water sector already exist or are foreseeable in the near future. Second, research examined Germany within the context of its global interdependencies, largely by addressing the issues of "virtual water" and "water footprint" (Hoekstra and Chapagain 2008).

From current and future challenges in Germany, three general questions can be discerned:

- How does climate change affect regional water balance and what are the consequences for water resources?
- How can we utilise regional water resources in a locally sustainable manner so as to also protect global resources?
- In what ways can we expect global change to affect the quality of water (especially groundwater)?

The project group addressed these questions in working groups on three themes: "Climate Change and Water Balance", "Water Utilisation and Water Efficiency in Landscapes" and "Water Quality". Cross-cutting issues like "Monitoring", "Research Funding", and "Technologies" helped to interlink these thematic concerns.

A fourth question arises from the need to achieve sustainable planning and water resources management in Germany:

- In terms of achieving the sustainable management of water resources, which challenges are of a regulatory or institutional character?

The recommendations given to science, economy, politics and state administration represent the main output of the project. This short version of results and recommendations (published in the series acatech POSITION) is scientifically substantiated in a longer report (published in the series acatech STUDIE: Hüttl and Bens 2012). Moreover, numerous publications have emerged from the project. The 13 commissioned expert reports were published successively and are available on the acatech website.[4] Additionally, two conference volumes were published, which add to discussions on the a) current water balance and water management in Northeastern Germany (Kaiser et al. 2010) and b) water-related adaptation measures to landscape change and climate change in Germany (Grünewald et al. 2012). Furthermore, a workshop was held on the history of water balance and water utilisation in Central Europe (Kaiser et al. 2012). Finally, articles were published in academic journals (Libra et al. 2011, Germer et al. 2011).

4 Available under http://www.acatech.de/de/publikationen/materialen.html.

2 CLIMATE CHANGE AND WATER BALANCE

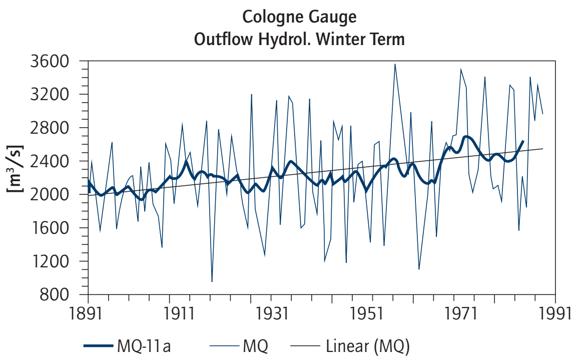
2.1 INTRODUCTION

Hydrological change: diagnosis and prognosis

Water balance in Germany has undergone significant transformations over the last one hundred years (Petrow and Merz 2009, Bormann 2010, Kaiser et al. 2010, Maurer et al. 2011). This "hydrological change" (Bronstert et al. 2009) results from climate change, changes in land use and intensified water management (Huntington 2006). The relevance of each of these factors and their impacts vary from region to region.

A few examples help to elucidate changes as regards water balance. In the case of the river Rhine, it was first and foremost climatic changes that led to increasing runoff volumes. For the winter period, the average runoff at the Cologne gauge has risen from 2.000 to 2.400 cubic metres per second; in the summer, it has remained almost constant and fluctuates around 1.900 cubic metres per second (Maurer et al. 2011; fig. 3). Changes in runoff and flood dynamics throughout the course of the 20th century have also been observed for other German rivers (Bormann 2010). Flood events have increased particularly with regards to many rivers in the west and south. This is mostly attributed to climatic causes (Petrow and Merz 2009). Some regions have also experienced changing groundwater levels. In parts of Western Germany, levels have risen considerably over the last twenty years or so (Kämpf et al. 2008). This change is largely attributable to climatic factors but is further reinforced by shrinking municipal and industrial water withdrawal. This can be contrasted with a large-scale drop in the top groundwater level in Northeastern Germany, especially in Brandenburg. This development has been apparent for around 30–40 years and is ascribed in a differentiated manner to impacts of either land use or climate change (Kaiser et al. 2010).

Figure 3: Development of the Average Discharge (MQ = Annual Values, MQ-11 a = Moving Average of a Period of 11 Years) at the Cologne Gauge in a Hydrological Winter Term (November-April) Throughout the 20th Century. For the Rhine-basin, temperature, precipitation, and outflows have all increased throughout this period of time (see: Maurer et al. 2011).



We can thus state that the future appears rather uncertain in terms of both the climate and hydrology. Accordingly, the instruments for "prognosis" available to us are still subject to considerable uncertainties. Due in part to extreme variations in results many of the studies available have described possible future situations in a quite general manner. At best, the results can be regarded as a rough guide. At worst, they are close to being random (Blöschl and Montanari 2010, Maurer et al. 2011). Basically, the scenarios drawn by climate models are more cogent for future changes in temperature than for precipitation dynamics. Likewise, findings on long-term averages are more reliable than those on extreme values. Moreover, in relative terms, more precise predictions can be made for large areas than for small ones.

River runoff projections show varying regional trends. While a further increase of the average runoff from the Rhine can be expected, runoff volumes are likely to drop for the

Upper Danube and the Elbe. A number of smaller rivers (especially in Eastern Germany) will dry out occasionally, as has already occurred in recent years of drought (fig. 4). Forecasts on the development of floods and low waters are still highly problematic (Barthel et al. 2010, Hattermann et al. 2010, Maurer et al. 2011). In line with the overall climatic differentiation across Germany, there are large regional differences also in terms of groundwater recharge. In the state of Hesse, for example, we can expect an increase of around 25 per cent until 2050, while a decrease of ca. 40 per cent is predicted for Northeast Germany over the same period of time (Gerstengarbe et al. 2003, DWA 2011). These figures correspond to a continuation of existing regional trends.

Figure 4: Dried-Out River Schwarze Elster (Lausitz) at the Weir in Senftenberg During the Drought Year 2006. The channel flow downstream of the weir is caused by the intake of mining water from the mine water treatment station Rainitza nearby (Foto: R. Ender).

Adaptation options for water management

The impacts of global change affect many sectors of water use and water demand (Koch and Grünewald 2011). As a result of increasing episodes of heavy rainfall, floods and low waters and groundwater fluctuations, the distribution of the available water volume may vary more widely in the future – even if the long-term average amounts of water remain constant. In order to compensate for these fluctuations in availability, it will become ever more important to utilise both natural and artificial reservoirs and to enable supra-regional water transfers. In some regions, such as Eastern Germany, periods of water scarcity might occur more frequently in the future. Despite the overall decline in demand for water across Germany, some regions have repeatedly experienced shortages of water in recent years (Zebisch et al. 2005), for example, during the drought years of 2003 and 2006 (BfG 2006). The need for agricultural irrigation will increase. In contrast, we can expect a further decline in both the municipal and industrial demand for water (Hillenbrand and Böhm 2008), particularly as the population in Germany will drop from 83 million to an estimated 67 million in 2050 (BMU 2010). With the aid of scenario techniques and vulnerability studies, we can observe the resilience of water management systems in the context of the regional specificities of natural areas, economic conditions and settlement patterns. By this means, we hope to identify vulnerable regions where the need for tackling risks appears to be particularly great. Each vulnerability analysis should include an assessment of sectorally and regionally varying adaptation capacities (Bundesregierung 2011).

2.2 RECOMMENDATIONS

(1) Improve hydrological quantification and communicate uncertainties more clearly

Apart from climate change, water balance is influenced by a range of factors, such as land use, waterway developments and water withdrawal. These variegated driving forces increasingly call into question the assumption of unalterable ("quasi-stationary") hydrological conditions. This often serves as a basis for analyses in the field of water management and as such may lead to inaccurate forecasts (Milly et al. 2008). With the aid of different techniques (such as monitoring, modelling and scenarios) past and future changes in the water balance have been quantified in the field of hydrological research (Knutti 2008, Blöschl and Montanari 2010, Blöschl et al. 2011, Hundecha and Merz 2011, Kumar 2011). In terms of the advancement of quantification and the management of results, we wish to make the following recommendations:

- **Quantification of potential changes and insecurities**
  The currently prevailing approach to the quantification of changes in water balance utilises complex and expansive model chains. In view of the fact that this approach (still) faces various limits, it appears wise to concentrate efforts on pursuing alternative approaches. For example, one could conduct systematic analyses on cause-and-effect relationships. Furthermore, research may focus on how hydrological and water balance systems react to change. Against the background of ever faster change, the increasingly close entanglement of man and nature, and in view of the potential for severe damage, it is necessary to research not only what is probable, but also what is possible. However, this requires new approaches to modelling that take into account both interactions between systems and the potential for threshold value behaviour and regime change.
- **Direct communication of contexts and limits**
  Underlying assumptions, limits to insights and the partially non-reducible uncertainties regarding the quantification of changes in water balance should be outlined more clearly than they have been. For these purposes, the classification of knowledge into "hard" and "soft" facts or into "insecure knowledge", "known gaps in knowledge" and "unknown gaps in knowledge" would be helpful. Similarly, we should distinguish between problems and questions which we are able to address with a reasonable degree of clarity and those which we can only speculate about.

(2) Improve the standard of knowledge on the past variability of the water balance

An analysis of hydrological change requires a deep understanding of the variability of water balances resulting from natural and anthropogenic processes. For statistical reasons, this hydrological variability can be deduced only from extremely long time series of hundreds or thousands of years (Gregory and Benito 2003, Schirmer et al. 2005, Brázdil et al. 2006). For Germany, however, data are only available for around the past one hundred years (Striegel et al. 2010); historical-hydrological and paleohydrological studies remain limited (Mudelsee et al. 2003). For these reasons, forecasts of long-term hydrological and thus also ecosystemic variability are possible only to an unsatisfactory level. Here, the focus lies approximately on the past three thousand years (Late Holocene) with climatic conditions comparable to those of the present. We suggest the following measures for improving the standard of knowledge:

- **Exploiting the potential of historical data**
  Historical data on water balances offer huge potential as regards the various parameters of water balance (e. g. run-off from watercourses, groundwater- and lake-water levels). Thus far this potential has been exploited only rudimentarily by hydrologists and water managers (e. g. as regards the risk of floods and low waters). The reconstructed hydrological statistical series have to be combined with available instrument data. By these means it becomes possible to generate long time series which can then be utilised to improve the understanding of systems and water balance modelling. To achieve this, close cooperation is required between historians and geo-scientists on the one hand, and hydrologists, climatologists and water mangers on the other.
- **Conducting studies on various spatial scales**
  Acquiring new data entails carrying out historical-hydrological or paleohydrological studies on various spatial scales (ranging from small catchment areas up to the national level). If possible these studies should be quantitative and aimed at complementing findings in other disciplines.

(3) Optimise Water quantity management and establish risk management

The impacts of climate change on water levels can vary across regions. Both a decrease (e. g. an intensification of periods of low water) and an increase (e. g. more frequent and extreme floods) of flow rates or water levels are possible (Maurer et al. 2011). Bound up with this is the increasing risk for water management and other sectors (Merz et al. 2011). In particular, economic sectors such as the energy industry, mining or agriculture, as well as regions such as the Eastern German Lowlands are already characterised by the high potential for conflict in relation to achieving the sustainable management of water. As such, they have to develop precautionary measures to deal with the increasing risks emerging from a lack or surplus of water (Koch and Gruenewald 2011). It is thus necessary to develop differentiated adaptation options for water management. We propose the following recommendations (others are mentioned in Merz et al. 2012):

– **Prioritising water usage**
  By prioritising water usage we mean reducing water usage. This represents an important step towards protecting water resources, in particular in times of low water levels and water scarcity. In cases where particular pre-defined water level thresholds are not reached, low water planning may help to reduce water extraction rights for prioritised forms of water usage such as agricultural irrigation. The European Water Framework Directive provides the legal framework for these measures.

– **Optimising water consumption in thermal power plants**
  The replacement of through-flow cooling in thermal power plants with circuit cooling systems containing integrated evaporative cooling towers helps to reduce the thermal load of the utilised water. Although water consumption increases due to the effects of evaporation, circuit cooling systems are still the most efficient technology in terms of water consumption if thermal energy is used for heating or other purposes. Accordingly, we should use this technology more extensively and seek to further develop it. As the water does not necessarily have to meet drinking water standards, it is also possible to use more low-quality water for cooling purposes.

– **Water management and risk management**
  In the field of water management, climate change should serve as a motivation to develop and adopt more well-founded strategies of risk management (e. g. improving management of river dams and strategies for coping with high and low water levels). Thus far risk management, with its components of risk analysis ("what might happen?"), risk assessments ("what must be avoided?") and risk management itself ("how can we deal with residual risks?"), is yet to be broadly recognised in water management. With climate change providing an additional source of risks, it is more than ever important that this way of thinking becomes better embedded. In order to generate trust and thus increase acceptance of risk management measures in society, the clear communication of risk and pre-emptive measures is essential.

3 WATER UTILISATION AND WATER EFFICIENCY IN LANDSCAPES

3.1 INTRODUCTION

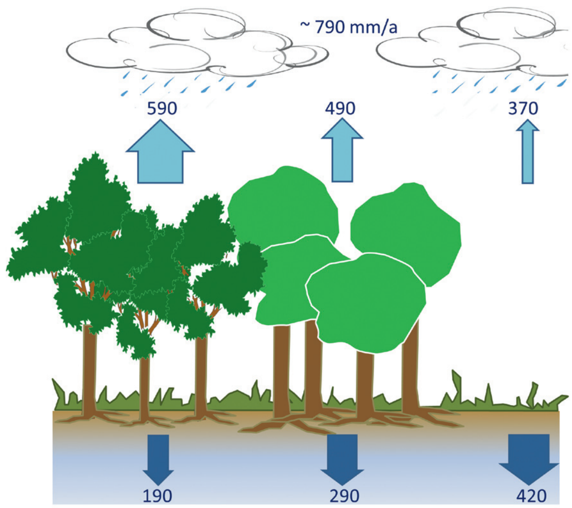
Land use and water resources

Rural landscapes serve various purposes: they are living spaces for animals and plants, enable genetic diversity, regulate the climate, produce groundwater, allow for the production of biomass for foodstuffs and animal fodder and the generation of bio-energy[5]. Man uses landscape for settlement and economic purposes as well as for acquiring raw materials. By this means we permanently interfere with their multifunctionality in both quantitative and qualitative ways. This applies not least to the water resources of landscapes characterised by heavy vegetation.

About 80 percent of the Federal Republic of Germany is covered with vegetation. While there is some permanent vegetation (woods, forests, pasture), the much larger share consists of temporal vegetation in the form of agriculture (Destatis 2011, UBA 2011). Since surfaces are strongly influenced by evapo-transpiration and the new formation of groundwater, both the distribution and the vegetation's state of development play a key role in a landscape's water balance. For instance, the level of groundwater which gathers underneath a pine forest is significantly less than that found underneath a mixed forest of beech and oak trees or beneath a pasture (Figure 5). Through their utilisation of surface areas covered by vegetation, humans influence both the quantity and quality of water.

Apart from (re-)designing agrarian and forest-related land-use forms and intensity (type of use, forest conversion, etc.), humans can also alter water circulation in landscapes for the better through irrigation measures and the form of soil management adopted. For example, groundwater reservoirs in a certain region can be conserved through optimised forms of irrigation; well-adapted soil treatment reduces inefficient evaporation and the risk of wind erosion on farmlands.

Figure 5: Hydrological Parameters of Different Stock Types (Left: Pine Forest; Middle: Beech/Oak Mixed Forest; Right: Grassland). Light blue arrows indicate the average total evaporation (interception, transpiration, soil evaporation), dark-blue arrows display the average deep seepage in litres per square meter and year (=mm/a, rounded values). Precipitation (also rounded) ca. 790 mm/a. Own illustration based on values taken from Zimmermann et al. (2008).



Water use conflicts

The natural resources of landscapes are limited. This leads to conflicts of use, unavoidable when it comes to water resources (Figure 6). Global change with rising temperatures and shifts in precipitation patterns, along with socio-economic changes is likely to exacerbate conflicts or restrictions in usage (see Section 1). Even in relatively "water-rich" Germany, some regions have repeatedly experienced restrictions in water usage. These were partly connected to insufficient water availability (water quantity) but also to increased water temperatures (water quality) (Koch and Grünewald 2011). However, conflicts of use may also emerge from the development of infrastructure like pumped storage hydro-power stations (conflicts between climate protection and protection of waters) or through construction

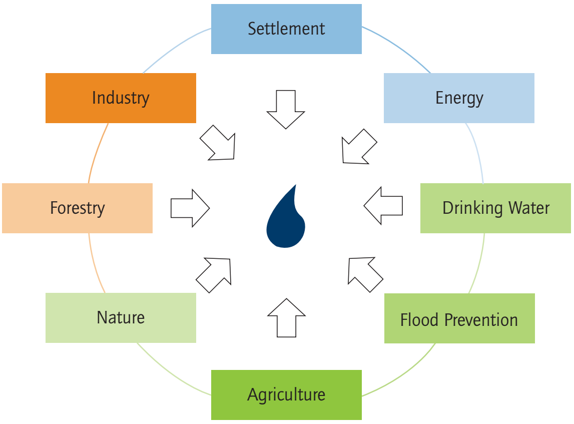
5 These diverse "tasks", largely taken for granted, can be subsumed under the term "eco-system services".

and re-naturalisation measures on rivers (conflicts between agriculture, environmental protection and flood protection).

These phenomena are always linked to the question of whether the competing usages of water resources are able to make compromises (so-called trade-offs) and perhaps also arrive at win-win situations or whether it is more appropriate to set specific priorities for an optimised use of resources. In general, competing aspirations necessitate assessment criteria which balance diverse needs and interests and ultimately lead to "fair" and environmentally sustainable solutions for all participants (Hansjürgens 2011).

As a consequence, future-orientated use (i. e. the sustainable utilisation of water and soil resources) requires strategic decision-making which addresses the diverse and sometimes competing demands, objectives and possible courses of action pursued by local actors from the fields of water management, agriculture, forestry and politics. Including and informing the public is another important element in the sustainable management of water resources.

Figure 6: Differing Claims to Water Utilisation (a selection; for more see Frede et al. 2012)



Water efficiency in an international context

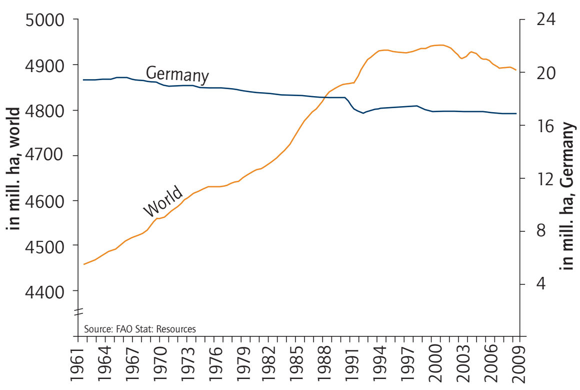
In global terms, the growing population and rising standards of living have increased demand for foodstuffs and other natural resources such as plant fibres or bio-fuels.

Furthermore, the demand for freshwater is rising continuously (GWP 2009). At the same time, the land available for agricultural use is decreasing due to soil degradation (salinisation, erosion, desertification) and the expansion of human settlements (BMELV 2011; Figure 7).

With approximately 70 percent of the total water extractions worldwide, agriculture is the largest water user (cf. Table 1). The level of water consumption depends on climatic conditions (precipitation, evaporation, soil fertility) as well as socio-economic factors (such as the availability of technologies, know-how). Especially in terms of water long-term land-use can therefore only be achieved if economic management also conserves resources, is compatible with social and environmental needs and safeguards provision of foodstuffs. Economic hardships and constraints, absent or insufficient controls, a lack of knowledge and ill-judged actions continue to lead to an overuse of water resources in the production of foodstuffs and other products in many parts of the world. According to WWF (2010), at present 71 countries overuse water resources in some form, while 45 suffer from moderate to serious water problems.

In the meantime, however, a range of technologies and management approaches have emerged which allow for the reduction of water consumption or an improvement in water efficiency in agriculture and the food industry (Grimm et al. 2008, Drastig et al. 2010). This is commonly referred to as the "more crop per drop" principle i. e. more productivity per unit of water. Only by this means will it be possible for existing or even decreasing farmlands to provide the world's population with sufficient food in the future.

Figure 7: Development of Agricultural Area Worldwide (Left Ordinate) and in Germany (right Ordinate). Data taken from the FAOStat internet-database (2011).



Germany, through the application of future-oriented forms of agriculture and forestry and a fair management of differing usage claims, should not only aim for a responsible use of the georesources water and soil at home. Through successful research, creative ideas and the development and application of innovative technologies, Germany can also contribute to solving water problems abroad brought about by global change (see also Frede et al. 2012).

3.2 RECOMMENDATIONS

(1) Reassessing water in landscapes

At least in certain regions and during drought periods, even a water-rich country like Germany experiences conflicts between differing, sometimes competing claims to water utilisation (tourism, agriculture and forestry, environmental protection, industry, energy, transport, fishing, flood protection, drinking water supply). Conflicts of interest among different persons, sectors, or administrative units may also emerge in response to climate change adaptation measures – for example in the form of river dams, hydroelectric power plants and flood protection. As yet there are still no effective strategies for detecting and assessing potential conflicts of use at an early stage; moreover, approaches need to employ means of better integrating all stakeholders if they are to help alleviate conflicts (Hansjürgens 2011).

– **A new way of assessing water in landscapes**
  For the purpose of assessing water and water-related conflicts, we recommend the introduction of a broad approach encompassing a range of values. This assessment should not only contain what is measurable or monetisable. Instead, it should consider qualitative as well as monetary and quantitative values in equal measure. As a consequence, novel assessment models must go beyond easily measurable criteria and encompass that which is seen as valuable by the wider population or regional users of water. These might refer, for instance, to aesthetic factors or the preservation of flora and fauna. Moreover, we also have to take into consideration the “services” rendered by water eco-systems (see for instance chapter 4.1, eco-system service “clean water” and figure 10). Previously, assessment projects as well as publicly monitored evaluation methods have often focused on rather one-dimensional cost-benefit analyses. Decision support procedures should, however, also incorporate the abovementioned principles of equal treatment and – to give an example – include citizens in assessment procedures.
– **Strengthening acceptance by including affected interest groups at an early stage**
  We recommend the inclusion of citizens and interest groups in assessment procedures from the outset. By doing this it is possible to more adequately take into account the interests of those affected. Furthermore, such an approach helps to increase support for water-related projects, measures and decisions. To achieve this it is necessary to define the affected groups at an early stage. Such groups should then be included in the

process of developing assessment criteria and weighting factors for the decision-making process. Likewise, the implementation of risk assessments should be a joint, cooperative effort. In general, assessment procedures that explicitly integrate interest groups should be prioritised. In doing so, it is necessary to determine more than rights to a stake or claim; it is just as important to define the duties (responsibilities) of all parties involved as clearly as possible.

– **Increased use of scenario methodology**
  The future development of rural areas should be seen as resting on a combination of processes (drivers) that are difficult to predict and the controlled interventions (courses of action) of human-environment systems. For this reason, the development of scenarios ("images of the future") is a key method in order to analyse potential future developments. Hence, it should be further embedded in planning and administrative institutions so as to a) sensitise actors to the problem of planning uncertainties, b) create a sound basis for discussions between various actors and c) to suitably prepare for water-related conflicts. Furthermore, we should also explore the benefits of transferring already developed scenarios or assessments to other situations.

(2) Promote water efficiency in agriculture through targeted measures

Agricultural products provide the basis for the supply of food and animal feed, renewable raw materials and energy crops. In some regions, however, high productivity has a strong impact on the landscape's water resources. Reinforced by the effects of global change, increasing water shortages may occur particularly in agriculturally highly productive or drought-threatened areas. As these regions are characterised by a very high water demand in the agricultural sector, it is necessary to make water-efficient or water- and soil-preserving technologies more attractive. This can be achieved with the aid of the following measures:

– **Advancement and application of efficient irrigation technology**
  Nationwide incentive and remuneration programmes for the purchase of efficient technical solutions such as drip irrigation increase the attractiveness of water-saving technologies. The same is true of precise control and management technologies for irrigation. Obviously, such technologies increase water efficiency, but they may also contribute to the reduction of nutrient inputs into waters. Related to this latter objective, it will be particularly important to further examine the combinations of irrigation and fertilisation practices. In addition, modelling the future need for irrigation in Germany and the impacts this will have on water resources in rural areas should also be prioritised.
– **Intensification of consultation and training programmes**
  To further sustainable practices in agriculture, it is necessary to extend consultation schemes for individual companies and concerns. In general terms, it is desirable to train farmers as water managers. This can be achieved, for example, by means of extending (further) education and training opportunities. In principal it is necessary to preserve existing experimental infrastructures so as to utilise them for the purpose of knowledge transfer.

(3) Explore the functionality and possible applications of soil additives

Soil additives can be viewed as a potentially promising technology that may help to increase both the water storage capacity and productiveness of agricultural soils. They are produced from natural or synthetic substrates and have already been used in horticulture and pomiculture to improve the hydrologic and nutrient balance of soils (superabsorbents). Soil additives can also contribute to carbon storage in soils ("C-sequestration", e. g. biochar). According to recent research, the application of soil additives in drought-threatened regions or those with marginal yields has achieved the desired improvements (Gerwin et al. 2011). Moreover, it may be possible to export soil additives to arid regions. Prior to an extensive application on open land, it is necessary to address the following issues:

- **Elaboration of the legal framework**
  In all cases, the use of soil additives on open land must fulfil legal requirements as regards precautions to avoid contamination. Indeed, the legal requirements concerning these products must be more clearly formulated. We have to bear in mind that requirements may differ according to product types (superabsorbers, biochar) as well as the type of application (soil improvement, carbon sequestration, etc.) and thus need to be implemented in a product-specific manner.
- **Developing knowledge on the characteristics and effects of soil additives**
  As the production and application of soil additives affects several sectors, there is a great need for research, on all relevant phases (development, production, application, disposal). In particular, responsible research on soil additives is required to identify potential environmental risks (e. g. accumulations of pollutants) and to calculate the carbon balance for biochar or HTC-char. Depending on both the source material and the manufacturing process, the product characteristics of soil additives vary considerably. Prior to application on open land, appropriate analyses and laboratory tests are therefore needed in order to adequately characterise the physical and chemical effects of products as well as their intermediate and decomposition qualities.

(4) Raise awareness of methods of sustainable water use in both the economic sector and the general public

Having a glass of water or eating a steak – which of these two actions is more water-intensive? Our water footprint, i. e. the total amount of water consumed, contaminated or evaporated in the production of the goods we use (food, clothing, cars etc.) is many times higher than the directly visible daily domestic water demand. Water footprints comprise both the amount of water directly consumed by a person and the "virtual water" consumed during the production of foodstuffs or other goods (see also Frede et al. 2012). We can discern three types, namely green (precipitation water), blue (groundwater and surface water) and grey (dilution of contaminated water) virtual water. Essentially, the water footprint illustrates a product's "water intensity". However, a large water footprint itself does not reveal anything about the sustainability of water utilisation or certain products (Schubert 2011 a, b). Instead, it is necessary to consider the following aspects if we want to make use of the concept to preserve our global water resources:

- **Analysing unsustainable water consumption in agriculture**
  The concept of water footprint undoubtedly provides a sound foundation for the management of the limited resource of water. Nonetheless, it is necessary to make a clear distinction between a sustainable and an unsustainable water footprint. For example, decreasing groundwater levels in a particular area may serve as an assessment criterion. In the future, it will be essential to determine systematically the size of the unsustainable water footprint (or to add it to already existing data). As a first step, we recommend confining analyses to unambiguous cases of unsustainable agricultural practice. Once the data are available, they should be taken on board by international companies so that they can better devise the processes through which they produce goods in certain regions and move towards a more sustainable water footprint.
- **Non-misleading information brokerage**
  With regard to the issue of sustainable and unsustainable water utilisation in the production of consumer goods, substantial improvements need to be made in the

provision of information to the public. In particular, this applies to the water footprint of products. For example, in regions with a sufficient amount of precipitation, cultivation of coffee is sustainable despite the large water footprint. As no additional irrigation water is needed, existing blue water resources (i. e. rivers/groundwater) will be preserved. It is therefore unnecessary to reduce the water footprint in general terms (e. g. by avoiding coffee). Instead, we have to ensure that savings are made in regions where a high consumption of water will have negative impacts on man and the environment.

4 WATER QUALITY

4.1 INTRODUCTION

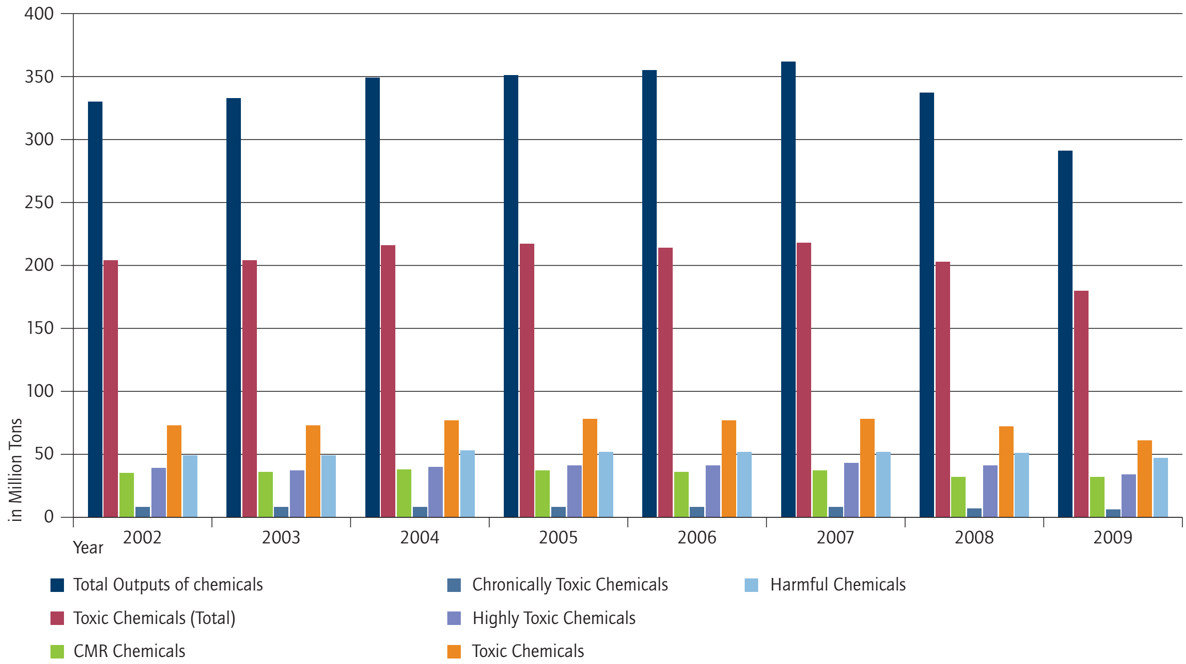
Substance inputs into the natural water cycle

Through their activities, humans exert considerable influence on water ecosystems. Dam building, the straightening of watercourses, or forms of construction on or near to rivers alters both the flow velocity and the ecological consistency of rivers and hence also affects the living conditions for organisms within these waters (*inter alia*, see Knacker and Coors 2011). The discharge of water used for cooling in industrial production or thermal power plants may contribute to increasing temperatures in surface water and even groundwater. Agricultural activities such as the irrigation of fields with groundwater may affect the water balance by reducing groundwater levels. The input of plant nutrients (e. g. phosphates due to soil erosion) may impair the quality of natural water resources. For instance, heavy metals released through mining contain pollutants discharged into aquatic ecosystems by human beings. Less obvious examples include numerous everyday and household products such as detergents or cosmetics (which also contain industrially produced chemicals), plasticisers contained in synthetic materials, paints, etc. or pharmaceuticals like antibiotics, antidepressants and beta blockers.

Industrial countries in particular are constantly developing numerous new substances; worldwide, some 50 million substances are currently registered (Muir and Howard 2006,

Figure 8: Production of Toxic Chemicals in the EU (in Million Tons; Source: Eurostat 2011).

Note: The diagram illustrates the trend in aggregated outputs of toxic chemicals and is divided into five “toxicity” classes: carcinogenic, mutagenic chemicals and/or chemicals toxic for reproduction (CMR); chronically toxic chemicals; highly toxic chemicals; toxic chemicals; dangerous chemicals.



Bergmann 2011). In the EU alone, an annual 150 million tons of dangerous chemicals are produced (within the 27 countries of the EU; figure 8). Added to this are industrial production residues or undesired by-products, as well as numerous transformation or decomposition products that are generated only after their input into the environment. Many of these products are released into the environment via wastewater systems, sewage treatment plants and – in particular – industrialised agriculture (especially pesticides and fertilisers). These substances are eliminated or transformed in rivers, lakes and soils before they reach the groundwater. Once they have arrived there, they (either indirectly or directly) enter the drinking water supply and thus ultimately the human food chain.

Synthetically produced substances (xenobiotics) are released into the environment only through human activities and do not decompose quickly. Hence, we can reasonably expect these substances to enter the water cycle, with potentially harmful consequences. At best, it can be said that their toxicological potential is not sufficiently known. As a basic principle, we should therefore aim to avoid completely the input of these substances. Efforts to control water pollution in Germany over recent years have already helped to reduce significantly the anthropogenic input of substances and as a result, water quality has been improved. However, given the effects of global change, the preservation of water quality, in the sense of a "good chemical" and "good ecological" status (as mentioned in the European Water Framework Directive (WRRL; Europäische Gemeinschaft 2000), will remain a huge challenge. As the inventory of German waters according to the Water Framework Directive has shown, around 60 to 85 per cent of surface waters and 53 per cent of groundwater bodies will not attain (or will only attain with the aid of additional measures) the good status stipulated in the directive by 2015 (BMU 2005, SRU 2008). These difficulties frequently result from the already mentioned high nutrient inputs from areas for agricultural purposes.

As postulated most notably in the European Water Framework Directive, sustainable water pollution control implies an integrated consideration of groundwater and surface waters. The special challenge as regards groundwater protection lies in the fact that – unlike surface waters – extensive means of intervention and quick improvements in water quality are practically impossible because of the large spatial and temporal dimensions involved.

New organic trace substances

In the past few years, a "new" group of substances has grown in prominence: organic trace substances (see figure 9). A direct outcome of activities in highly developed industrial societies, their existence within the water cycle also serves as an indicator of possible effects on the environment and natural water resources. Even in low concentrations, organic trace substances may have negative consequences for humans or the (living) environment. Many of these "new substances" remain insufficiently researched. Moreover, there is an absence of adequate data that would allow for a comprehensive toxicological evaluation and risk assessment (Bergmann 2011).

Moreover, pharmaceutical substances, which are metabolised and excreted by humans and animals in an altered form are also of particular relevance. With regard to demographic changes and ageing societies, we can expect a steady increase in the use of pharmaceuticals – and thus also the input of active medicinal substances and their residues – into the water cycle in the future. Additionally, advances in methods of analytical measurement will result in constant "new discoveries", the detection of novel substances in waters (Bergmann 2011, Knacker and Coors 2011).

Global change

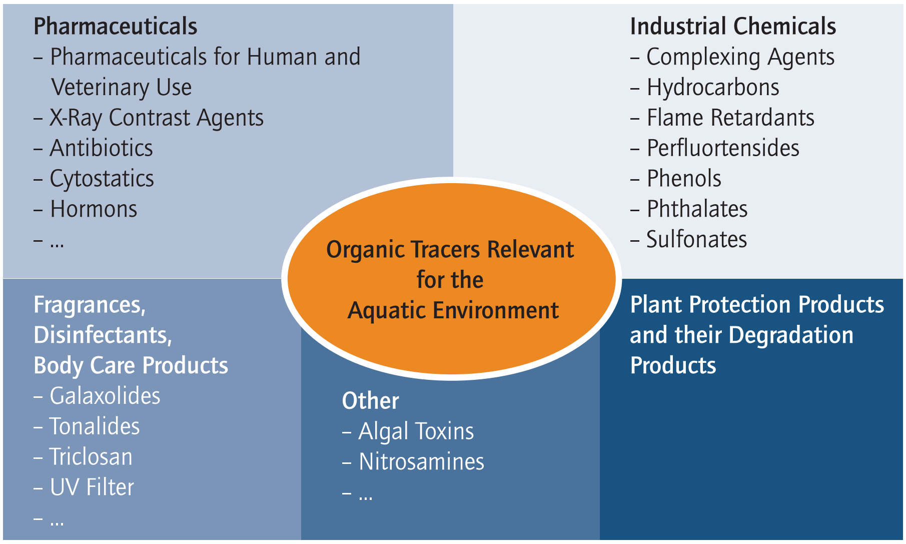
To date, it has been possible only to a rudimentary degree to identify the extent to which climate change affects groundwater quality. Global change and a further intensification of agricultural production are likely to coincide with an increased use of plant protection products and thus also an increased input of pollutants to groundwater. Furthermore, differing and, in terms of their spatial and temporal dimensions, sometimes competing demands on the subsurface are already apparent today. For example, these demands relate to drinking water supply, industrial water withdrawal, storage purposes, or the utilisation of geothermal energy. These developments and forms of use have led to a shift in pollutant patterns, concentrations within the subsurface, as well as changes in the transformation processes of pollutants. Apart from water availability, issues such as the input of substances, competing forms of utilisation, and conflicting goals related to groundwater as an object of protection will all become vital challenges in the future management of natural water resources in Germany.

Ecosystem service "Clean Water"

In Germany as elsewhere in the world, the natural self-purification of ecosystems is an essential part of water processing. Almost 75 percent of our drinking water comes from groundwater, which must therefore be regarded as the most important basis of life (BMU 2008). A smaller share (about a quarter) is gained from surface waters, i. e. from lakes, dams, rivers and bank filtrate.

Every day, substances are industrially produced which may enter the (drinking) water resources (groundwater, river water) at any time. Hence, it is particularly probable that water soluble pollutants will have direct detrimental effects at some point (depending on the ecosystem's buffering capacity). As ecosystems contribute to the self-purification of water and help to delay considerably the effects of pollution through retention and dilution, it is vital to preserve their functionality (Avramov et al. 2010). For drinking water in Germany groundwater plays a particularly key role – the most important ecosystem service consists in water processing (i. e. the lasting removal of contaminations and a buffering of the effects of modern industrial societies).

Figure 9: Groups of Organic Tracers of High Importance to an Adequate Environment (Bergmann 2011).



As a result of these processes, it has been possible to ensure a sustainable water supply for humans and the environment over a long period of time (centuries). A comprehensive understanding of this ecosystem and its processes is thus required if we are to ensure the sustainability of groundwater resources and to use the resource of "clean water" as an ecosystem service on a long-term basis.

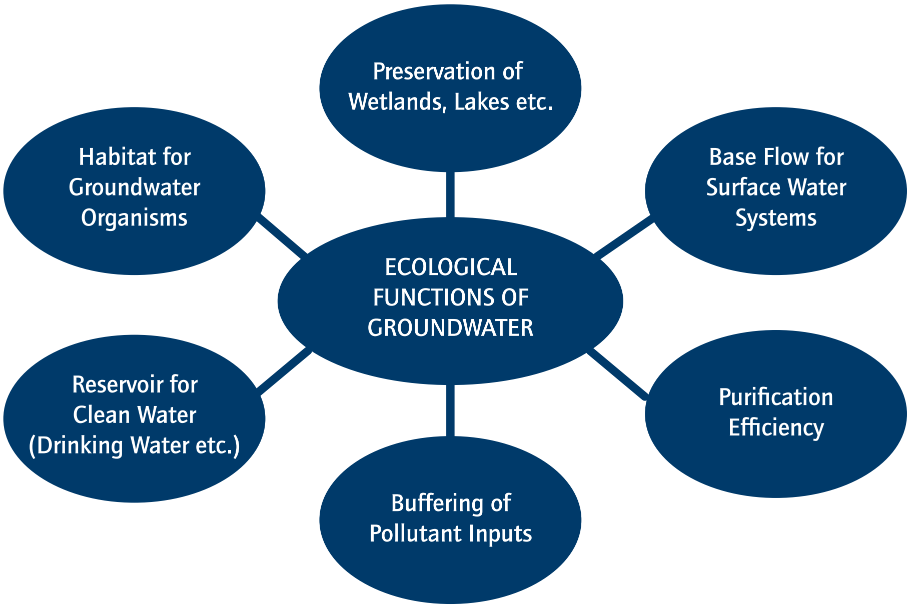
Against this background, the following recommendations relate mostly to the qualitative and quantitative preservation of groundwater resources as a key component of ecosystems and as a provider of drinking water. They are based upon the results presented in the acatech STUDIE (Grathwohl et al. 2012).

4.2 RECOMMENDATIONS

(1) Avoid the discharge of undesired substances into the water cycle and eliminate them from sewage

In highly developed industrial societies, a multitude of new substances enters the market each year. These will find their way into the water cycle even though there are no analytical detection methods for environmental samples or drinking water. This often coincides with an absence of satisfactory environmental risk assessments. The subsequent removal of substances from the water cycle requires considerable effort (implementation of technologies, use of energy and other costs) and often remains only partial. For these reasons, we should either minimise or stop totally the

Figure 10: Ecological Functions of Groundwater of Importance for Humans and the Environment (Ecosystem Services). Source: Grathwohl et al. (2012)



input of non-natural substances into the water cycle. This can be achieved by implementing admission regulations for substance production and application. For this purpose, we have to develop regulations, utilise and optimise existing potentialities of technology, whilst also developing new technologies. In particular, we should promote the following:

- **Production-integrated environmental protection using new technologies**
  Despite significant progress over the last two decades, there is still much potential to reduce both water demand and the input of substances into waters in industrial production. In this context, production-integrated environmental protection means a) integrating water processing in the production process, b) recycling water as far as is economically feasible and c) depending on the form of use, using water only of a quality necessary in the different process stages (and not water of a higher quality). Measures directed at avoiding wastewater or wastewater loads should have priority over conventional end-of-pipe wastewater treatment. This implies that we have to redesign production processes in a way which considers cost effectiveness but also allows for water to be saved and the contamination resulting from production wastewaters to be reduced. In doing so, the main focus should be on the implementation of new processes and technologies for water treatment (e. g. membrane processes) and the reuse of water.
- **Management approaches to the input of substances**
  One starting point for reducing the use of undesired substances is documenting their behaviour inside sewage treatment plants, the environment and in waterworks as early as during the admission procedure. The producers of these substances (co-polluters) have to be involved in this documentation process by way of appropriate obligations. To ensure the early recognition of problems, it is necessary to improve the detection and assessment of substance levels released into the environment and waters. This is especially important in the case of the oft-problematic direct and indirect dischargers such as rainwater runoffs of sewage systems. Whenever possible, toxicologically relevant substances that are hard or impossible to eliminate, or substances generating toxic transformation products should be replaced by alternative, environmentally friendly substances. Moreover, we should develop new instruments that help to steer consumer behaviour (e. g. information on environmental harmfulness and available substitutes, labelling of products, adoption of rules).
- **Further development of process combinations and membrane processes in sewage purification and water conditioning**
  The further development of process combinations in sewage purification and water conditioning should be a priority for the future. An enhanced form of performance that takes into account both the safety and flexibility of conditioning is to be demanded from these procedures. As a supplement to conventional processes, membrane filtration offers enormous development potential. Membrane processes allow for an economically viable reuse of sewages and the desalination of seawater, e. g. for drinking water provision or industrial and agricultural water use. Depending on the field of application, membrane filtration produces concentrates, which might necessitate detoxification and sustainable forms of disposal. At present, these concentrates constitute a significant obstacle to the broader application of membrane technologies for reverse osmosis and nanofiltration.

(2) Conceptualise risk assessments for mixed substances and trace elements

Water that has been altered as a result of human intervention usually contains a large number of substances. While the concentration is often low, the mixture is at the same time rather complex. Thus far, however, it is individual substances that have most often been assessed and knowledge of the health risks mixtures of substances might entail remains inadequate.

- **Assessing mixtures of substances and the toxicity of substances in low concentrations**
  Conceptualising novel assessment approaches and a systematisation of existing evaluation approaches are required in order to better assess mixtures of substances. More precisely, we need to develop an integrated and mechanism-based assessment system, one which will allow us to filter out those substances with toxicological effects. Both empirical toxicological data (or tests) and the clarification of possible degradation pathways should provide the basis for an advanced assessment strategy. Alternative methods are required for toxicological evaluations. In combination with a further validation step, it may be possible to replace extremely costly and complex testing methods such as animal testing with a combination of testing methods and non-test-based methods (*in vitro* and *in silico*). There is also a lack of knowledge concerning the assessment of the toxicity of substances in low concentrations over long time periods. The epidemiological data currently available on the impact of pollutants on human health is both small and deficient. In this field, larger and long-term studies are required to be able to capture the impacts of long-term expositions (e. g. in drinking water) caused by weakly concentrated trace substances.
- **Minimising risks related to the degradation and transformation of substances**
  Given the wide range of processes which degrade the environment (chemical: organic and inorganic; toxicological), new concepts of risk minimisation are required. These concepts should be designed in ways that allow risk prediction for complex mixtures and potentially toxic transformation products. Knowledge on the degradation and transformation of substances and the emergence of potentially toxic transformation products are an integral component of risk analysis. In this sense, we need to improve research on the degradation behaviour of substances degradation in the environment and by this means lay the foundation for risk assessments.
  For all substances that have been classified as environmentally important through monitoring or risk analysis, we should be aware of the possible forms of pollution under differing environmental conditions.

(3) Promote the multiple use of water

Population growth, changing eating habits, increasing wealth and ongoing industrialisation have led to a growing demand worldwide for high-quality water. These processes coincide with rising levels of wastewater and hence an increase in the pollution of waters. Modern forms of water management and a shift towards a more direct recycling economy are needed in order to safeguard freshwater supply in the long run. Especially in arid regions, the reuse of wastewater or industrial water and different forms of utilisation adapted to various purposes could make a significant contribution to preserving water resources. By exporting technologies for water treatment and the removal of contaminants, Germany can play a role in solving global water problems.

- **Selective water treatment depending on the type of use**
  Water may be supplied in different levels of quality, if it is differentiated according to usage types and requirements for water quality. For particular kinds of use as well as in arid regions, multiple use is a sustainable strategy that helps preserve water resources. It appears reasonable to adjust water treatment and processing to the respective demands use, not least because of the sometimes high costs entailed in processing.
- **Technologies for a targeted removal of contaminants during water treatment**
  Too many water substances are usually eliminated in a rather random manner in the course of water treatment. In order to reduce the effort (and hence also the costs) involved, it is necessary to develop processes that eliminate only those water substances that are undesirable for the required type of use. Contaminants are defined

as water substances that are disruptive for toxicological or sensory reasons, for reasons related to processing, distribution and utilisation, or for fundamental reasons (e. g. they are unnatural). In order to determine the potential for savings, the effort and cost of processing with a targeted elimination of contaminants should be contrasted with previous procedures. We should advance technologies which allow for a targeted elimination of contaminants and conduct further research on the selective removal of particular substances (particularly persistent pollutants).

- **Definition of legal standards**
  For a reuse of water, the quality needs to be sufficient to the intended type of use. However, all kinds of water recycling have to meet the highest standards guaranteeing and safeguarding public health, irrespective of the particular type of use. Thus far standards or guidelines for water reuse around the world vary according to the type of use, the regional context and the overall societal perceptions of risk. In Germany and the rest of the European Union there are no binding standards. As a consequence, there is a need to define legal standards for the various types of use, such as irrigation in agriculture, groundwater recharge and industrial use.

(4) Monitor and safeguard the hygienic quality of raw water and drinking water

In Germany, the hygienic standard of drinking water is very high. As a result of climate change, we can expect an increase in subsurface water temperatures (groundwater, drinking water infrastructure systems) and therefore we cannot rule out the potential for an increase in the generation of pathogens in water. Furthermore, temporally and spatially limited contaminations of drinking water may occur as a consequence of more frequent extreme events such as flooding. Institutions like hospitals – for which it is essential to have permanent access to completely uncontaminated drinking water – will face particular challenges in the future. In this context, the hygienic monitoring of water resources and the guarantee for perfect drinking water must be accompanied by enhanced efforts in research and development in the future.

- **Improving the monitoring of raw water with regard to pathogens**
  We recommend the adoption of the risk assessment for pathogens (especially for viruses) as developed by the WHO in its *Water Safety Plan*. It combines an assessment of raw water quality with the efficiency of the applied processing method. This includes regular testing of raw water taking into account extreme climatic and weather-related events like heavy precipitation, floods and the melting of snow. Moreover, modern water management concepts should also consider the vulnerability of catchment areas and aquifers. This would facilitate the designation of protection zones, particularly in regions whose aquifers face an increased risk of contamination. Given the ever more numerous sources of contamination, we also recommend developing an integrative indicator plan, which takes into account all relevant groups of waterborne pathogens. An identification of hygienic danger potentials requires the implementation of a nationwide obligation to report all diseases that can be transmitted through water. In connection to this, we need comprehensive epidemiological investigations that help connect the outbreak of diseases to the potential sources.
- **Guaranteeing hygienically safe drinking water**
  Hygienically safe water has to be guaranteed at the users' point of withdrawal. This implies that it is also necessary to consider the entire conduit system (from the site of drinking water purification all the way to the end-user). Through the improvement of existing technologies and the development of new technologies, it must be ensured that only water classifiable as hygienically safe reaches the consumer.

(5) Consider the effects of using the subsurface on water

As a result of technological developments, subsurface is exposed to an increasing number of utilisation types, competition and conflicts. In particular the subsurface is the subject of much competition between different types of usage: storage, supply and abstraction of thermal energy, intermediate storage of water resources (irrigation water), storage of carbon dioxide (CCS) and other novel processes (e. g. *hydrofracking* as a means of gas production). In order to ensure the sustainable management of water and soil resources in the face of all these competing claims, it is first necessary to explore thoroughly the potential risks. Examples for this are:

– **Utilisation of thermal energy near the surface**
  The utilisation of thermal energy close to the surface presupposes an analysis of the impacts on water and soil condition. We have to ensure the protection of natural resources (particularly water resources) as well as the proper functioning of all processes that serve to preserve and regenerate these resources.

– **Substance inputs resulting from massive subsurface-interventions**
  Substances from construction materials also account for a considerable share of all substances released into the environment. They comprise, for example, heavy metals (which, as an "old" topic, have slipped out of focus) and synthetically produced additives. In order to be able to assess material flows, there is a particular need for research on the recycling of (construction) materials (e. g. building rubble and slags in road construction and in landscape design; ashes and slags in concrete foundations and tunnel constructions). From this we have to develop ways of handling construction and recycling materials in terms of water protection. In case of large buildings in sensitive aquatic systems (e. g. tunnel constructions) it seems appropriate to demand a disclosure of data on the ingredients and the quantities of the materials, especially as we tend to know nothing about the ingredients of concrete and other construction materials (which companies classify as confidential).

The assessment of CO_2-storage in the subsurface and aquifers also belongs to this area; research on these issues is still in its infancy and urgently needs to be accelerated.

5 REGULATORY AND INSTITUTIONAL APPROACHES FOR SUSTAINABLE WATER MANAGEMENT

5.1 INTRODUCTION

Sustainable management of the georesource water not only refers to single wells, waterworks, river dams, lakes, creeks and wetlands. Instead, it refers to the georesource water in the water catchment area as a whole (DFG 2003). Sustainability is without doubt a complex concept with a multitude of facets (e. g. Turner 1993, Trzyna 1995). To put it very simply, we can define sustainable water management as follows: never use more than is naturally replenished; take precautionary measures in terms of both quality and quantity; minimise pollution when water is used; promote participation (Grambow 2009: 236).

Considering the spatially and temporally diverse conditions of availability and demand, the sustainable planning and management of water resources represents a huge challenge for many regions around the globe, including Europe and even parts of Germany. The problems connected to this challenge will increase when large-scale and profound (global) changes of existing conditions are observable – for example in the event of changing forms of water and land use and/or climate change.

The projected changes in climate are most likely to affect the average water availability, the shifting patterns of extreme hydrological events (floods and low waters) and water quality across time and space. For these reasons, water-related adaptation strategies – particularly in areas that are already affected by conflicts over water availability (as concerns amounts, time, quality, etc.) – are regarded as necessary (e. g. Koch and Grünewald 2011). In general, these strategies should be of sufficiently flexible design to allow for compatibility with subsequent, possibly necessary adaptation measures (*flexible and no regret strategies or low regret strategies*). At the same time, however, they have to consider other problems connected to global change (agricultural and economic policies on EU and global scales; international and national energy policies; demographic change, population development, etc.) with all their imponderability. In order to incrementally reduce this uncertainty, variegated and well-founded analyses and efforts are required on a case-by-case basis, particularly in the fields of research and implementation, as well as with regard to institutions.

Proceeding from two international UN conferences (Dublin Conference on Water and Sustainable Development (1992); Conference on Environment and Development, Rio de Janeiro (1992)), the concept of integrated water resources management (IWRM) has become a key part of the international agenda (UN 1992, Grambow 2008). To implement this international initiative, the Global Water Partnership (GWP) was established with the support of the World Bank. TAC (2000) describes integrated water management as a process, one which allows for the development of water and land resources to achieve a maximum of both economic profit and social welfare, without impairing the viability of the affected ecosystems.

Regardless of the fact that there is far-reaching evidence on the close interrelatedness between water use and land use in Germany, the tendency in research and public administration to consider land and water separately still prevails e. g. in agricultural science and hydrosciences or, in other words, agriculture and water management.

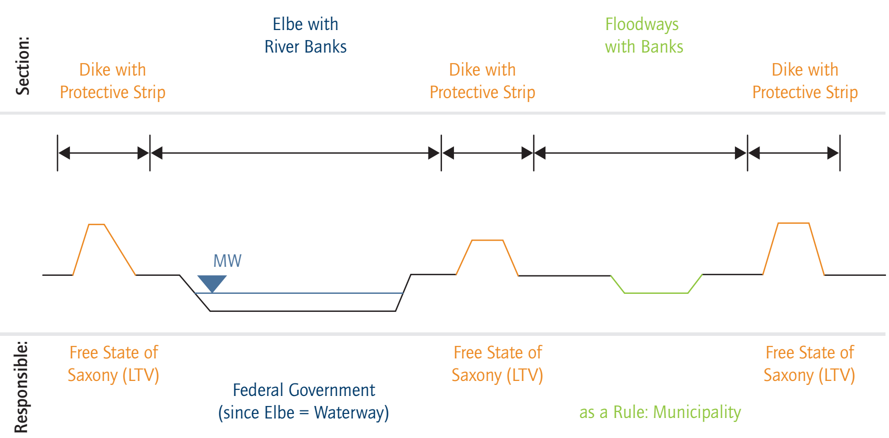
It is only in recent years and particularly in connection with the European Water Framework Directive (WFD) and the European Flood Risk Management Directive (FRMD) that notions of IWRM have become more extensively embedded. For example, the Federal Ministry of Education and Research (BMBF) has provided a substantial amount of funds for IWRM research over the past five years. In the coming five years, another BMBF funding programme will focus on "sustainable water management" (NaWaM). Similarly, the Water Science Alliance, which was founded by the Helmholtz Centre for Environmental Research (UFZ) in

2009, aims to promote a new and dynamic approach to the IWRM-concept in the context of global change and emphasises the marked need for further research and development in this field (Water Science Alliance 2010).

The implementation of the WFD in Germany has undoubtedly, if indirectly, been based on the IWRM-concept. The WFD outlines the management of river basin districts, the preparation of action plans and the comprehensive involvement of the public. These measures do, however, pose numerous challenges to the administrative authorities of the water sector. Most notably, the necessity to manage river basin districts across political or administrative boundaries requires a high degree of coordination between authorities, regions and member states. Due to Germany's federal structure with 16 different water policy and legislative frameworks, there is a lack of correspondence between spatial extensions (the river basins) and political responsibility (of authorities; see figure 11). Hence, there is an incompatibility (*problems of fit*, Fichter and Moss 2004) between the political-administrative planning unit of the federal state ("Bundesland") on the one hand and the natural-regional planning unit of the "river basin" on the other hand (see e. g. Grünewald 2008a). The new demands resulting from the WFD have substantial impacts on the diverse institutional aspects of water management. This requires reform of current practice and possibly the introduction of new structures (Moss 2008, Theesfeld and Schleyer 2011).

On this note, deficits and risks have not solely been detected by the German Council of Environmental Advisors (SRU), but also by the German water industry – particularly in connection with current administrative reforms (bureaucracy reduction, etc.) and the federal states' aspirations in terms of municipalisation processes (e. g. DFG 2003, SRU 2007). In a detailed way, the SRU (2007) critically examines and scrutinises both current reform efforts in the federal states and environmental protection within the complex fabric of departments on the national and federal state levels. Criticism has been most harsh as regards the reallocation of

Figure 11: Scheme of Responsibilities within the Cross-Section of the River Elbe in the Urban Area of Dresden (taken from: Grünewald et al. 2003, modified).



tasks in the federal state administration. The CEA states that a transfer of administrative responsibilities to municipalities will impair the performance of environmental administrations. This delegation of tasks to cities and districts leads to fragmentation and a loss of expertise, expert knowledge, networks and administrative routines (ibid.). For example, once assigned to districts, water management authorities will hardly be able to work out a differentiated and efficient climate adaptation strategy in the framework of (integrated) water resources management *alongside* already existing tasks, such as the implementation of the WFD and the FRMD.

Politics has to deal with these deficits and, where necessary, change its course within the context of various political scales (federal vs. state) and areas of responsibility (departments). As flood events (for example in the Elbe region) have shown, both the georesource water and climate-induced changes require a pre-emptive rather than reactive management. (Grünewald 2008b).

5.2 RECOMMENDATIONS

(1) Considering and managing natural resources in an integrated manner

Sustainable water resources management in Germany should be aligned to the regionally differing conditions in water availability and water demand. Moreover, it has to take into account the natural functions of the regional aquatic and (semi-)terrestrial systems. A sustainable managment of water resources cannot be attained by means of isolated strategies, e. g. by exerting influence through water-related measures within the context of a narrowly understood integrated water resources management (IWRM). Instead, IWRM itself has to be implemented in a cross-sectoral, cross-departmental and cross-stakeholder way. This would allow for water availability and water demand to be re-shaped. In other words, integration should not confine itself to a shared management of surface waters and groundwater across all administrative levels; instead, it should also take account of various resources such as water, soil, land, woods and water ecosystems.

(2) Connecting theory and practice more closely by means of strengthening regional networks

The incompatibility between federal states ("Bundesländer") as a political-administrative planning unit and river basins as natural-regional planning units (which are to be steered in the context of the WFD and its implementation) requires increased efforts to connect a multitude of actors and decision makers operating on various scales. In order to compensate for the absence of a river basin authority with legally binding decision-making power, the federal state-based water authorities have to find more intensive forms of interaction with public institutions, associations and other interest groups than this has previously been the case. It will then be important to further promote these connections in the form of regional networks. Furthermore, we will also have to make a stronger effort to integrate research into the development of practice-oriented strategies. One starting point is a strengthened coupling of the development of action strategies and concrete packages of measures with thematic orientation of research projects and tendering procedure.

(3) Finding adequate forms of communication for the fields of academia, economy, politics and the public

As far as water resources are concerned, a reasonable trade-off between the conflicting interests of utility and protection can only be achieved by means of constant communication. As the following example illustrates, communication will only be successful if we manage to provide clarity in terms of *how* to communicate externally (e. g. with the public) and *what* to communicate (e. g. internally in the fields of academia, politics, economy, or administration): The implementation of the FRMD has brought about a transition from the previous promise of flood *protection* towards a conscious examination and handling of flood risks in terms of flood *prevention*. As most recent flood events in the years 2010 and 2011 have shown, the promise of flood *protection* still prevails in the language used by politicians and authorities. As a consequence, it does not come as a surprise that the classic claim for flood *protection* has also remained dominant in public as well as in the media.

6 CROSS-CUTTING ISSUES

6.1 INTRODUCTION

In the context of global change, Germany has to address a number of challenges in terms of its water resources: the impact of climate change on the water balance, achieving more efficient water utilisation and the preservation of water quality. Several cross-cutting issues must be considered to ensure a sustainable and integrated water resources management.

Monitoring

A key basis for ascertaining previous and future changes as regards the quantity and quality of water resources lies in the collection, documentation and provision of long-term data. All over the world, we can observe a) the incomplete provision of data that is also often incompatible with other sources by monitoring networks, b) a worrying tendency to reduce monitoring networks (on hydrology, substance spectrum/pollution) and c) the unsatisfactory provision and exchange of data between different monitoring systems and geographical areas (WWAP 2009). There is a comprehensive monitoring system for various water-related parameters in Germany. Data are gathered and archived at different administrative levels. At present, however, corresponding databases have not been linked up to each other. There is thus no overview of these separately collected parameters and on the locations covered (Hüttl and Bens 2012). Moreover, in most cases there is hardly any coordination of the data collection methods used. Finally, both the coverage and funding of monitoring programmes in Germany has been drastically reduced in recent years.

Research funding

In water sciences as in other disciplines, strengthening interdisciplinary research has been adopted as a core principle of research funding programmes for the last two decades (DFG 2003). A success of this approach is that it has been possible to successfully overcome or reduce a number of barriers (e. g. between natural sciences and social sciences). Irrespective of such achievements, large deficits still persist in terms of the coordination between individual disciplines – particularly when it comes to developing a joint strategic alignment of research projects and programmes (BMBF 2010). Besides, there is too little temporal coordination between basic research and application-oriented research. Problem-oriented environmental research can be regarded as an interconnecting middle way between basic research that is exclusively targeted towards to the acquisition of knowledge and applied research geared, for example, towards developing technical products (Daschkeit 2006, Schumann 2011). Problem-oriented environmental research seizes academic issues that are oriented towards societal problems. The framing of societal problems (soil degradation, flooding, pollution of groundwater, etc.) in scientific research projects and the communication of the findings to initiate societal discourse must be regarded as key challenges for the future. In this context, coordinated action will be essential for the strategic development of funding programmes.

Technologies

Sustainable technologies make a major contribution to solving global water problems. Germany's water technology sector is characterised by high technical and quality standards. Further, in the sectors of water supply and wastewater disposal, German technology is internationally known. However, the regional orientation customary in the water sector and its small-scale, compartmentalised structure are barriers to the successful positioning of German companies in the global marketplace (GWP 2008, Moss and Schlippenbach 2011). While the numerous small and middle-sized companies posses great potential for innovation, they often lack both the capital resources and the networks necessary to be able to compete with *global players*. High price levels and inefficient structures further explain German companies' poor performance in international markets (Schippl et al. 2009). Especially in view of the abovementioned small scale-structures, the marketing of "adapted solutions" is a huge opportunity. As a consequence, action is required to improve the framework conditions required for exporting German water technologies. Apart from financial resources, the realisation of demonstration projects and the construction of demonstration plants are key to accomplishing this objective.

6.2 RECOMMENDATIONS

(1) Introduction of integrated monitoring, systematisation of monitoring programmes

Through coupling, it is possible to more efficiently organise and structure previously separated systems of qualitative and quantitative data acquisition. It thus becomes possible to merge available databases and to standardise data collection methods. This applies particularly to the examination of identical parameters in similar natural areas. On a larger scale, it appears equally useful to coordinate and systematise data collection between the relevant institutions (national and federal state facilities, research institutes) and across regions and states. One idea, for instance, would be the establishment of observatories and measuring programmes that entailed coordination across administrative boundaries. In general, it is possible to improve both the documentation of and the access to data. Moreover, the development of approaches which span spatial boundaries serve the purposes of data exchange and data analysis.

- **Promoting novel technologies for the quantitative assessment of water balance**
  Technology is providing ever greater opportunities to capture the water balance. Prominent examples include the use of satellite-, plane-, or ground-based gravimetric measurements for detecting changes in water storage in landscapes over time and the utilisation of satellite systems (GPS) to determine the atmospheric water content. New generations of affordable, smaller, and self-organising sensor networks can produce comprehensive datasets that are available in real time. As the potential to gather multidimensional datasets has increased rapidly, it is now time to ascertain whether we can move beyond approaches that are based upon simulation models and data calibration and describe and quantify hydrological phenomena more accurately by direct measurements ("data-driven approaches"). Ultimately, it will be necessary to combine both approaches in a meaningful way.
- **Early detection of changes in water quality**
  One objective of qualitative monitoring is to promote the early detection of new problematic substances so as to allow for a timely initiation of (counter-)measures. For these purposes, it is necessary to provide financial resources – to allow for the continuous gathering of data and the shrewd expansion of measuring capacities. A concerted monitoring programme by the federal states (perhaps including coordination measures and financial contributions from the national government) to address pollution in surface waters and groundwater might help to provide a solid database for the assessment of environmental risks. In this way, both long- and short-term trends regarding substance inputs would become identifiable and could thus inform political decision-making. The detection of anthropogenic trace substances does, however, require certain indicators. To this end, it is necessary to develop further the chemical and biological methods of analysis that serve to establish and control quality standards on anthropogenic trace substances in sewages and receiving waters.
- **Provision of a sufficient number of measuring stations and coverage of the current range of polluting substances**
  The detection of individual substances has been successfully improved in recent years. Still, the scope of measuring and monitoring activities in EU countries' is confined to those substances that must be reduced in line with the Water Framework Directive. As a result, new groups of substances have either not been

detected or only in a sporadic manner over a short period of time and in a few federal states. For this reason, there is a need for action to adapt the monitoring network to properly address the current status of trace substances. Existing monitoring systems have to maintained and optimised. We need to ascertain whether the improved cooperation of authorities with both university and non-university research institutions can help to realise a reduction of costs and improvements in quality – for instance by means of joint measuring programmes. It appears reasonable to screen and adapt the range of substances every three years. The predefined lists of substances have to be spatially differentiated (e. g. according to river basins) and complemented by particularly important substances.

(2) Strengthening interdisciplinary, application-oriented research

An innovative "research model" is required if we are to achieve the sustainable management of georesources such as water and soil in the context of global change. It is also necessary if we want to understand the multifaceted influences and interdependencies connected to these processes. This new research model needs to be geared towards the better coordination and interlocking of single sectors as well as towards a strengthening of interdisciplinary research. For these purposes, increased cooperation between the disciplines that play a key role in integrated water resources management is essential (inter alia: hydrology/ water management, soil sciences, agricultural and forest sciences).

- **Integrated research funding**
  The improvement of integrated research requires a more system-oriented alignment of research programmes so as to promote interdisciplinary research projects (e. g. hydrology and soil sciences). Most notably, it is necessary to push for innovative instruments and empirical findings based on interdisciplinary cooperation, to further the acknowledgement of interdisciplinary publications and to support interdisciplinary studies, conferences and exchange programmes. In doing so, a focus of research funding should be ensuring that new and existing interdisciplinary long-term projects are complemented with overarching measuring methods.
- **Improved coordination and information exchange between disciplines and sectors**
  The establishment of an international coordination centre could serve as a means to augment the exchange between basic research and application-oriented research as well as between science, the economic sector and politics. Such a centre may help to support the coordination of preliminary conceptual and organisational work. It could help to improve information exchange by means of encouraging interdisciplinary events (workshops, expert discussions) and interdisciplinary, problem-oriented research and development projects. On the basis of its interdisciplinary expertise, this coordination centre could bring together ideas and approaches to help address current challenges (such as the implementation of the Water Framework Directive).
- **More long-term orientation in funding programmes**
  Far-reaching interdisciplinary funding programmes require ample runtimes. Only on the basis of long-term oriented funding programmes will it be possible to achieve improved coordination, a joint (i. e. multidisciplinary) definition of objectives and the sensible organisation of working steps that build upon one another.

(3) Improving future-oriented technologies, improving framework conditions for innovation

Germany is a pioneer in technological innovations in the water sector. Action is required in order to maintain high-quality research and development in this field and to extend the future market "water" in Germany (GWP 2008). In particular, we need to improve the framework conditions for rendering technologies marketable and commercially viable. While in many cases the presentation of innovative technologies is decisive for their sale, there is often a lack of demonstration plants. From the project group's perspective, there is significant research and development potential in (inter alia) the following technology fields:

- **Promoting remote sensing-based water balance detection and accounting**
  For some remote sensing-based technologies it is possible to capture water balance variables more cost-effectively and with a higher spatial and temporal coverage than before. In this context, soil moisture plays an essential role for understanding the hydrological and ecological processes on the earth's surface. Satellite-based procedures using microwaves are an efficient (and in some regions of the globe the only) possibility for detecting soil moisture in runoff modelling, irrigation control and drought monitoring. While considerable progress has been made in recent years in terms of developing suitable techniques, substantial improvements need to be made with regard to exploiting their vast technological potential.
- **Advancing technologies of artificial groundwater recharge**
  If we want to extend irrigation in agriculture (also in Germany), it is necessary to render new water sources accessible. By means of the increased adoption of artificial groundwater recharge (e. g. by utilising winter surface water surpluses or from treated water from sewage plants), it is possible to provide large amounts of irrigation water without additionally polluting surface waters and groundwater to a significant degree. Prior to practical application, however, site-specific inspection is required to ensure the suitability of aquifers and to check that the groundwater is not contaminated with pollutants. Pilot plants are urgently required to develop system solutions in terms of water supply, water infiltration and storage management.
- **Advancing technologies for eliminating micropollutants**
  Demographic change and ever ageing populations are likely to result in the increased consumption of pharmaceuticals. This will in turn increase the input of medicinal products and their transformation properties into municipal water and sewage. Existing wastewater treatment processes are unable to remove these substances to a satisfactory level. For these reasons, there is a great need for technologies and processes that are able to eliminate micropollutants (like residues of medicinal products) from sewage and optimise the process of drinking water purification. Pilot plants also play a key role in this context and should thus be further encouraged. Much action is required in the field of utilising bank filtrates from rivers which are potentially heavily affected by pollution from treated sewage.

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GLOSSARY

TERM	EXPLANATION
Runoff (discharge)	The share of fallen precipitation that runs off into streams and rivers. It is measured as amount of water per time and is mostly expressed in cubic meters per second (m^3/s).
Adaptive Capacity	The skills, resources or institutional capacities of systems, organisations, or (single) actors to a) adapt to altered or prospective changes in climate conditions and their potential consequences and b) to take effective adaptation measures so as to reduce vulnerability (see below).
Anthropogenic Trace Substances (micro-pollutants)	Many synthetically produced organic trace substances are utilised in everyday products. They find their way directly into waters, mostly through urban drainage systems and discharges from sewage treatment plants. This may have detrimental effects on aquatic organisms and ecosystems, even if only traces of these substances are detectable in very low concentrations. For this reason, they are also referred to as micropollutants. By way of bank infiltration, they also seep into the groundwater and therefore represent an increasing challenge for the purification of drinking water.
Biochar/HTC Char	Products similar to brown coal or charcoal, which are produced from biomass. They are produced either by 1) pyrolysis (thermal decomposition) at temperatures around 450 °C under exclusion of oxygen or by 2) hydrothermal carbonisation (HTC; aqueous charring) at ca. 180–200 °C. This process generates biochar with differing properties. Scientific debates on their suitability as soil additives and as a means of carbon storage are ongoing.
Soil Moisture	Water content in the soil within the pore space.
Soil Additives	Soil additives are substances with no significant nutrient content, which help improve the physical, chemical or biological state of the soil and its water holding capacity. Moreover, they enhance the efficiency of fertilisers and may help to reduce leaching.
Soil Science	Soil sciences explore the development, characteristics and distribution of soils, their biotic and abiotic processes, their utilisation, endangerment, regeneration and remediation within the context of soil landscapes.
Evapotranspiration	The vaporisation of soil and water surfaces is referred to as "evaporation", while the evaporation of plants is known as "transpiration". Both are subsumed under the term "evapotranspiration".
Geothermics	On a global scale, Germany ranks 15th with its annual terrestrial heat use of ca. 1.680 gigawatt hours. At present (2006), by far the largest share of this directly utilised geothermal energy is extracted from shallow depths (up to 250 meters) by means of geothermal probes (ca. 800 megawatt thermal). 177 megawatts account for about 140 centralised facilities, each of which has a capacity of more than 100 thermal kilowatts. Notwithstanding that the generation of electricity from geothermal energy is still in its infancy in Germany, the Renewable Energies Act (EEG) has stimulated a number of geothermic projects to generate electricity.
Global Change	The concept of global change comprises all changes in nature and society which are global in their effects and thus (often) irreversibly influence the livelihoods of human beings.
Hydrofracking	Fracking or hydrofracking (in connection with water) refers to a special technique of producing natural gas from shale, which is currently used on a large scale in the US and Canada. Hydrofracking provides access to natural gas deposits situated deep underground
Hydrology	The science of water and its manifestations above, on, and below the land surface, its characteristics and natural relations.
IWRM – Integrated Water Resources Management	Integrated Water Resources Management (IWRM) is characterised by its integrated consideration of several resources such as water, soil, woods and aquatic ecosystems. The aim is to develop and cultivate these resources in a sustainable manner with the aid of a cross-sectoral and participatory process. In doing so, IWRM attempts to overcome sectoral strategies and inefficient utilisation systems. It is a relatively new concept that has been principally developed and advanced in international research and water policy forums.

TERM	EXPLANATION
Climate Change	Statistically significant change in the climate's average status or variability that persists over a longer period of time (i. e. mostly decades).
Sustainability	Sustainable development entails meeting the needs of today's generation without impairing the potential for future generations to satisfy their own needs. This also implies that the consumption of natural resources, substances, and energies must remain within the limits of regenerative and substitutive capacities. Moreover, air, soil, and water pollution must be kept within limits that are acceptable to all living creatures.
Trace Substances	Trace substances are organic compounds which may exist in nature and waters as "traces of substances", i. e. in very low concentrations. Organic trace substances are seen as critical if they pose a risk from a human- or eco-toxicological perspective.
Interfering Materials	Within the context of this paper, interfering materials refer to those substances in water that cause toxicological or sensory disruption due to their processing, distribution and utilisation simply because of their unnatural character.
Sensitivity	The degree to which a system or actor is influenced (in either a positive or negative way) by climate variability or climate change.
Scenario	A plausible, often simplified description of possible future developments, which is based upon a coherent and internally consistent number of assumptions about driving forces and essential inter-relationships. Although scenarios may be derived from projections, they frequently rest upon additional information from other sources, often combined with a storyline.
Transformation Products	Transformation Products are degradation or metabolic products that originate from a microbial or chemical reaction and differ chemically from the initial substance.
Virtual Water Trade	The transfer of virtual water resulting from the trade of products. Unlike products that have to be transported in real terms, the total amount of virtual water traded is only a notional volume that does not need to be transported.
Vulnerability	The extent of a system's or actor's susceptibility to (or inability to cope with) the detrimental effects of climate change, including climate variability and extremes. Vulnerability is dependent upon the kind, extent, speed and fluctuation margin of climate change to which the system is exposed. Moreover, it depends on the system's or actor's sensitivity (see above) and adaptive capacity (see above).
Water Yield	The amount of water available from surface water or groundwater within a certain period of time, which hence can be withdrawn without harming ecosystems.
Water Footprint	Total amount of water per time unit that is needed for a particular person or group of persons. It is also possible to relate the water footprint (WF) to regions (e. g. cities, countries), or companies producing goods. Recently, the WF has been related to the mass of a product without reference to time. In this case, the virtual water content of the respective product is assessed in terms of the usual dimension litres of water/kg product. For example, depending on the mode of production WF = 10.000 – 20.000 litres of water/kg beef.
Water Balance	The quantitative assessment of the water cycle as well as water balance and its regulation; an essential part of water management.
Water Resource	Water earmarked for a specific kind of utilisation, which is (or can be made) available in sufficient quality and quantity at a particular place for a particular period of time.
Water Consumption	The amount of water that is withdrawn from the natural water cycle per time unit and hence is no longer available for use within the respective balance scope (e. g. a region or a nation). The water is mainly withdrawn from the balance scope by means of evaporation or sublimation. However, if water is used for cleaning purposes, it may be used again after a suitable purification process and is thus still available in the balance scope.

APPENDIX:

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